DEFECT ASSESSMENT OF SPOT WELDS BY NDI

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ABSTRACT

DEFECT ASSESSMENT OF SPOT WELDS BY NDI

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Resistance spot welding is used frequently as a successful joining method for a variety of work commonly in automotive and other manufacturing processes. Spot weld nugget is generally hidden between two sheets, causing its inspection difficult and expensive. Undersized nuggets, brittle or cracked nuggets, and excessive indentation of electrodes reveals the lack of fusion between the parts that can make the weld sub-standard.

Visual inspection, pry testing and physical teardown with chisel and hammer method or a combination of them are being used traditionally. However, this study presents a more effective nondestructive inspection method based upon an ultrasonic pulse-echo technique.

The theory of the technique together with the experimental verification are presented and its advantages over the other destructive and nondestructive techniques are considered.

Keywords : Resistance spot welding, nondestructive inspection (NDI), ultrasonic pulse-echo technique

ÖZ

PUNTO KAYNAKLARINDAKİ HATALARIN TAHRİBATSIZ MUAYENE İLE TAYİN EDİLMESİ

KOÇAK, Okan Okay
Metalurji ve Malzeme Mühendisliği
Tez Danışmanı : Prof. Dr. Alpay ANKARA

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Dirençli punta kaynağı, başta otomotiv ve diğer imalat işlemlerinde olmak üzere bir çok işte başarılı bir birleştirme metodu olarak sıklıkla kullanılmaktadır. Punta kaynağının birleşme noktasının genellikle iki levha arasında saklı olması bu bölgenin muayenesini zor ve pahalı kılar. Olması gerekenden daha ufak birleşme noktaları, kırılgan veya çatlak birleşme noktaları ve elektrotların aşırı baskısı parçalar arası kaynaşma eksikliğini gösterir ki, bu durum kaynağı standart altı kılabilir.

Gözle muayene, açma metodu ve keski ve çekiç ile fiziksel kırma metotları veya bunların birleşimi geleneksel olarak kullanılmaktadır. Bununla birlikte, bu çalışma ultrasonik darbe-yankı tekniğine dayanan daha etkili bir tahribatsız muayene metodu sunmaktadır.

Tekniğin teorisi, deneysel doğrulaması ile birlikte sunulmakta ve bu tekniğin diğer tahribatlı ve tahribatsız muayene tekniklerine üstünlükleri dikkate alınmaktadır.

Anahtar Kelimeler : Dirençli Punto kaynağı, tahribatsız muayene (NDI), ultrasonik darbe-yankı tekniği

To My Parents

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H	Heat deliverd to the weld zone
I	Current through the weld zone
R	Effective resistance
t	Time during which the current flows through the weld zone
F	Welding Force (Pressure)
T	Thickness of the sheet metal
A	Amplitude of a wave
A_0	Initial amplitude
x	Distance travelled by the wave
α	Attenuation rate of decay) coefficient
B	A coefficient accounting for factors as preferred orientation of grains and anisotropy of individual grains.
V	A variable approximately proportional to grain volume
f	Frequency

CHAPTER 1

SPOT WELDING

1.1 WELDING

The term ‘’welding’’ can be defined as the process by which two or more pieces of metal are united under the influence of heat, so that the junction is as nearly as homogeneous. The process can be achieved in a number of different ways which can be brought together under two headings:

- Forge and Resistance Welding
- Fusion Welding

The forge and resistance welding may be defined as the union effected by the pressure while the localities to be united are in a plastic state. Although it is usual for the components to be raised in a temperature to attain the desired degree of plasticity, it should be appreciated that developments in cold welding are going forward, especially with light alloys, whereby union is effected by pressure alone, advantage been taken of the high ductility of the material, even when cold.

Fusion welding involves actual melting at the point, with or without the addition of a molten filler. This category includes arc and gas welding.

1.2 PRINCIPLES OF SPOT WELDING

Spot welding is the welding method that uses the heat generated by the resistance of the material to the electrical current together with the gripping pressure simultaneously. There is no extra external heat source. Heat is produced only on the parts to be welded and pressure is applied by the rocker arms or electrode arms. The high current density is provided by the tranformators and the pressure is provided by the hydraulic and pneumatic equipments.

It is the most common form of electric resistance welding as its method is very easy, practical and easeful [1]. Although it is seemed to be very basic, its process is very complex and requires the continuous control of specified parameters. The method may be used for joining sheet to sheet, sheets to rolled sections or extrusions, wire to wire, for sundry special applications using combinations of the above. By far the widest application in industry is the spot welding together of sheet-metal parts, as in the hollow-ware industry (handles to kettles and saucepans) or the automotive industry. For example, the typical car body contains about 5000 spot welds joining a mixture of sheet metal material types and thicknesses.

This welding method is very advantageous corresponding to its high speed of operation, hence its adaptability to mass production, its cleanliness, no need for welding rods, and its high degree of control possible by electrical means (i.e., reducing the necessity for a degree of operational skill).

The process spot welding involves the joining of two or more pieces of sheet metal in localized areas (spots) where the melting and coalescence of a small volume of material occurs from heating caused by resistance to passage of an electric current. The electric current is carried to the sheets via electrodes that are also used to clamp the workpieces together.

The heat H in joules delivered to the weld zone is determined by the equation :

$$H = I^2 R t \qquad (1.1)$$

Where I is the current through the weld zone, R is the effective resistance in the current carrying circuit, and t is the time during which the current flows through the weld zone.

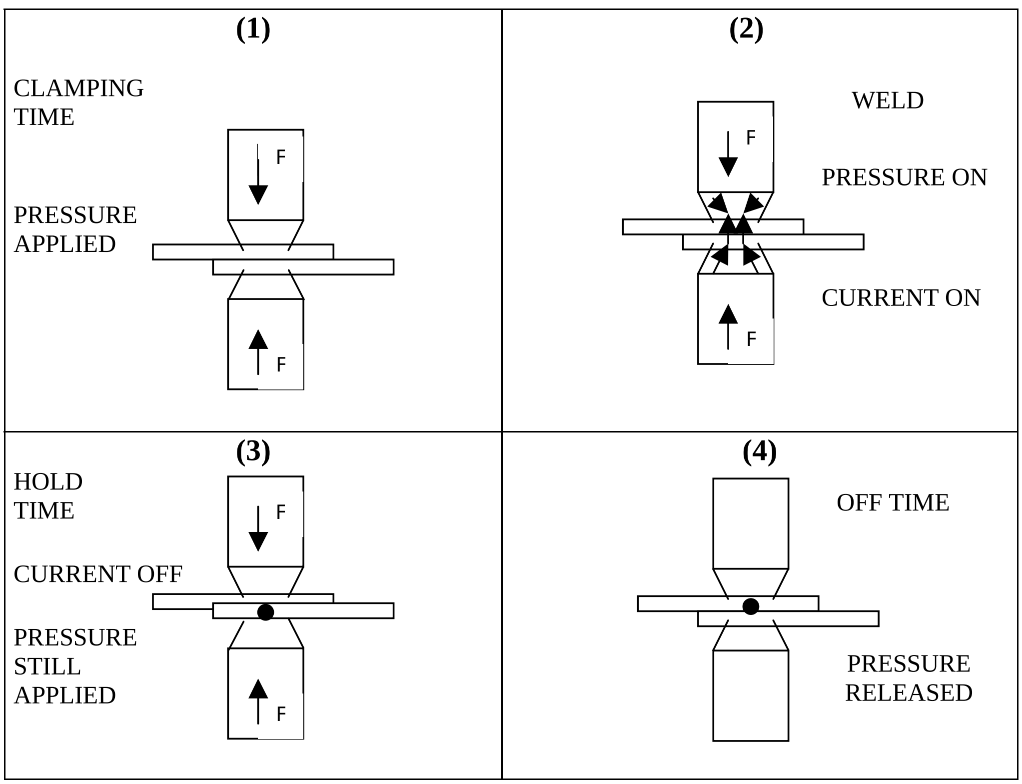

Figure 1.1 Time sequence of the resistance spot welding cycle: (1) clamping time , (2) weld time, (3) hold time and (4) off time

The sequence in a complete welding cycle comprises clamping the workpieces with the electrodes (at a controlled clamping force) and the passage of the weld current for a specified period, followed by holding the pieces clamped for a specific time period with the weld current off, and finally releasing the clamping pressure and the workpiece. This sequence is illustrated in Figure 1.1 below [2].

As the weld current flows through the clamped workpieces, the highest resistance will be at their contacting surface. The heat develops at this sides, causing a rapid rise in the temperature. The temperature rise culminates in melting of the metal starting at the center of the current path. Thus, a pool of molten metal from the workpieces begin to grow outward for the duration of the current flow. When the weld current is turned off, this volume of molten metal cools down and solidifies.

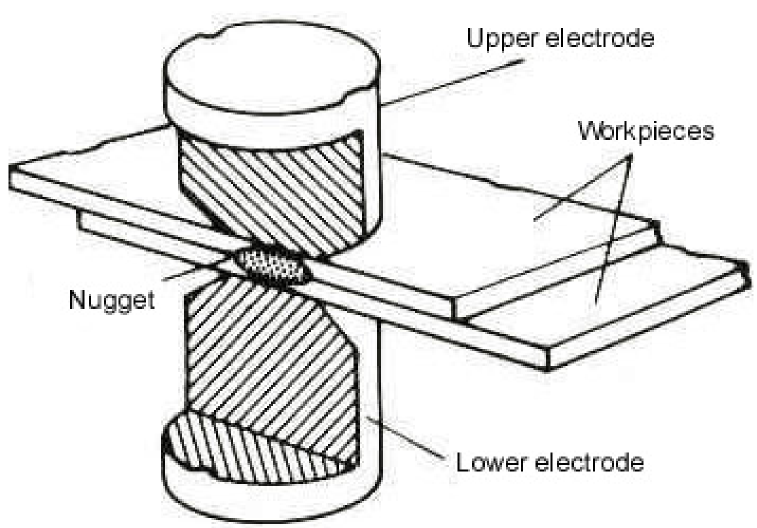

Figure 1.2 The cutaway view of the location and shape of a weld nugget [1].

The volume of metal from the workpieces that has undergone heating, melting, fusion and resolidification is called the *weld nugget*. The cutaway view of a typical spot weld nugget is given in Figure 1.2. The weld nugget forms at the faying surfaces, but does not extend completely to the other surfaces. In a cross section, the nugget in a properly formed spot weld is obround or oval in shape; in plan view it has the same shape as electrode face and approximately the same size.

The ratio of the temperature gradient to the growth rate, G/R, governs the mode of solidification. The product of the temperature gradient and the growth rate, GR, on the other hand, governs the scale of the solidification structure. It has been observed that the greater the product GR, the finer the solidified cellular or dendritic structure. It is also to be noted that the product GR is equivalent to the cooling rate, since both have the same units of degrees centigrade per second [3].

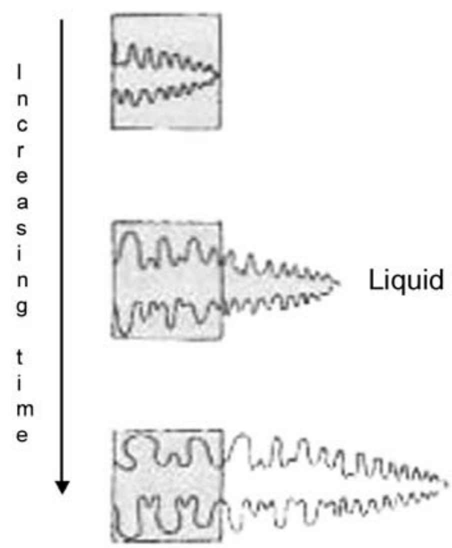

Figure 1.3 Schematic diagram of the growth of dendrite in an alloy at a fixed position at various stages of solidification [3].

The Figure 1.3 shows a schematic sketch of the growth of a dendrite during solidification. As can be seen, large dendrite arms grow at the expense of smaller ones as solidification proceeds. The slower the cooling rate during solidification, the longer the time available for this mechanism to operate, resulting in larger dendrite arm spacing. This phenomenon is called the coarsening effect.

The effect of the temperature gradient G and the solidification rate R on the solidification microstructure of alloys is summarized in Figure 1.4.

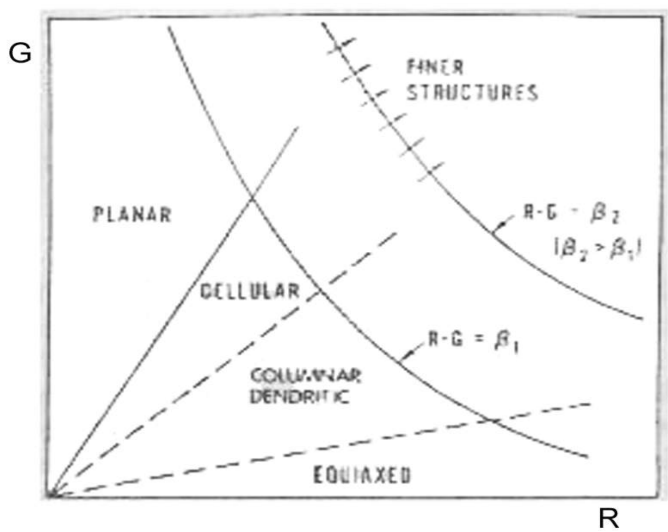

Figure 1.4 Schematic rate-gradient map showing transitions in microstructure as well as the refining effect of high cooling rates [4].

The product GR is lower for spot weld nuggets than the parent metal since temperature gradient and growth rate is expected to be lower and higher than that of the parent metal, respectively. So, the grain structure in the nugget volume takes on a cast-like columnar and dendritic structure, which is considerably coarser than the grain structure in the parent metal (Figure 1.5). The difference in microstructure between the nugget volume and the parent metal is a central basis for the ultrasonic pulse-echoe technique of weld inspection reported in Chapter 4.

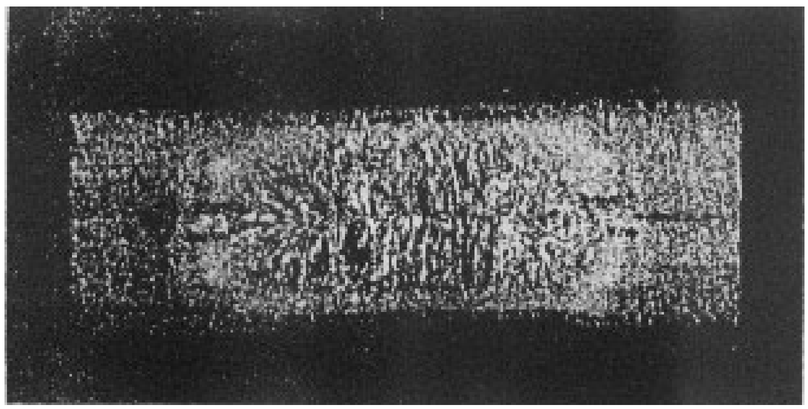

Figure 1.5 Photomicrograph of a grain structure in a good spot weld [2].

Like other welds, spot welds are subject to shrinkage on cooling. To minimize distortion, welds should be positioned to balance shrinkage forces. Distortion can also result from electrode skidding. This is related to stress introduced at the time of electrode impact and machine deflection under high electrode force. The components must be designed to provide methods of accomodating variations.

Spot-welded assemblies should be designed so that joint areas are readily accessible to the electrode and simple, inexpensive electrodes can be used. Deep, narrow joint areas should be avoided. Figure 1.6 provides guidelines for the accessibility of joints.

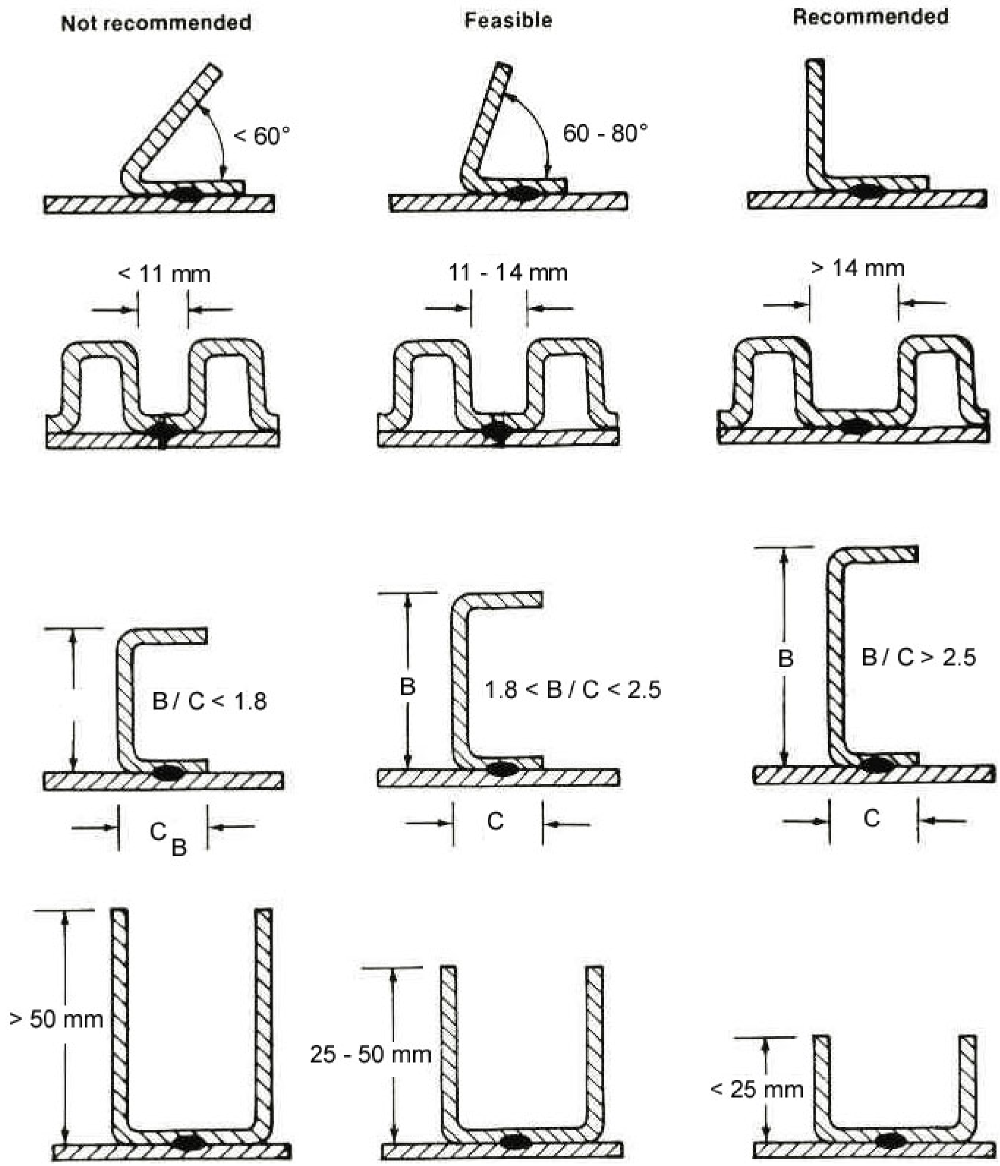

Figure 1.6 Gradual improvements in joint design that provide optimum access to selected joint configurations using standart electrodes [1].

The strength of a single spot weld in shear depends on the cross-sectional area of the nugget in the plane of the faying surfaces. A minimum nugget diameter that is unique to the type of the base material, surface condition and metal gage used is required in order to obtain failure by base metal tearing.

Increasing the nugget diameter above this minimum value can produce an increase in the weld strength. Figure 1.7 shows the slight increase in strength values obtained for low carbon steel as a result of incereases in nugget size.

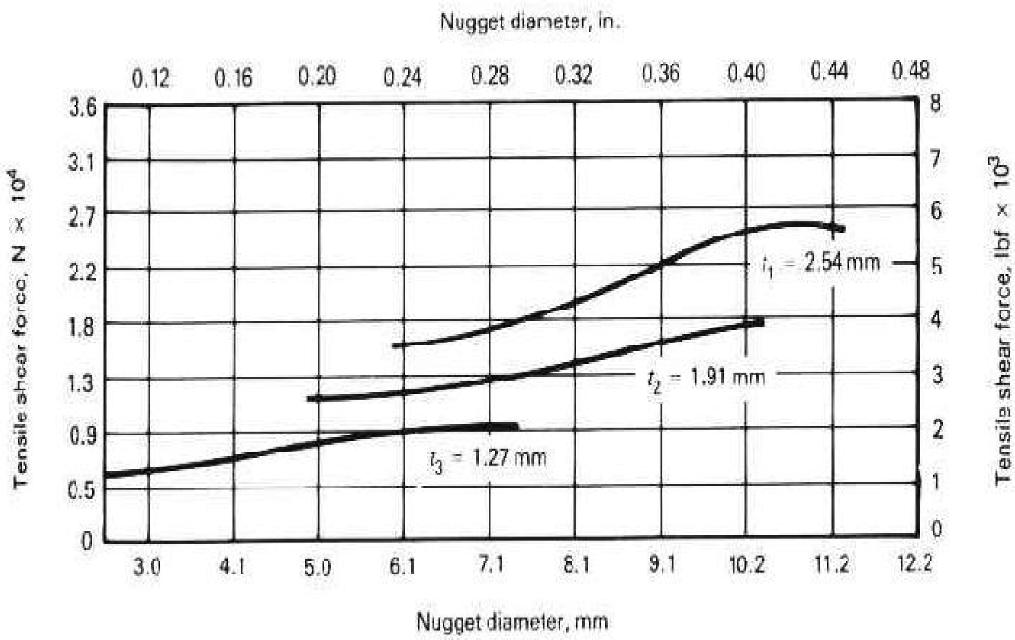

Figure 1.7 Plot of tensile shear strength vs spot weld nugget diameter as a function of sheet metal thickness, t, for 1008 low-carbon steel [1].

The strength of multiple spot- welded joints depends on material thickness, spot weld spacing and weld pattern. As the spacing between adjacent spot weld decreases, the joint shear strength may decrease.

1.2.1 TYPES OF SPOT WELDS :

1.2.1.1 DIRECT SINGLE-SPOT WELDING :

In a direct weld the current path is directly through the work between opposed electrodes. Single spot welds are usually made by direct welding. Figure 1.8 shows schematically three arrangements for making these type of weld; these arrangements may be modified to meet special requirements. In all of these arrangements shown, one transformer secondary circuit makes one spot weld.

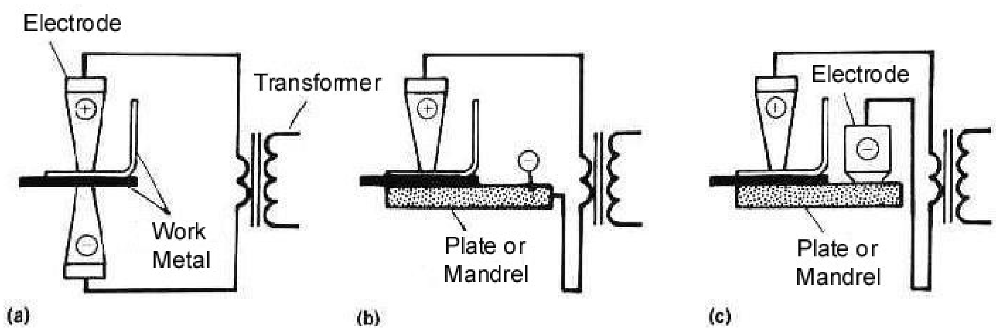

Figure 1.8 Single spot weld positions by direct welding

The simplest and most common arrangement in which two workpieces are sandwiched between opposite upper and lower electrodes, is shown in Figure 1.8(a). In figure 1.8(b), a conductive plate or mandrel having a large contacting surface is used as the lower electrode; this reduces marking on the workpiece and conducts heat away from the weld more rapidly and may be necessary because of the shape of the workpiece. In the arrangement in Figure 1.8(c), a conductive plate or mandrel beneath the lower workpiece is used for the same purposes but in conjunction with a upper second electrode.

1.2.1.2 DIRECT MULTIPLE-SPOT WELDING :

Two arrangements for the secondary circuit for making two making two or more spot welds simultaneously by direct welding are shown in Figure 1.9(a) and (b). As well as in series multiple spot welding, described below, in direct multiple-spot welding, tip contour and surface condition must be the sam efor each electrode. Also the force exerted by all the electrodes on the workpieces must be equal, regardless of of inequalities in work-metal thickness. The force can be equalized by using a spring-loaded electrode holder or a hydraulic equalizing system. The use of conductive plate or mandrel, as in Figure 1.9(b) minimizes weld marks on the workpiece.

1.2.1.3 SERIES MULTIPLE-SPOT WELDING :

Three arrangements for making multiple a number of spot welds simultaneously by series welding are shown in Figure 1.9(c), (d) and (e). In Figure 1.9(d), each of the two transformer secondary circuits make two spot welds. A portion of the current bypasses the weld nuggets through the upper workpiece.

In Figure 1.9(e) is commonly referred to push-pull welding. The advantage to this process is that the secondary loop area is quite small. This is common for components such as floor pans where a normal welding unit would have a throat several feet deep.

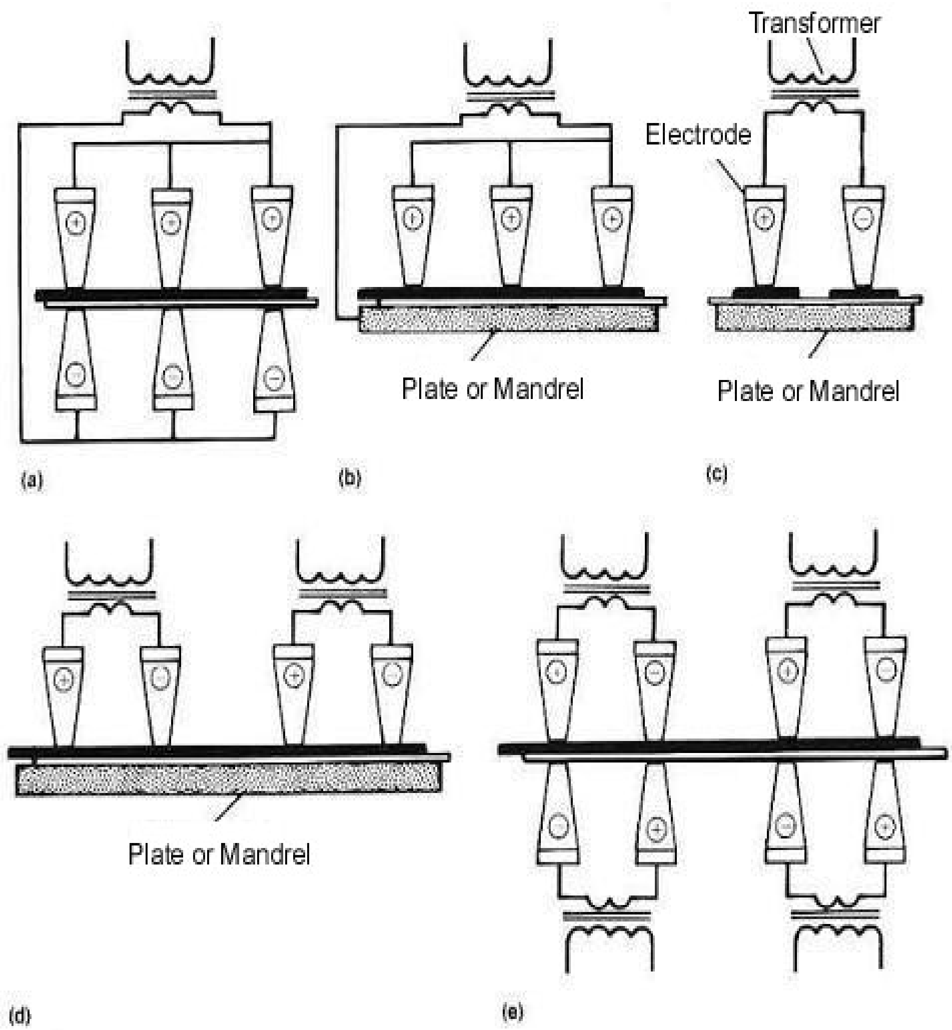

Figure 1.9 Multiple spot weld positions :

(a) and (b) direct welding. (c), (d) and (e) series welding.

1.2.2 RESISTANCE SPOT WELDING EQUIPMENT

The equipment needed for resistance spot welding can be simple and inexpensive or complex and expensive, depending on the degree of automation. Spot welding machines are generally composed of three principal elements :

- **Electrical Circuit :** It is composed of a welding transformer, tap switch and a secondary circuit.

- **Control Circuit :** It initiates and times the duration of current flow and regulates the welding current.

- **Mechanical System :** This system consists of the frame, fixtures and devices that hold and clamp workpiece and apply welding pressure.

Welding operations in highly automated production lines are based primarily on multiple spot welders and robotic cells. In addition, manual welding operations can be used to manufacture either subassemblies, which are fed into the main production/assembly lines, or in many instances, finished products. These differing end uses require machines of varying designs and characteristics. RSW machines can be divided into three basic types :

- Pedestal-type welding machines
- Portable welding guns
- Multiple welding machines incorporating lightweight gun welding units.

Specifications for resistance welding equipment have been standardized by the Resistance Welder Manufacturers Association (RWMA), and specifications for controls are issued by the National Electrical Manufacturers Association (NEMA). The drawing of a typical standardized spot welding machine is given in Figure 1.10 below.

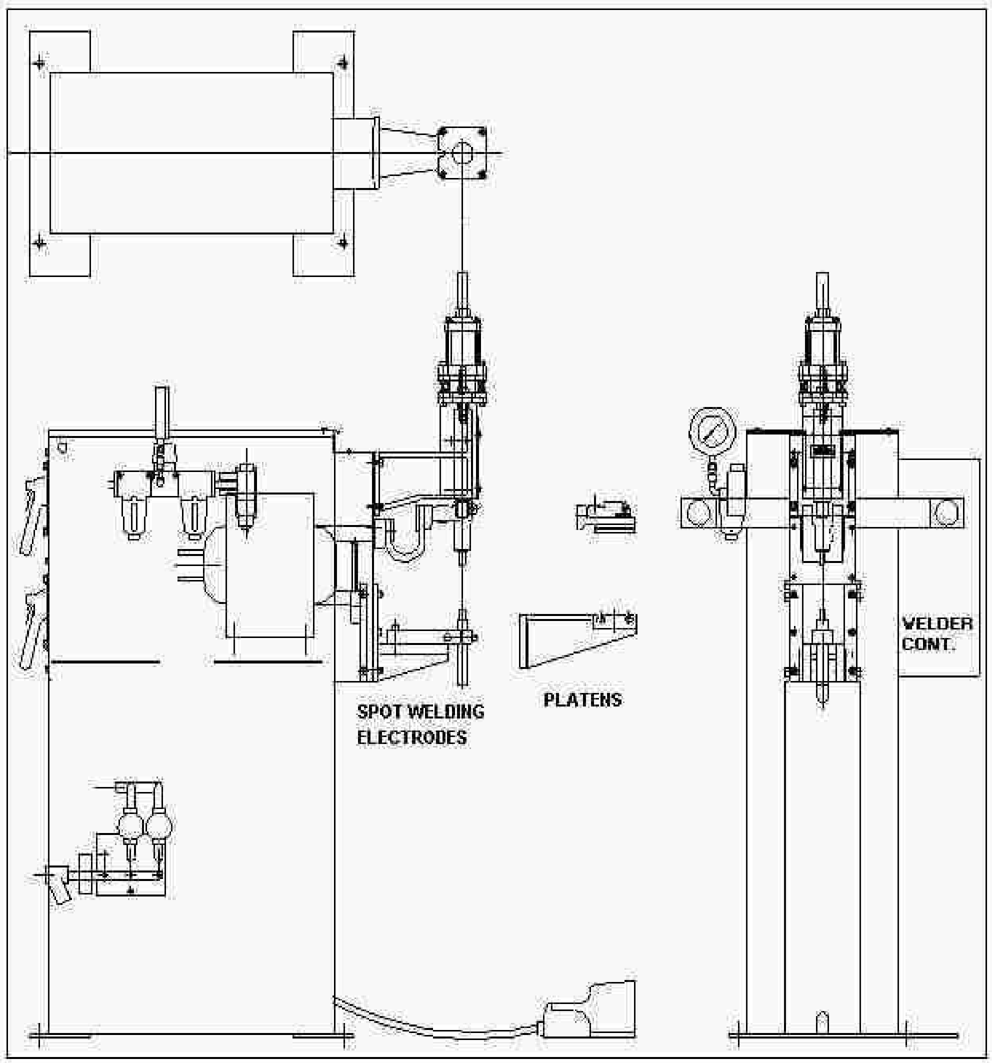

Figure 1.10 The drawing of a typical resistance spot welding machine

1.2.3 ELECTRODES FOR SPOT WELDING :

Resistance spot welding electrodes should be made of the materials having high thermal and electrical conductivities and sufficiently low contact resistance to prevent burning of the workpiece surface or alloying at the electrode face. In addition, the electrode should have adequate strength to resist deformation at operating pressures and temperatures. Electrode materials for resistance spot welding have been classified by RWMA and in International Standards Organization (ISO) standard ISO 5182.

Using the proper electrodes for the spot welding application is necessary in order to achieve the best results in any spot welding operation. Selection of the alloy is important since this can help modify the heat balance or reduce the tip wear. The tip face diameter and contour must also be considered since these factors control the welding pressure and current density which must be within an acceptable range for satisfactory results. Incorrect tip face geometry will also result in increased surface marking.

Although there are many alloys, types, sizes and shapes of electrodes commercially available, there are six standard nose configurations and, of these, there are three that are most frequently used for spot welding. There are: flat, radiused and domed. Most of the welding schedules are based on these three shapes. Other sizes and shapes are often required to conform to the contour of the weldment or to suit other conditions. Each of the electrodes are manufactured using a number of different alloys to provide the best combination of electrical and mechanical properties for a particular welding operation [5].

1.3 RANGE OF MATERIALS FOR SPOT WELDING

Spot welding facilitates if :

- There is sufficient contact resistance sheet-to-sheet for heat to be generated by the heavy current flow.

- The heat is not conducted away too rapidly from the point at which welding is desired.

Therefore, that good conductors of heat and electricity such as copper, aliminium or silver present greater difficulties than do iron and steel, which are moderate conductors in comparison.

Notes on the spot welding of metals of commerce are given below:

1.3.1 FERROUS METALS

1.3.1.1 MILD STEEL AND IRON

If the material, whether sheet or rolled sections, is clean, little difficulty should be experienced. Low-carbon steel can be satisfactorily resistance welded using a wide range of time, current, and electrode force parameters. The metal referred to as ''mild steel'' is that in which the carbon content does not exceed 0.15%. Carbon content has the greatest effect on weldability of steels; weld hardness increases rapidly with a small rise in carbon content. To obtain acceptable weld performance, carbon content should be kept below 0.10% + 0.3t, where t is the sheet thickness in inches. For materials above this range, postweld tempering may be necessary.

1.3.1.2 HARDENABLE STEELS (EXCLUDING HIGH-SPEED STEELS)

Only fairly thin material, the cooling rate from the welding temperature is exceedingly rapid, since the water-cooled electrodes conduct away much heat during the after-weld pressure period. The result of such a high cooling rate is an intense hardening effect on the weld nugget and its immediate surroundings, and such an effect might cause the welds to be brittle and unserviceable. To overcome this trouble with small parts, they are charged into an annealing furnace after welding, so that they are ‘’let down’’ gradually.

1.3.1.3 HIGH-SPEED STEELS

The welding of small pieces of high-speed steels to tool shanks for use in lathes, planers, etc., has received some attention, but it should be pointed out that in this respect spot welding is in nature of a makeshift, since modern electrically butt-welded tools are available with the advantages of cheapness and efficiency.

1.3.1.4 STAINLESS STEELS

These steels are divided into four groups:

1 - Ferritic (stainless irons, etc.)
2 - Martensitic (cuttery and similar quantities)
3 - Austenitic (non-stabilized)
4 - Austenitic (stabilized)

These groups behave differently with respect to spot welding, but it is doubtful whether very much spot welding is carried out in Groups 1 & 2.

Group 1 behave as mild steel :pressure should be kept on a little longer after welding, however.

Group 2 have pronounced air hardening qualities and should therefore be treated as hardenable steels under heading (b).

Group 3 includes the well known 18/8 variety of stainless steel. Since this particular quality is subject to the phenomenon known as *weld decay*, a machine of high capacity is to be preferred so that the heating and eventual cooling can take place in the shortest possible time.

Group 4 have additional elements such as titanium and niobium, the presence of which tends to inhibit weld decay. Such steels, therefore, may be spot welded in the polished condition, and require no further treatment other than a little buffing to remove handling marks.

The short welding period is necessary in stainless to prevent carbide precipitation when the carbon content is high enough to permit it.

1.3.1.5 ZINC-COATED STEELS

The present trend in the automotive industry toward the use of larger amounts of zinc-coated steels in assemblies demands that certain strict guidelines regarding the selection of equipment and the choice of welding schedules are rigidly followed. The available welding ranges for zinc-iron and zinc-nickel coated steels are similar to those for uncoated mild steel although displaced toward slightly higher currents. When these steels are coated, it is necessary that the film thickness not exceed 1 to 1.5 μm in order to facilitate breakthrough of the film to enable current flow between the welding electrodes at the low secondary voltages.

1.3.2 NON-FERROUS MATERIALS

1.3.2.1 ALUMINIUM, AL-MAGNESIUM AND AL-MANGANESE ALLOYS

All of these may be spot welded satisfactorily if the insulating skin of oxide is removed and the machine has a sufficiently high capacity since aliminium is a good conductor of heat and electricity and therefore a ‘’difficult’’ metal. In addition, the narrow plastic range between softening and melting means that welding pressures, time and current need to be closely controlled. Moreover, careful control of the electrode force is necessary to minimize the probability of cracking or porosity in the weld.

1.3.2.2 ALUMINIUM-COPPER ALLOYS

Duralumin type alloys become ‘’burnt’’ or over-heated if taken to temperature about 500 °C.

1.3.2.3 BRASS

Brass can give trouble in spot welding in two ways. Firstly, the high-copper brasses and gilding metals are ‘’difficult’’ according to their high electrical and thermal conductivities. Secondly, the low-copper zinc-rich brasses shows volatilization of the zinc in the weld, hence the porosity. Guidelines for resistance spot welding of high-zinc brasses are given in Table 1.1.

Table 1.1 Guidelines for resistance spot welding of high-zinc brasses

Thickness of thinnest sheet		Minimum spot spacing		Minimum contacting overlap (a)		Shear load of joint	
Mm	in.	mm	in.	Mm	in.	kN	lbf
0.81	0.032	16	0.625	13	0.500	1.47	330
1.27	0.050	16	0.625	16	0.625	2.28	512
1.63	0.064	19	0.750	19	0.750	3.02	680
2.39	0.094	25	1.000	25	1.000	5.20	1168
3.18	0.125	38	1.500	32	1.250	8.33	1872

(a) Minimum edge distance is equal to one half the contacting overlap.

1.3.2.4 BRONZE

Behaves in a similar way to a high-copper brass.

1.3.2.5 COPPER

Hard-faced or pure tungsten electrodes are necessary. Otherwise, the remarks made in 1.3.2.1 about the machine capacity apply also copper. If material in excess of 1.6 mm has to be joined, it is preferable to use methods other than spot welding. Copper alloys are more commonly resistance brazed. In many applications, the weldability of copper is increased if it has a tinned surface. The guidelines for resistance spot welding of some copper alloys are given in Table 1.2.

Table 1.2 Guidelines for resistance spot welding of selected copper alloys [1].

UNS No.	Alloy Name	Welding Parameter (a)			
		Weld time (cycles)	Electrode Force		Welding Current (Amperes)
			kN	lbf	
C23000	Red Brass	6	1.8	400	25000
C24000	Low Brass	6	1.8	400	24000
C26000	Cartridge Brass	4	1.8	400	25000
C26800-27000	Yellow Brass	4	1.8	400	24000
C28000	Muntz Metal	4	1.8	400	21000
C51000-52400	Phosphor Bronze	6	2.3	510	19500
C62800	Aluminium Bronze	4	2.3	510	21000
C65100-65500	Silicon Bronze	6	1.8	400	16500
C66700	Manganese Brass	6	1.8	400	22000
C68700	Aluminium Brass	4	1.8	400	24000
C69200	Silicon Brass	6	2.3	510	22000

(a) For spot welding 0.91 mm (0.036 in.) thick sheet using RWMA type electrodes with 4.8 mm (3/16 in.) and 30° chamfer and made of RWMA class 1 material.

1.3.3 DISSIMILAR MATERIALS

The dissimilar materials are more hard to weld because of their different melting temperatures, thermal and electrical properties, plastic ranges and the alloys formed in the weld region [5]. However, the majority of the combinations of ductile metals and alloys can be spot welded (Table 1.3). Some, like copper to aluminium, and aluminium to magnesium, form alloys having little strength. Others, such as zinc and some of the high-chromium alloys, experience grain growth even during a short welding period.

Table 1.3 Relative spot weldability ratings of selected metal and alloys

A: Excellent; B: Good; C: Fair; D: Poor; E: Very Poor; F: Impractical

METAL/ ALLOY	Aluminium	Stainless Steel	Steel	Galvanized Iron	Copper	Brass	Zinc	Nickel
Aluminium	B	F	D	C	E	D	C	D
Stainless Steel	F	A	A	B	A	E	F	C
Steel	D	A	A	B	E	D	F	C
Galvanized Iron	C	B	B	B	E	D	C	C
Copper	E	E	E	E	F	D	E	D
Brass	D	E	D	D	D	C	E	C
Zinc	C	E	F	C	E	E	C	F
Nickel	D	C	C	C	D	C	F	A

CHAPTER 2

SPOT WELDING QUALITY

2.1 FACTORS AND VARIABLES AFFECTING SPOT WELD QUALITY

The qualities of resistance welds are affected by many variables, including the properties of the material to be welded, the surface smoothness and cleaness, the electrode size and shape, and the welding-machine settings that determine welding time, pressure, and current. Successful welding depends on consistent weld properties, which in turn require uniform welding conditions. Experience has shown that a change in any single variable of more than 10% is sufficient to make the weld unacceptable. Unacceptability may represent failure to meet a specified property limit, such as a minimum tensile or impact strength, or it may define actual fracture of the weld [6].

There are numerous factors occuring during production which influence end weld quality. An understanding of these factors and their effect on quality is most important to individuals concerned with production, maintenance, manufacturing engineering and quality control. Some factors and variables affecting the spot weld quality are described below.

2.1.1 PRESSURE AND FORCE SYSTEMS

Weld force brings the metal between the electrodes together and provides electrical continuity, the required welding pressure, and forging force, so that a weld may be generated.

The welding equipment pressure systems are normally either hydraulic or pneumatic. Mechanical systems are encountered, but to a lesser degree.

With a hydraulic or pneumatic system the electrode force, or welding force, is generated by the pressure of the media acting over the area of the piston of the cylinder to which the movable electrode is attached.

The effect of an improper electrode force can be illustrated relative to the basic heat equation used in resisrtance welding; i.e. $H = I^2 R t$. Low electrode force will increase the resistance factor R of this equation. While a high resistance caused by a low force will generate more heat, the negative effects of metal expulsion, porous welds, surface whiskers of sharp metal spikes, sticking electrodes, poor electrode life and low strength welds will be encountered [7].

On a microscopic scale, the surfaces of electrodes and workpieces consist of peaks and valleys. When subjected to low force, the metal-to-metal contact will be only at the contacting peaks. The resulting contact area is less than that produced by an appropriate force. Contact resistance will therefore be higher, causing a greater amount of heat to be generated.

2.1.2 WELDING CURRENT

If the current passed during the weld time is too high for the combination of electrode caps in use, their condition and contact area, the weld time, the weld force, and the materials being welded, it will generate more heat as described in the previous section resulting in excessive indentation, cracks and holes, expulsion/burn through, sticking electrodes, rapid electrode cap wear and “brassy” appearance to weld surface on galvanized steels [8].

2.1.3 ELECTRODE CONDITION AND GEOMETRY

A complete weld schedule must include a recommended electrode shape and geometry. The loss of this shape, either through mushroomed electrodes or a change in electrode shape, can have disastrous effects on weld quality.

The actual contact area of an electrode tip on the material to be welded will determine the weld current density and the electrode force density, or pressure. When electrode tips are allowed to mushroom (Fig. 2.1), the pressure and current density decreases in an exponential fashion, since area is proportional to diameter squared.

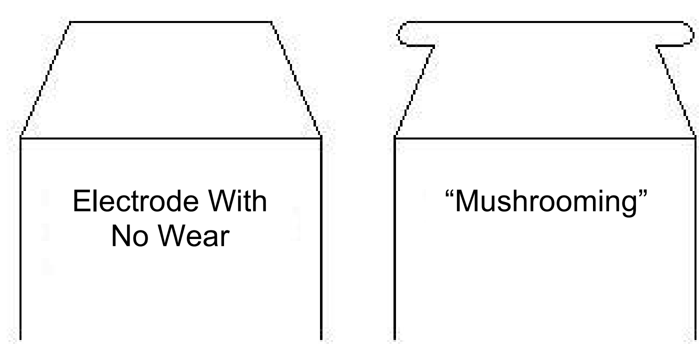

Figure 2.1 Deformation of tip face over time

Electrode wear can also occur by the pitting of the tip face (Fig. 2.2). In severe cases, localized current flow may result, potentially causing nonround welds.

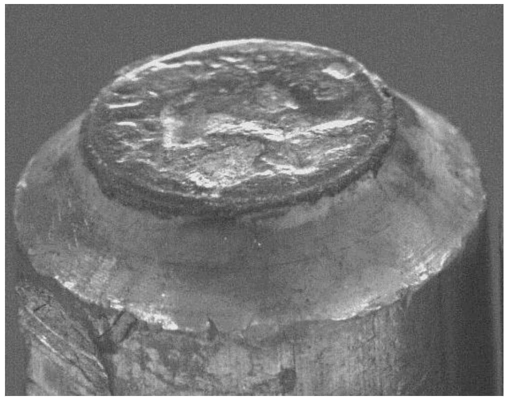

Figure 2.2 Badly pitted tip face

Full appreciation of actual electrode tip contact area relative to quality welds is of extreme importance. Tips should be redressed whenever the slightest amount of mushrooming or pitting is noted.

2.1.4 WELDING TIME

For a typical weld, weld time is the amount of time welding current flows through the metal. Since electrical power arrives at the weld control as alternating current, at a 60-cycle per second rate (50 in some areas), weld time is usually measured in cycles. This has become a convenient measuring standard for duration of weld heat. One cycle equals 1/60th of a second, for a 60-cycle per second supply and 1/50th of a second, for a 50-cycle per second supply.

For Direct Current (DC) welders, weld time is usually measured in cycles as a convenience. In some instances, however, with mid- and high-frequency DC welding, milliseconds are often used to measure weld time. However with DC welders, there is some difference in programmed weld time and actual weld time as the Fig. 2.3 below shows.

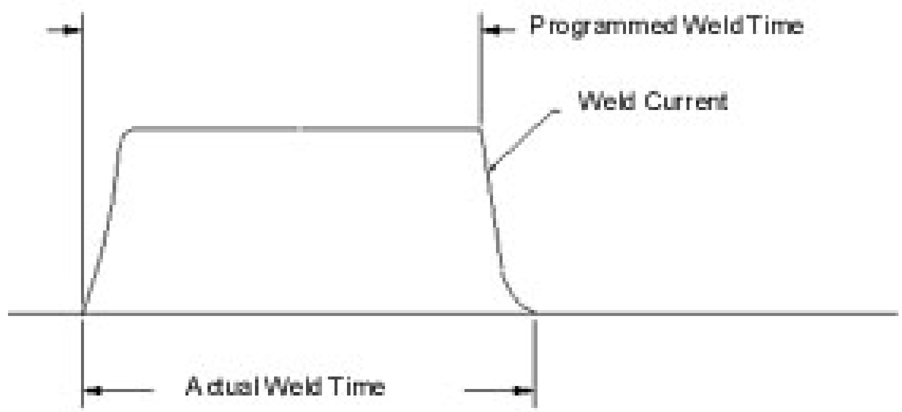

Figure 2.3 Programmed and actual weld time

In a typical single-pulse weld the metal between the electrodes is heated from room temperature to welding temperature and rapidly cooled. The growth and shape of the weld nugget is governed by the heat/cool cycles of the weld schedule (Fig. 2.4).

When weld time is too long, high indentation, excessive expulsion, and electrode sticking can occur. Worst case produces "burn-through" where

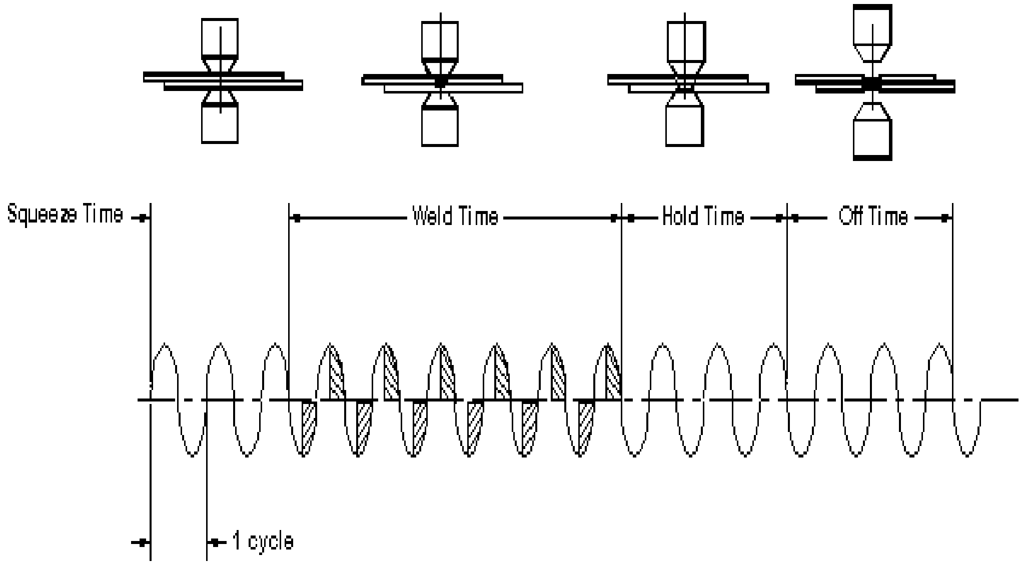

Figure 2.4 Weld Schedule

metal between the electrodes is completely melted, producing a hole in the parts to be welded. The electrodes penetrate through this molten metal and may contact each other.

On the other hand, when weld time is too short, a small nugget will result. Worst case will result in a missing weld, or a stuck weld can occur.

2.1.5 SURFACE CONDITION

A workpiece surface that is not free of substances that will degrade the welding operation. Since most surface contaminants have high electrical resistance, excessive heat is generated at the area of electrode contact and at the faying surface. This results in partial welding of the tip surface to the material, producing short tip life and degraded surface appearance. At the faying surface, metal expulsion may occur and slag inclusions or voids are frequently found in the fusion zone. The conditions described above are usually not consistent over all the work surface and will produce variations in the welding results.

When required, the material should be cleaned by suitable chemical or mechanical means.

2.1.6 OPERATOR

Securing adequately trained personnel and utilizing their skills most efficiently is one of the the greatest problems. The personnel problem includes all individual departments involved in the fabrication of the finished part from its design to its final acceptance.

The operation of an resistance spot welding machine requires a proper training in this welding method. A proper training comprises for example adequate knowledge of the theory of the resistance welding, surface preparation, resistance welding equipment, and experience on the selection of the parameters, such as welding force, welding current and welding time.

2.2 TYPICAL DEFECTS DUE TO SPOT WELDING

Defects inversly affects the quality of a spot weld. Hence their reasons and their appearances should be understood carefully to adjust the spot welding process parameters in order to avoid from them.

The weld issues and their possible causes are given briefly in Table 2.1 [9]. These spot weld issues will be explained in detail during this section.

Table 2.1 Spot weld issues and their possible causes [9].
S : Strong Relationship; W : Weak Relationship

		Weld Issues												
No.	Possible Causes	Missing Weld	Undersized Weld	Stuck Weld	Excessive Indentation	Expulsion/ Burn Throgh	Cracks& Holes	Mislocated/ Edge Weld	Sheet Metal Distortion	Extra Welds	Inconsistent Weld Quality	Brittle Weld	Nonround Weld	Interfacial Separation
1	Weld current low	S	S	S									S	
2	Weld current high				S	S	S							
3	Weld force low					W	S							
4	Weld force high		S	S	S									
5	Weld time short	S	S	W									S	
6	Weld time long				S	W								
7	Sequeeze time short					W	S							
8	Hold time short					W	S					W		S
9	Hold time long											S		W
10	Wrong tips		S	S	W	W	W	S	W				S	
11	Inadequate electrode alignment		S			W	W	S	W				S	
12	Electrode wear	W	S	S									S	
13	Electrode skidding/ sliding		S		W	W			W		S		S	
14	Insufficient cooling		S	W			S				W			
15	Incorrect material/ coating		S	W		W	W				W		W	
16	Dirty material		S	W		W	W				S		S	
17	Poor or varying fit-up	W	S	W	S	S	W	S	S		S		S	
18	Incorrect workpiece selected	S	W	W	W	W	W	S	S	S	W	W	W	W
19	Poor electrode follow-up		W			S					S		W	

2.2.1 SURFACE FUSION (OR BURNING)

It is the failure introduced with the melting of the metal surface which is in contact with the electrodes. Surface fusion or burning adversly affect the quality and appearance of the spot weld. The main reasons of this failure are:

- Improper surface or electrode condition
- Excessive welding current
- Insufficient welding pressure
- Improper fit-up of parts
- Improper weld sequence timing
- Insufficient electrode cooling
- Electrode material with a too low conductivity value
- Electrode skidding

2.2.2 BRITTLE WELD

It is a resistance spot weld that fractures with little or no plastic deformation in either the weld or the surrounding metal. The measurement of spot weld brittleness depends upon the test method. The size and shape of the welded structure under test, the rate of load application, the weld microstructure and surface conditions, and the ambient temperature all influence the amount and location of plastic deformation prior to fracture. Each must be considered when evaluating welds. Brittle welds (Fig 2.5) often fracture interfacially.

The brittle welds are generally formed due to the long hold time and incorrect test procedure. Brittle welds are frequently identified after testing by a visible granular fracture surface, with little or no stretching or yielding.

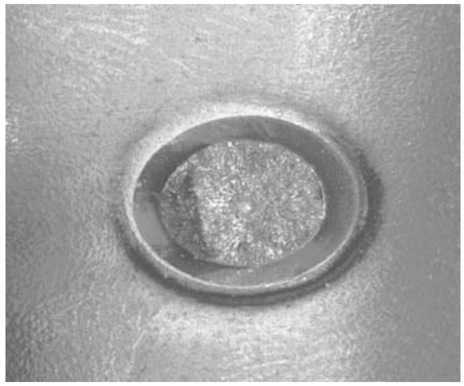

Figure 2.5 Brittle weld

2.2.3 NUGGET DIAMETER

The diameter or width of the fused zone must meet the requirements of the appropriate specifications or the design criteria. In the absence of such requirements, either accepted shop practices or the following general rule should be used. Spot welds that are reliably produced under normal production conditions should have a minimum nugget diameter of 3.5 to 4 times the square root of the thickness of the thinnest plate (Fig. 2.6). In cases of three or more dissimilar thicknesses, the nugget diameters between adjacent parts can be adjusted by the selection of the electrode design and materials. There is a maximum limit to the nugget size of a weld and is based on the economical and practical limitations of producing a weld together with the laws of heat generation and dissipation. The maximum useful nugget size is difficult to specify in general terms. Each user should establish this limit due to the design requirements and prevailing shop practices.

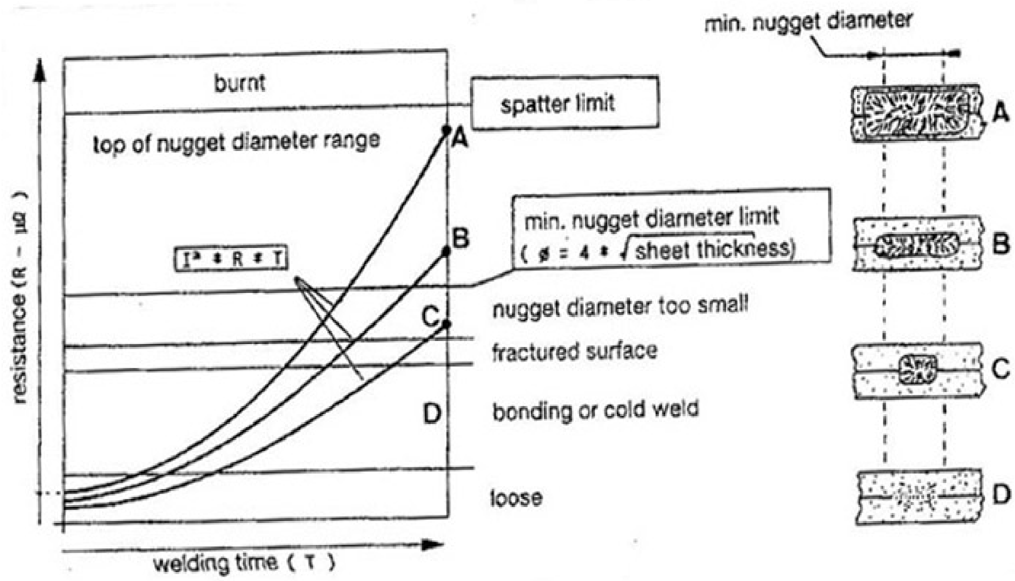

Figure 2.6 Nugget diameter due to resistance and the welding time

Undersized weld condition (Fig. 2.7) arises when the weld button/nugget diameter does not meet applicable specifications. (The weld nugget is the fused volume that joins the workpieces. The button is the material remaining attached to the fused area after destructive sheet separation.)

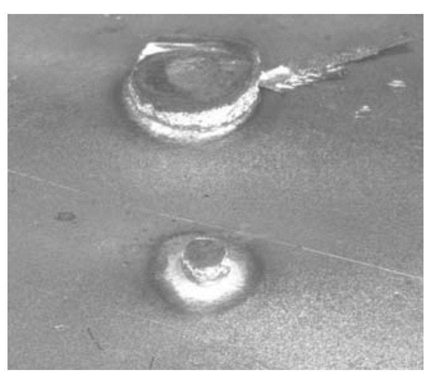

Figure 2.7 Undersized weld

Possible causes for the undersized weld issue are :

- Dirty material
- Electrode misalignment
- Insufficient cooling
- Poor weld accessibility
- Weld current low
- Weld force high
- Weld time short
- Wrong tips

2.2.4 EXCESSIVE INDENTATION

This type of a defect appears as a deep depression of the weld surface. Indentation on at least one side of the workpiece is an essential part of resistance spot welding. Vertical expansion of the weld metal by the pressure of the electrodes and hence some indentation is unavoidable [10]. Acceptable indentation and the method of measurement may vary among manufacturers. The weld classification may also influence the acceptable indentation and acceptable indentation may be different on each side of the workpiece. But there are limits for the acceptability of the indentation, and these limits generally range from 10 to 20 % of sheet metal thickness. Deep indentation results in a loss of strength due to the reduced metal thickness near the weld zone, so it is undesirable. The strong possibilities for this failure are listed below :

- Too small electrode tip contour
- Excessive welding force
- Excessive welding current
- Long weld time

- Excessive surface heating
- Poor or varying part fit-up

2.2.5 SYMMETRY

A well-formed nugget may be defined as being symmetrical to both horizontal and vertical axes. A weld that is incorrectly positioned compared to current workpiece design leads to a unsymmetry problem. Edge welds (Fig 2.8) are those welds that touch or extend beyond the edge of the workpiece.

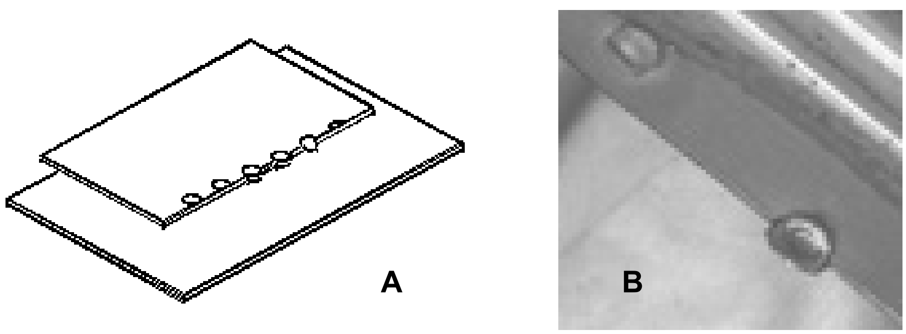

Figure 2.8 Edge weld, **A)** schematic wiev, **B)** an example to edge welds

Another type of unsymmetry, the missing weld (Fig 2.9) is a weld that is missing when there is no fusion of parent metal or coatings at the intended weld location. Missing welds can occur either because: the welding equipment never contacted the workpiece at the intended weld location or inadequate heat was developed at the intended location.

Unsymmetrical welds may be caused by one of the following reasons :

- Electrode misalignment
- Improper fit-up of parts
- Improper weld schedule
- Too narrow electrode tip contour
- Improper surface condition
- Poor weld accessibility

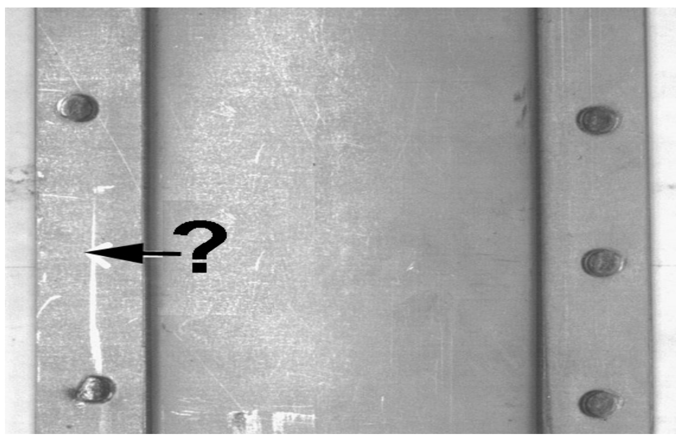

Figure 2.9 Missing weld

Reference should be made to the appropriate manufacturer's specifications to determine required locations for spot welds. Workpiece inspection may then determine whether visible welds are properly located or missing. Where welds are not visible (e.g., no indention or heat discoloration due to Class-A surface requirements), nondestructive or destructive test methods are required.

On the contrary to missing welds, the extra welds (Fig 2.10) are the additional welds on a workpiece compared to current workpiece design. Extra welds can occur either because of the selected incorrect workpiece or inconsistent location due to a fixture, robot or operator.

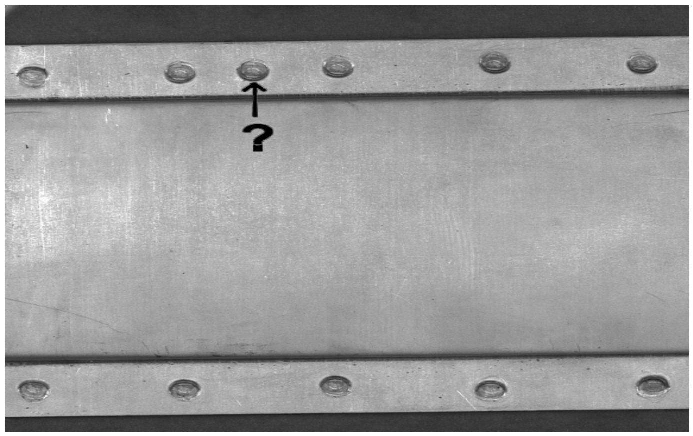

Figure 2.10 Extra weld

Detection of extra welds is made with a visual inspection of the workpiece by counting the welds and comparing with a quality inspection chart.

2.2.6 INTERFACIAL SEPARATION

As a result of the expansion and contraction of the weld metal and the forging effect of the electrodes on the hot nugget, sheet separation occurs at the faying surfaces. The amount of separation varies with the thickness of the base metal, increasing with greater thickness. Interfacial separation can arise due to the short hold time and incorrect test procedure.

Interfacial separation may occur with heavy stack-ups or certain materials such as aluminum and high strength steels. With stack-ups involving thick gages, the workpiece may be stronger than the weld nugget. Therefore during peel testing, chisel testing, etc., the crack that starts at the edge of the nugget will meet less mechanical resistance by growing through the nugget, rather than through the thickness of the workpiece (see Fig. 2.11).

Such welds may be acceptable if the fused area exceeds the minimum button size, and the surrounding material shows evidence that the weld had adequate strength, for example, the flanges may be distorted during testing. Extra care should be taken with interfacial separations in high strength steel, since these might be indicative of brittle weld failures.

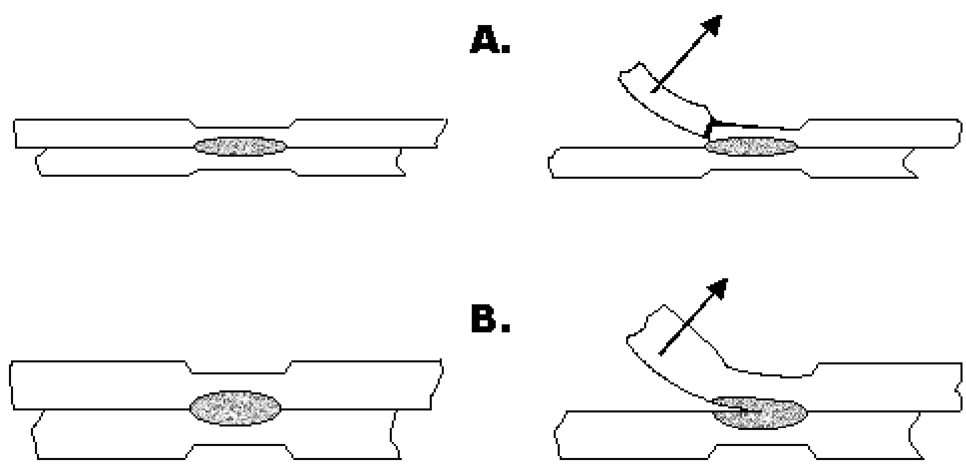

Figure 2.11 Normally during destructive testing the crack starting at the edge of the nugget travels through the thickness of the sheet, forming the button (A). With thicker or stronger stack-ups, or with certain materials, the crack may encounter less resistance by passing through the nugget (B).

A fused area where a button would normally be after teardown indicates an interfacial separation (Fig. 2.12). Welds that separate through the interface may indicate excessive edge porosity or brittleness and should be checked against company standards.

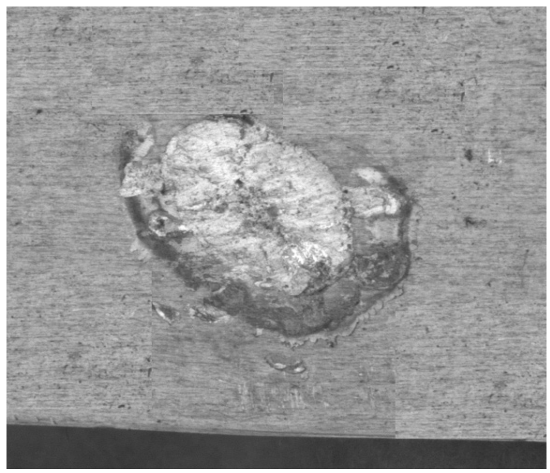

Figure 2.12 Interfacial Separation

2.2.7 EXPULSION

Expulsion is the forceful ejection of molten metal from the weld. Severe expulsion may eject enough material to create a through-hole in the workpiece, commonly termed "burn through". When the high current combines with inadequate electrode force, improperly faced electrodes, or inadequate follow-up of the electrodes, expulsion occurs due to overheating. Expulsion may occur at any interface, i.e. at the tip to workpiece interface, (Fig. 2.13A), or at any faying surface (Fig. 2.13B).

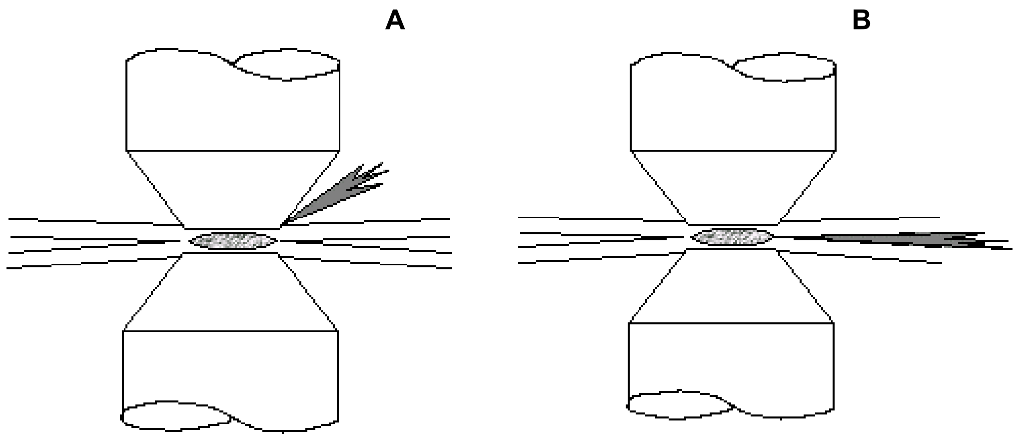

Figure 2.13 Expulsion **A)** at the tip to workpiece interface, **B)** at any faying surface.

Expulsion (Fig. 2.14) is caused by lack of containment of the expanding molten material between the electrode tip faces, and excessive expulsion is undesirable. Expulsion results in internal cavities, and generally reduces the strength of the weld. This tendency is so pronounced that the maximum current is normally limited to a value where the expulsion will not occur.

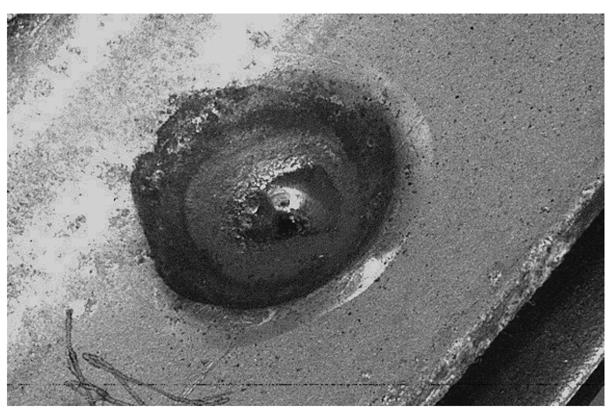

Figure 2.14 Burn through hole in a steel weld

Expulsion is a very significant issue for the spot welded product quality as expulsion at the weld interface may displace or damage adhesives and sealers. Whiskers may prevent the installation of seals, or may damage them during installation. Corrosion is more likely to occur when burrs/whiskers are present.

2.2.8 INADEQUATE PENETRATION

Penetration in a spot weld may be defined as the depth to which fusion extends into the member in which it occurs; it is expressed as a percentage of the thickness of the sheet metal. Except in aircraft-quality spot welding, limits of nugget penetration in welded parts are commonly not specified. Even for aircraft-quality, the range may be from 20 to 80% [11]. Inadequate penetration generally results from too low a current density in the weld perhaps from a malfunction or improper setting of the machine or other cause, such as mushroomed electrodes and partial alternate of the welding current through adjacent welds. The other reasons for inadequate penetration issue are :

- Improper heat balance
- Excessive pressure
- Insufficient welding time
- Improper material
- Improper surface condition

2.2.9 EXCESSIVE PENETRATION

When the penetration exceeds 80% for a spot weld, this situation may lead to other types of defects such as cracks, porosity and expulsion. Generally excessive penetration results from one or more of the following reasons :

- Excessive welding current
- Insufficient welding pressure
- Insufficient electrode cooling
- Improper weld sequence timing
- Too small electrode tip contour
- Improper surface condition

2.2.10 POOR WELD SHAPE

This issue consists a variety of defects that may result from part configurations causing undersized nuggets that can lead to failure. As an example, nonround weld is the weld or weld button that are not circular. Nonround welds (Fig. 2.15) may be caused in several ways. Typically they are the result of using worn electrode tips, improperly aligned welding equipment, or insufficient weld energy. Reference should be made to appropriate company standards to determine whether any nonround conditions are acceptable.

Figure 2.15 Nonround weld

Nonround welds may indicate that equipment maintenance is required, i.e. the detection of them is very significant. A noncircular and/or unsmooth electrode impression on the workpiece before teardown may indicate the presence of a nonround weld. Note that nonround welds can also occur under indentations with a perfect appearance. Furthermore, nonround welds can be indicated by the shape of the remaining button after teardown.

Possible causes for the nonround welds are :

- Dirty material
- Electrode misalignment
- Electrode skidding/sliding
- Low weld current
- Short weld time

2.2.11 SHEET METAL DISTORTION

The sheet metal is distorted if it is deformed such that the weld interface is out of the plane of the sheet metal, or if any of the sheets are displaced from their original plane.

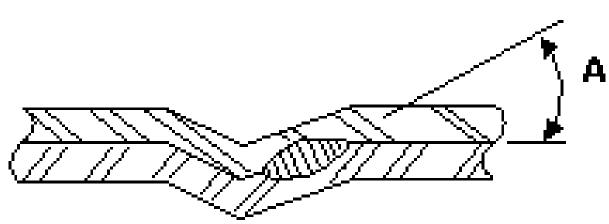

Figure 2.16 Out of plane condition

One of the most frequently encountered examples occurs if the weld is not in the plane of the surrounding metal (see Fig. 2.16). This condition is caused by the electrode faces not being parallel to the workpiece. Therefore, the application of welding force and current cause the weld to be made at an angle (A in Fig. 2.16) to the plane of the interface (out of plane condition).

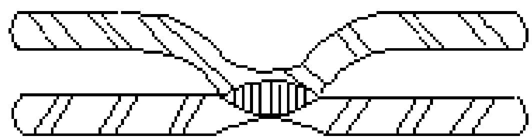

Figure 2.17 Poor fit-up

Another example arises if metals being welded do not have intimate contact in the area to be welded (Fig 2.17). The application of welding force and current causes one or both sheets to distort toward one another (poor fit-up).

Detection of the sheet metal distortion issue is typically made by a postweld visual inspection of the work piece. It is very critical for the quality of the product since thinning of the metal in the distorted weld area may cause a distorted weld to be weaker than a nondistorted weld and the distorted area may not meet the surface appearance requirements.

Excessive welding current, excessive welding pressure, insufficient edge distance, improper fit-up, poor weld accessibility or electrode skidding may cause distortion. When distortion or edge bulge occurs, the spot welds are placed too near a metal edge and there is a risk of edge cracking.

2.2.12 STICK WELDS

This type of a failure occurs when workpieces are held together by localized fusion at the welding interface, but no weld button is formed. Stick welds (Fig. 2.18) occur when there is insufficient heat at the welding interface to bring about nugget growth. Instead, fusion occurs only between point contacts between the sheets. With coated materials, coatings can melt and refreeze, effectively soldering the parts together. The resulting bonds are strong enough to hold the workpieces together under light loads, but reasonable force will pull them apart.

Figure 2.18 Stick weld

Pry testing or teardown will detect stick welds. Also ultrasonic pulse-echo method can also be applied nondestructively. Possible causes for the stick welds are :

- Low weld current
- High weld force
- Electrode wear
- Wrong tips

2.2.13 CRACKS

These are the discontinuities within the weld nugget and/or surrounding area caused by metallurgical changes resulting from welding. Weld containing cracks usually result from overheating, improper loading during the welding cycle, or the use of welding programs that are unfavorable for crack sensitive metals. Hot cracks are uncommon in resistance welding as the time at high temperature is too short.

Holes may be contained within the nugget at the weld center (Fig. 2.19), or distributed around the edge at the sheet interface, as is sometimes caused by interfacial expulsion (Fig. 2.20). Holes may also be surface cavities such as those formed by heavy surface expulsion.

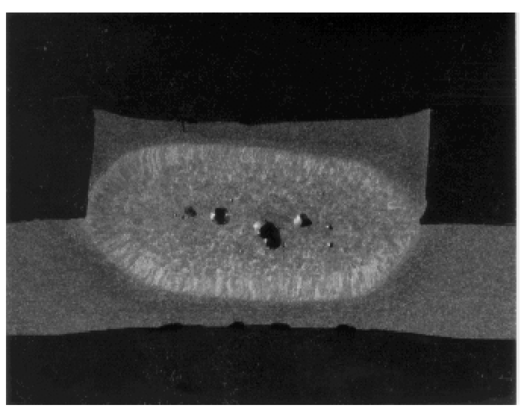

Figure 2.19 Holes at the center of the nugget revealed after teardown

Surface cracks usually radiate from the approximate center of the nugget (Fig. 2.20), and in extreme cases may pass through the entire thickness of the weld zone. Cracks internal to the nugget may be more random in orientation. Cracks may also exist in the material surrounding the nugget.

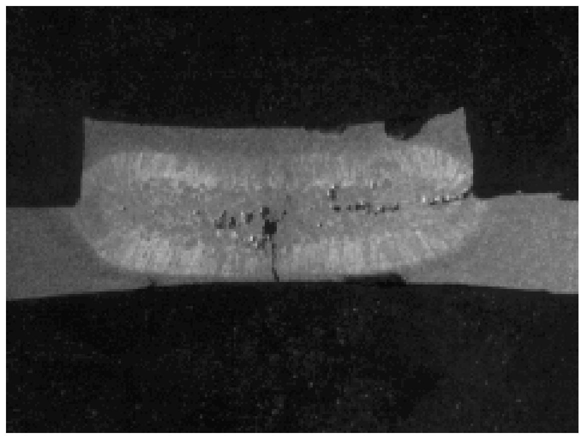

Figure 2.20 Nugget showing a surface crack and holes in the center of the weld. Holes at the edge of the interface were caused by interfacial expulsion.

Cold cracks may occur because the weld metal froze under insufficient pressure and was therefore forced to undergo thermal contraction relative to the surrounding matrix that demanded more deformation than the metal could tolerate. Such cracks weaken the weld considerably if they are at the weld center. These cracks may be avoided by proper pressure control, especially by application of forging pressure at the end of the weld cycle.

Unfavorable fabrication procedures or inadequate bend radii sometimes cause cracks that propagate in parts to induce failures that can be confused with weld-crack failures. There is a clear need to determine the true crack origin before assigning the cause of failure in such circumstances. Depending on their severity and position within the weld, cracks and holes may affect the weld performance. Holes or cracks at the edge of the weld interface may favor the growth of a crack during destructive testing.

Cracks extending to the surface of a spot weld normally indicate an improper force and current relationship. The welding force must be applied long enough to properly quench the fused area and it must be high enough to prevent excessive heat generation. Surface cracking lowers the strength and corrosion resistance of spot welds.

Surface cracks and holes may be visually detected before testing. If they have occurred at the sheet interface, they will not be visible until after teardown. Discontinuities within the nugget or at the sheet interface will not be visible until after teardown or joint sectioning.

Internal cracks may occur in the transverse or longitudinal direction in a spot weld and may be detected destructively by sectioning the weld or nondestructively by radiography. They may extend to the heat-affected zone or be confined to the center of the nugget, i.e. shrinkage cracks.

The main reasons for external cracks together with the internal cracks are:

- Excessive welding current
- Insufficient welding force
- Electrode misalignment
- Insufficient electrode cooling
- Short hold time
- Short sequeeze time

2.2.14 INCLUSIONS

The sources of inclusions in spot welding includes the surfaces of the parts being joined and their internal structures. Surface contaminants that may cause inclusions are dirt, rust, scale, certain types of coatings and sometimes oil and grease. These may be between the surfaces to be joined or may be between a part of the electrode contacting the part. Whether or not the inclusions cause failure depends on their quantity, size, location with the weld microstructure, and such properties as melting point or softening range. An inclusion that is likely to become fluid enough at the nugget-fusion temperature to penetrate a grain boundary would be particularly damaging.

2.2.15 POROSITY :

Some inclusions may cause weld porosity, which is generally considered undesirable but is totally unacceptable if certain limitations are exceeded. Other inclusions may generate blowholes, usually a cause for immediate rejection. Improper machine settings, particularly those causing excessive current and insufficient pressure, can cause porosity or blowholes. Furthermore, other machine settings such as insufficient welding time and improper rate of welding current rise can also result in porosity. These defects at the weld surface can cause part rejection, but moderate porosity near the center of the weld nugget is usually acceptable.

2.2.16 COPPER PICKUP :

Copper pickup in a spot welding is undesired since it increases the corrosion susceptibility of the weld [10]. Copper deposits may be completely removed with steel wool, by wire brushing or sanding the affected area. Copper pickup can be caused by one or more of the following reasons :

- Improper choice of surface preparation
- Too infrequent electrode cleaning
- Insufficient welding force
- Condensation on electrode tips.

2.2.17 INCONSISTENT WELD PROPERTIES :

Conditions that affect nugget formation include surface coatings, preweld cleaning, electrode overlap, spot weld-to edge distance, sheet thickness, and wall thickness of embossed projections. Any variation in properties that influences the electrical resistance between the parts will influence the weld quality.

Inconsistent weld quality can be determined through properly scheduled quality checks. Quality may vary as a result of a trend (Fig. 2.21A) or in a more random pattern (Fig. 2.21B).

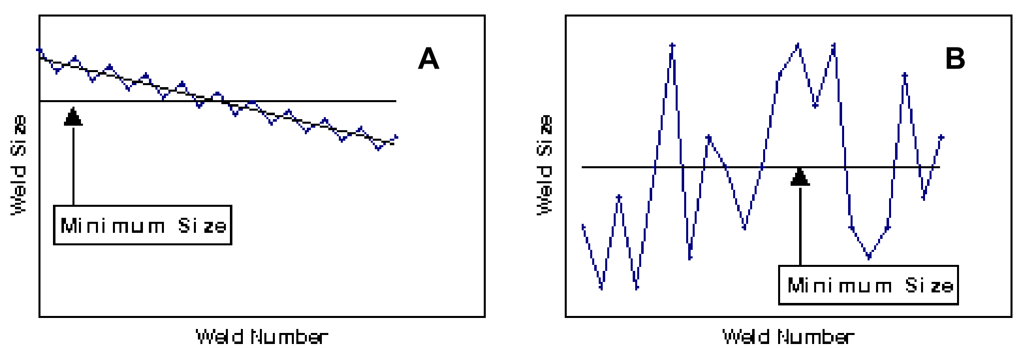

Figure 2.21 Weld quality variation: **A)** As a result of a trend, **B)** In a random pattern

A gradual decrease in weld quality (Fig. 2.21A) can occur because of an increase in the face diameter of the tips. Random variation about this trend may eventually fall below the minimum standards. Countermeasures to address the trend may include current steppers, tip-dressing etc.

Intermittent weld failures can result from variations in surface conditions that are not machine controlled. Examples include the presence of rust or of die-casting flash or mold-release compound in layers of varying thickness [12]. Careful cleaning and inspection before welding are the only presentatives.

Parts made of hardenable alloys may be hardened by the high heat and rapid quench of a typical resistance welding cycle. Such parts will be brittle, and the welds can easily be broken unless they are tempered, either as an added portion of the weld cycle or in a seperate operation outside the welding machine.

CHAPTER 3

SPOT WELD QUALITY

ASSESSMENT

3.1 STANDART TEST METHODS FOR TESTING SPOT WELD QUALITY

Resistance spot welding is frequently used as a successful joining method for a variety of work commonly in automotive and other manufacturing processes. For example, the typical car body contains about 5000 spot welds joining a mixture of sheet metal material types and thicknesses. If the quality of the products is considered, it is clear that the quality of the product is directly related to the quality of the spot weld. However, the spot welding process contains several parameters that are not easily controlled. Since these variables directly affects the quality and integrity of the weld joint, monitoring is necessary to achieve weld quality. Therefore, an adaptable and economical testing procedure for spot welds should be formed [13].

The principle test methods used to test the spot weld quality are :

- Destructive Tests

- Tension – Shear Test
- Tension Test
- Impact Test
- Torsional Test
- Peel Test
- Fatigue Test
- Macroetch Test
- Bend Test
- Chipping Test
- Hardness Test

- Non-destructive Tests

- Visual Test
- Radiographic Test
- Ultrasonic Test

3.1.1 DESTRUCTIVE TESTS FOR DETERMINING SPOT WELD QUALITY

The appearance of spot welds can be very deceiving. A weld may appear good even though, in essence, no weld exists [14]. Hence, some destructive tests may be used as a common practice to determine the spot weld quality in industry. Destructive testing, that is, testing to failure, gives a set of quantitative and qualitative measures of the properties under consideration. Tests of standard laboratory specimens are usually carried to failure for this reason.

The obvious disadvantage of testing the entire weldment to destruction arises from the fact that the test can be applied to only a fraction of the number of weldments produced, and the quality of the ones to be used must be inferred from the data relating to those destructed.

Resistance welded parts are frequently tested by selection of production parts which are tested to destruction. The testing procedure must be adapted to the particular work. Frequently, strength tests can be made on the finished articles. At other times bend or deformation tests will reveal defects. The etch test can be used in almost all cases to reveal lack of soundness, and Rockwell or similar tests for determining hardness [15].

In these test methods, consistent test results can be obtained only with careful attention to surface condition. The test material should be essentially free of grease, scale or other foreign substances likely to cause a high surface resistance. The sheared specimen should be essentially flat and free of burrs. Sheared burrs on heavy stock may cause shunting of the current through the edges of the pieces; therefore, the burrs should either be removed or the parts placed together with the burrs toward the outside faces of the specimens. Moreover, specimens showing obvious misalignment or lack of centering should be discarded [16].

The percentage testing or sampling method is not to be used when no defects can be tolerated. However, there are some final products which, by their nature, can only be evaluated by destructive tests, and others where it is not economical to test every unit. The acceptance quality level frequently specified as the number of defects or defective pieces per hundred.

3.1.1.1 TENSION-SHEAR TEST

This test consists of pulling in tension, to destruction, on a standard testing machine, a test specimen obtained by lapping two strips of metal and joining them by a single weld. The dimensions of the test specimen are shown in Figure 3.1. The ultimate strength of the specimen and the manner of failure, whether by shear of the weld metal, or by tear of the parent metal, and whether a ductile or brittle fracture is obtained, should be recorded.

Measurement of the diameter of a weld corresponding to the weld in tension-shear specimen is desirable. When no other test is intended, an approximate value of the diameter can be obtained by measurement on the fracture transverse to the direction of pull. More precise measurements can be made with tension, impact, macroetch and torsional test [17].

T (mm)	W (mm)	L (mm)
T < 0.8	16	76
0.8 – 1.3	19	76
1.3 – 2.5	25	102
2.5 – 3.3	32	127
3.3 – 4.8	38	127
T > 4.8	51	152

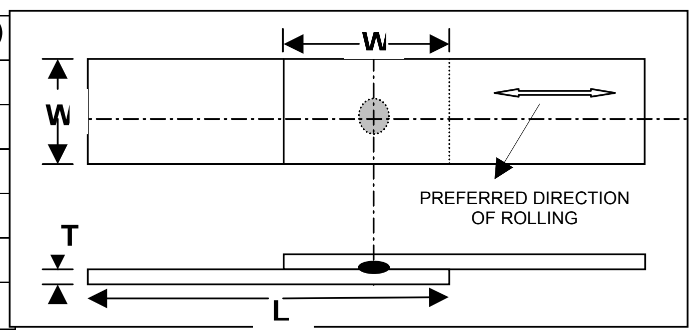

Figure 3.1 Tension-Shear Test Specimen

The record of the specimen should also include a complete description of the properties of the metal such as thickness, tensile strength, ductility and chemical composition.

The effect of eccentricity in the use of above specimens may be disregarded. For specimens having a thickness is equal to or more than 2.5 mm it is recommended that the grips of the testing machine be offset to avoid bending at the grips.

3.1.1.2 TENSION TEST

The purpose of the tension test is to provide a better measure of notch sensitivity than is obtained with the tension-shear test. The ratio of the tensile strength to the tension-shear strength is frequently referred to as the ductility of the weld. The ultimate strength of the weld, the diameter of the weld and the method of fracture should be recorded. There are two types of tension tests :

- Cross Tension Test
- U-Tension Test

This type of spot weld test is used to measure the strength of welds for loads applied in a direction normal to the spot weld interface. It is used mostly for welding schedule development and as a research tool for the weldability of new alloys. The tension test can be applied to ferrous and nonferrous metals of all thicknesses.

3.1.1.3 IMPACT TEST

The impact test differentiates between different degrees of weld toughness. It is valuable where the assemblies involved are subjected to dynamic loading.

There are four types of impact tests :

- Shear-Impact Test
- Drop-Impact Test
- Shear-Impact Loading Test
- Tension-Impact Loading Test

The shear-impact test is recommended as it a faster test, but is limited to thickness of 3.2 mm and under. The other types of tests are used for thicknesses over than 3.2 mm.

3.1.1.4 TORSIONAL TEST

Two types of torsional tests are used as described below.

Twist Test : A standard tension-shear specimen may be used as a twist test specimen to determine the weld diameter, as well as the angle of twist at failure. One end of the specimen usually is clamped edgewise in a vise, in a horizontal position. A sleeve, having a protractor mounted at its end is slipped over the protruding end of the specimen so that the the protractor is centered on the weld. The sleeve is rotated horizontally (i.e., in a flat arc about the vertical center line of the weld) until failure occurs. The angle of twist at failure is measured and recorded.

(a) Torsional Shear Test : The torsional-shear test for evaluating spot welds may be used where a measure of strength and ductility is required. Torsional-shear is applied on the weld of a square test specimen by placing the specimen between two recessed plates, the upper of which is held rigid by means of a hinge while the lower is fastened to a rotatable disk. After the specimen is placed in the square recess of the lower plate, the upper plate is closed over it and locked in position. Torque is applied by means of a rack and pinion attached to the disk. It is important that the upper and lower sheets of the specimen be engaged seperately by the two plates and that the weld be centrally located with respect to the axis of rotation. Three values are determined for the weld area :

- Ultimate torque required to twist the weld to destruction
- Angle of twist at ultimate torque (measured by the angle of rotation at maximum load)
- Weld diameter (measured after the test specimen is broken)

The weld strength can be determined using the ultimate torque and weld diameter, and the ductility by the angle of twist.

3.1.1.5 PEEL TEST

The peel test is a simple shop test that can be made with a minimum equipment, and if correlated with tension-shear and tension tests, it makes an ideal control test. It is applicable to all thicknesses of material up to 3.2 mm. The test consists of peeling apart, to destruction, a test specimen obtained by lapping two strips of metal and joining them by a single weld as shown in Figure 3.2. If it is desired to determine shunting effect several spots can be made using the desired spacing and then the sample cut transversely before peeling is started, using the last weld made as the test sample. Three welds are recommended for this adaptation.

The size of the fused zone can be measured by means of this test. An indication of the penetration is also obtained in that if sufficient penetration is not present, the metal from one piece will not be torn out in its entirety.

Irregularity of shape of torn metal also indicates insufficient penetration.

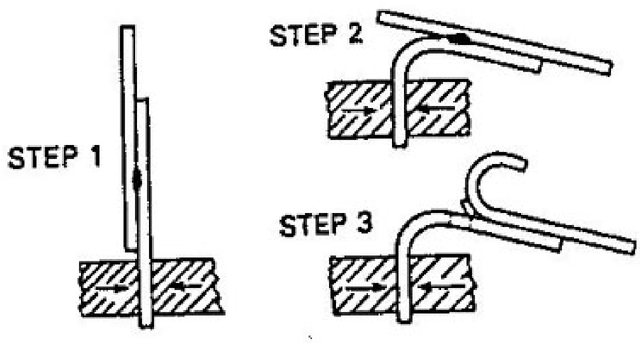

Figure 3.2 Step 1: Grip in vise or suitable device.
Step 2: Bend specimen. Step 3: Peel pieces apart with pincers or etc.

3.1.1.6 FATIGUE TEST

The tension-shear fatigue test makes use of the tension shear specimen. Mounting holes must be drilled using upmost care to align the holes with the weld. The specimen is loaded in tension with a static load. A dynamic load is then applied and the dynamic load oscillated until failure of the test specimen takes place.

3.1.1.7 MACROETCH TEST

The purpose of this test is to determine the weld diameter and penetration as a shop control measure. To prepare the specimen, lay a straight edge across the weld and scribe a line on a diameter of the weld as judged by eye. Saw to one side of the line, filing or grinding the specimen to the line. Etch until satisfactory definition is obtained between the weld zone and unaffected base metal. The weld diameter may be measured by means of a pair of dividers and a steel scale. The penetration may be estimated. For more precise measurement these values may be determined with a microscope.

This test is intended as a quick check, and its accuracy depends upon the care taken in preparation of the sample. Where more accurate information is required, the samples require mounting and careful preparation to obtain the true diameter.

3.1.1.8 HARDNESS TEST

The macroetch specimen can be prepared and used in this test exercising care to avoid overheating of the weld area in cutting so as to affect the surface hardness. A second cut parallel to the first should be made to obtain a sample of suitable height to mount in the hardness tester. The weld section is finished with 3/0 paper and etched. Care should be taken to select a hardness test method so that the impression does not distort the edge of the specimen.

3.1.1.9 CHIPPING TEST

In the destructive chipping test, the spots are subjected to load using simple test means, without recording a measured value, until they break. The type of breakage and the size of the ruptured spot are used as evaluation criteria [18]. The advantage of the chipping test rather than the other destructive methods lies in the fact that it can also be used on a finished product. However, it is mostly used as a nondestructive test in some applications, i.e. the load is not applied all the way up to the breakage of the welded joint.

The costs for this test are comparably low, the same as the information from the test results. It can only be used for detecting defective spots whose strength already lies way below the permissible minimum value, i.e. so-called “stick welds”. Added to this is the fact that the test results vary within a wide tolerance range due to the relatively indefinite test conditions which can not be constantly observed. One more disadvantage of the chipping test is that, it produces a considerable percentage of scrap.

3.1.1.10 BEND TEST

The bend test is a relatively simple shop test included to provide a quick check test of production spot-weld soundness, particularly freedom from cracks (microfissures). It is intended as an aid to process control rather than a requirement. It can be performed with equipment which is readily available in most shops and requires only visual examination for evaluation. The test is specifically limited to a maximum of two thicknesses of 3.2 mm and has been developed for use on aliminium and aliminium alloys.

The bend test is not precise enough for equipment calibration nor for evaluating machine performances nor the setting up or qualification of welding schedules.

The test consists of bending a test specimen which is removed from a routine macrosection containing three welds. The bend test specimen is bent along its length to the angles such a manner as to produce a concentration of the bending stresses successively in each of the three welds. Before bending , the edges of the specimen should be rounded and smoothed to remove the burr [5]. After bending the specimen is examined for the presence of cracks or any other surface defects. The same test can also be used for seam welds.

CHAPTER 4

NONDESTRUCTIVE INSPECTION

METHODS

4.1 INTRODUCTION

Nondestructive evaluation (NDE) comprises many terms used to describe various activities within the field. Some of these terms are nondestructive testing (NDT), nondestructive examination (NDE) , nondestructive inspection (NDI). These activities include testing, inspection and examination, which are similar in that they primarily involve looking at (or through) or measuring something about an object to determine some characteristic of the object or to determine whether the object contains irregularities, discontinuties, or flaws [19].

4.2 SELECTION OF NDI METHODS

Several different ways of comparing the selected NDI methods are presented in this section, but there is no completely acceptable system of comparison, because the results are highly dependent on the application [19]. Therefore, it is recommended that a comparison be developed specifically for each NDE area and application. Nondestructive evaluation can be conveniently divided into eight distinct areas :

- Flaw detection and evaluation
- Leak detection and evaluation
- Metrology (measurement of dimension) and evaluation
- Location determination and evaluation
- Structure and microstructure characterization
- Estimation of mechanical and physical properties
- Stress (strain) and dynamic response determination
- Chemical composition determination

The nondestructive inspection of weldments has two functions: quality control of the welding process and acceptance or rejection criteria of a welded product. Nondestructive tests do not require the original welded structure to be altered in any way. It is possible to inspect the welds while the entire structure is in its normal position [1]. Because nothing has to be destroyed, we may consider this method to be less expensive; however, the initial cost of equipment for most of these tests is considerable.

The most commonly used methods of weld inspection are visual, liquid penetrant, magnetic particle, radiographic, eddy-current, and ultrasonic inspections. The selection of the appropriate NDI method(s) is influenced by a number of factors related to test conditions. The leading test conditions are material type, weld geometry, and type of flaw. There may be other constraints on selection, such as the availability of testing equipment and trained staff. The methods shown in Table 4.1 to Table 4.3 are rated according to their applicability [1].

Table 4.1 Selection of NDI method on the basis of material type.

MA: Most Applicable; A: Applicable; LA: Least Applicable, NA: Not Applicable

MATERIAL TYPE	VISUAL INSPECTION	LIQUID PENETRANT	MAGNETIC PARTICLE	EDDY CURRENT	ULTRASONIC TESTING	RADIOGRAPHIC TESTING
Low-carbon steel	A	A	MA	LA	MA	A
High-alloy steel	A	A	LA	A	A	A
Stainless Steels	A	A	LA	LA	A	MA
Aluminium Alloys	A	A	NA	A	A	MA
Titanıum Alloys	A	A	NA	A	A	MA
Copper Alloys	A	MA	NA	LA	LA	A

Table 4.2 Selection of NDI method on the basis of weld geometry.

MA : Most Applicable; A : Applicable, LA : Least Applicable, NA : Not Applicable

WELD GEOMETRY	VISUAL INSPECTION	LIQUID PENETRANT	MAGNETIC PARTICLE	EDDY CURRENT	ULTRASONIC TESTING	RADIOGRAPHIC TESTING
One side access	LA	LA	LA	LA	MA	NA
Both-side access	A	A	A	LA	MA	MA
Single V	LA	LA	LA	LA	MA	A
Double V	A	A	A	LA	MA	MA
T grove	A	A	A	LA	MA	LA
T fillet	MA	A	MA	LA	LA	LA
Branch groove	A	A	LA	LA	MA	LA
Branch fillet	MA	A	MA	LA	LA	LA
Groove plate/pipe	A	A	A	LA	MA	MA
Lap	MA	A	MA	LA	LA	A
Node	A	A	A	A	A	LA

Table 4.3 Selection of NDI method on the basis of flaw type.

MA : Most Applicable; A : Applicable, LA : Least Applicable, NA : Not Applicable

FLAW TYPE	VISUAL INSPECTION	LIQUID PENET.	MAG. PARTICLE	EDDY CURRENT	ULTRASONIC TESTING	RADIOGRAPHIC TESTING
Microcracks	MA	LA	LA	LA	LA	LA
Longitudinal cracks	LA	A	A	A	A	MA
Transverse cracks	LA	A	A	A	MA	A
Radiating cracks	LA	MA	A	LA	A	MA
Crater cracks	A	A	A	LA	LA	MA
Porosity	LA	A	LA	LA	LA	MA
Shrinkage cavity	MA	A	A	LA	LA	A
Inclusion	NA	NA	NA	LA	A	MA
Incomplete Penetration	A	A	A	LA	A	MA
Excessive Penetration	MA	NA	NA	NA	LA	A
Incomplete Sidewall Fusion	LA	A	A	LA	MA	A
Undercut	MA	A	A	LA	LA	A
Overlap	A	MA	A	LA	LA	LA
Miscellaneous	MA	LA	LA	NA	A	NA

Source : ISO 6520

4.3 PRINCIPAL NDI METHODS :

The most commonly used nondestructive inspection methods for welding are visual, liquid penetrant, magnetic particle, radiographic, eddy-current and ultrasonic inspection methods. These methods will be briefly described below.

4.3.1 VISUAL INSPECTION METHOD

Visual inspection, although not itself a test method, is the most common nondestructive inspection method and, arguably, the most important. Indeed, a through visual examination is a prerequisite of successful nondestructive inspection.

Visual inspection is generally done with the naked eye, but magnifying glasses, optical microscopes, boroscopes, endoscopes, video microscopes, etc. can also be used. Among these, boroscopes and endoscopes are useful when surfaces to be inspected are not accessible.

For many noncritical welds that are not required to withstand heavy loads, integrity is verified principally by visual inspection. Visual inspection can and should be done before, during, and after welding [20]. Although visual inspection is the simplest inspection method to use, a definite procedure should be established to ensure that it is carried out accurately and uniformly.

Visual inspection is useful for checking the following:

- Dimensional accuracy of weldments
- Conformity of welds to size and contour requirements
- Acceptability of weld appearance with regard to surface roughness, weld spatter, and cleanness.
- Presence of surface flaws such as unfilled craters, undercuts, overlaps and cracks.

Although visual inspection is an invaluable method, it is unreliable for detecting subsurface flaws. Therefore, judgement of weld quality must be based on information in addition to that afforded by surface indications [19].

Before a weld is visually inspected for discontinuities such as unfilled craters, surface holes, undercuts, overlaps, surface cracks, and incomplete joint penetration, the surface of the weld should be cleaned of oxides and slag. Cleaning must be done carefully.

4.3.2 LIQUID PENETRANT INSPECTION METHOD

It is sometimes referred to as *dye penetrant* or *fluorescent penetrant inspection,* because it is possible to use colored dye or a fluorescent liquid in this process. This inspection method is useful for surface defects only, since the liquid must be able to penetrate the flaws. It does have the advantage of being useful on non-ferrous materials such as aliminium, brass, and copper as well as on cast iron and steel.

Liquid penetrant is applied to the surface of the part, where it remains for a period of time and penetrates into flaws. For the correct usage of the liquid penetrant inspection, it is essential that the surface of the part be throughly clean, leaving the openings free to receive the penetrant.

After penetrating period, the excess penetrant remaining on the surface is moved. An absorbent, light-colored developer is then applied to the surface. As the penetrant is drawn out, it diffuses into developer, forming indications that are wider than the surface openings. The inspector looks for these colored or fluorescent indications against the background of the developer.

4.3.3 MAGNETIC PARTICLE INSPECTION METHOD

Magnetic particle inspection, as the name implies, requires the use of magnetic field. The work to be checked must be able to accept magnetism. This process is therefore limited to magnetic metals. It is also limited to surface or near-surface faults.

The magnetic particle inspection of weldments requires that the weld bead be free of scale, slag and moisture. After cleaning the inspection surfaces, weldments are inspected magnetically usually by using the dry particle method. The type of the magnetizing current to be used depends on whether the possibility of the surface or subsurface defects. Alternating current is satisfactory for surface cracks, but if the deepest possible penetration is essential, direct current, direct current with surge, or half-wave rectified alternating current is used.

The voltage should be as low as practical to reduce the possibility of damage to the surface of the part from overheating or arcing at contacts. Another advantage of low voltage is freedom from arc flashes if a prod slips or is withdrawn before the current is turned off.

Steel castings, forgings, and sections that have been welded are the most common parts to be inspected by the magnetic particle process.

4.3.4 RADIOGRAPHIC INSPECTION METHOD

Radiography uses x- rays or gamma rays, which have the ability to penetrate materials that absorbed or reflect ordinary light [21]. X-rays are created under controlled conditions by bombarding a specific area with a flow of electrons. Gamma rays are produced by radioactive isotopes. These isotopes never stop giving off radiation; therefore, they must be stored in special shielded containers.

The ability of the material to absorb radiation is dependent upon its density and the wavelength of radiation being used [22]. This absorbtion or radiation also varies with the thickness of a piece of material. A thinner piece of material will absorb less radiation as the rays pass through the object, therefore, more radiation will escape through the object. A film placed behind the object to be inspected will be affected more in thin sections than thick sections. Defect in the part being examined will allow more radiation to pass through it and the defect will be visible on the film.

A radiograph is the recorded image produced on a photographic plate by x-ray. The flaw in the specimen will not absorb as much radiation as does the rest of the part. Therefore, a darker image is present on the film where the flaw exists [23].

Real-time radiography, which involves the display of radiographic images on television monitors through the use of an image converter and a television camera, is a rapidly developing method for weld inspections. One of the main advantages of real-time radiography for weld inspection is the cost savings that results from reducing the use of x-ray films. However, the possibility of expanding such an inspection system to include automatic defect evaluation by the image processing system can yield significantly greater advantages. Automatic defect evaluation systems will result in objective and reproducible x-ray inspection, independent of human factors. Computer programs for the efficient automated evaluation of weld radiographs are currently being developed and refined [24].

Resistance welds, mainly spot welds and seam welds, are used to join relatively thin sheets. In the radiography of spot welds and seam welds, the central beam is ordinarily directed normal to the surface of one of the sheets and is centered on the depression that indicates the location of the weld. Radiography can detect discontinuities in both weld metal and base metal, including cracks, inclusions and porosity in the weld, cracking and deformation in the base metal, segregation in the in the fusion zone of the

resistance welds in light alloys, and expulsion of molten metal between the faying surfaces. Normally, deficiencies such as underbead cracking and incomplete fusion are not revealed by radiography, although incomplete fusion can sometimes be inferred from the presence of other discontiniuities.
A view other than the normal view is sometimes dictated by the shape of the weldment, especially when portions of the weldment may cast shadows that would detract from the clarity of the weld zone image. In such cases, it is best to select a view as near to normal as possible so as to minimize distortion. In contrast to arc welds, in which an oblique view adversly affects both the intensity of the transmitted radiation and the sensitivity, only sensivity is affected by using an oblique view for the inspection of the resistance welds. Most resistance welded assemblies are thin enough that the section can be penetrated by relatively low energy radiation. The sensitivity, expressed as minimum detectable discontinuity size, varies with the cosecant of the angle between the viewing direction and the sheet surface. This relationship indicates that the smallest value of minimum detectable discontinuity size occurs with a 90° viewing direction, and viewing directions between 90° and 65° give no more than about a % 10 increase in this value. The main disadvantage of oblique views is their inability to resolve the images of transverse cracks in either the weld or adjacent heat affected zones.

4.3.5 EDDY-CURRENT INSPECTION METHOD

Eddy-current (electromagnetic) tests are defined as tests which require the object under test to be subjected to the influence of an alternating electromagnetic field. The electromagnetic tests are used to detect and, in many cases, to evaluate surface or subsurface discontinuities which may occur in the form of cracks, seam, voids, etc. The effect of the electromagnetic field may be twofold: eddy currents are induced and, if the material is magnetic, magnetic fields are set up. A complete separation of these two effects in magnetic materials is not readily accomplished; however, by selection of the magnetizing frequency and by proper design of the test circuitry, a high degree of discrimination may be obtained.

The alternating electromagnetic field is usually produced by an inductor positioned in close proximity to the specimen under test. The inductor may assume a variety of shapes and arrangements. The selection of shape, dimension and arrangenment is governed by the sensitivity required to detect the discontinuities involved, by the orientation of the defects sought and by the geometry of the specimen.

In eddy-current tests the magnitude and direction of the eddy currents are altered by discontinuities in the material. The change in the eddy currents is detected by a detector coil which acts upon appropriate electronic circuitry to register the discontinuity [25]. Since eddy currents may be induced in any conductor, eddy current testing may be employed on either magnetic or non-magnetic materials.

Changes in the eddy current or the magnetic flux may be interpreted by means of several different electrical variables such as voltage, current, impedance, phase, or some combination of the above. These variables are analyzed electronically to provide the desired information in a useful form. Electromagnetic tests may be absolute measurements relating to the discontinuity itself or comparisons of variables relating to both the discontinuity and the adjacent sound material.

Electromagnetic tests may be applied to welds of various configurations. The design of the inductor, which is used for producing the magnetic field, is usually dependent upon the geometry of the material to be tested and on the type of defects that are sought. The technique most commonly used on welded tubular products involves a coil or coils which surround the material.

Other eddy current test techniques employ probe coils that do not surround the material to be tested. One that has been used with considerable success provides a probe coil with its axis at right angles to the axis of the material. It induces eddy currents following the shape of the coil in the portion of the material closest to the coil. The circuitry used in this technique is responsive to changes in the current flow caused by discontinuities as the specimen progresses past the probe coil.

4.3.6 ULTRASONIC INSPECTION METHOD

Ultrasonic inspection is a nondestructive method in which beams of high-frequency sound waves are introduced into materials for the detection of surface and subsurface flaws in the material. The sound waves travel through the material with some attendant loss of energy (attenuation) and are reflected at interfaces [26]. The reflected beam is displayed and then analyzed to define the presence and location of flaws or discontinuities.

The degree of reflection depends largely on the physical state of the materials forming in the interface and to a lesser extent on the specific physical properties of the material. For example, sound waves are almost completely reflected at metal/gas interfaces. Partial reflection occurs at metal/liquid or metal/solid interfaces, with the specific percentage of reflected energy depending mainly on the ratios of certain properties of the material on opposing sides of the interface [27].

Cracks, laminations, shrinkage cavities, bursts, flakes, pores, disbonds, and other discontinuities that produce reflective interfaces can be easily detected. Inclusions and other inhomogeneities can also detected by causing partial reflection or scattering of the ultrasonic waves or by producing some other detectable effect on the ultrasonic waves.

Ultrasonic inspection is one of the most widely used methods of nondestructive inspection. Its primary application in the inspection of metals is the detection and characterization of internal flaws: it is also used to detect surface flaws, to define bond characteristics, to measure the thickness and extent of corrosion, and (much less frequently) to determine physical properties, structure, grain size, and elastic constants [28].

The primary functional requirement from a nondestructive technique for spot weld inspection is the capability to assess and classify the spot weld quality into acceptable, undersize and unacceptable catagories. Other requirements include cost effectiveness of the inspection method and suitability for implementation and in the production enviroinment without requirement of highly skilled operators. The category of unacceptable welds is mostly comprised of "stick" welds, where the mating surfaces are weakly bonded in the weld zone because of shallow heating and melting. "Stick" welds are a prodominant failure mode of the spot welding process. These welds have the same appearance as the acceptable welds, but will not produce a weld nugget when the sheets are peeled apart [2]. In other words, the weld tears rather than the parent metal around it.

The method described in this section is based upon an ultrasonic pulse-echo technique. By using transit time and attenuation of the ultrasonic energy, it enables detection of the presence and size adequacy of a weld in the weld zone. Early works pointed toward the probable success of the ultrasonic pulse-echo method applied through the thickness of the weld nugget. The technique has been successfully applied to heavier-gage sheet metal automotive parts for several years.

4.3.6.1 PRECONDITIONS FOR ULTRASONIC INSPECTION

In this section, three most important requirements for a safe and reliable ultrasonic inspection will be mentioned [29] :

- The operator training,
- The knowledge of the special test requirements and limits,
- The choice of appropriate test equipment.

4.3.6.1.1 OPERATOR TRAINING

The operation of an ultrasonic test device requires a proper training in ultrasonic test methods. A proper training comprises for example adequate knowledge of the theory of sound propagation, the effects of sound velocity in the test material, what happens to the sound wave at the interfaces between two different materials, the propagation of the sound beam, the influence of sound attenuation in the test object, and the influence of surface quality of the test object.

Lack of such knowledge could lead to false test results with unforeseeable consequences. To eliminate these unpleasent situation, consulting NDT societies or organizations in any country (DGZfP in germany, ASNT in the USA), or the manufacturers of NDT instruments and test equipment or any other organization may be necessary for information concerning existing possibilities for the training of ultrasonic inspectors as well as on the qualifications and certificates that can finally be obtained [29].

4.3.6.1.2 TECHNICAL TEST REQUIREMENTS

Every ultrasonic test is subject to specific technical test requirements. The most important ones are :

- The definition of the scope of inspection,
- The choice of the appropriate test method,
- The consideration of material properties,
- The determination of the “limits for recording and evaluation”

It is the task of those with overall responsibility for testing to ensure that the inspector for fully informed about these requirements. The best basis for such information is experience with test objects. It is also essential that the test specifications be clearly and completely understood by the inspector.

4.3.6.2 WAVE PATH

The ultrasonic wave must be a beam directed perpendicularly to the faces of the metal sheets and through the center of the nugget. The width of the sound beam must be approximately equal to the smallest allowable weld diameter. In general, an ultrasonic wave is reflected when it impinges an interface where a change in acoustic impedance occurs.

In Figure 4.1 reflections are shown to occur at the outer surfaces of the two sheets. Reflections can also occur at the interface (air) between the two sheets if the nugget is small as in Figure 4.1.

The nugget-to-parent metal boundary does not produce perceptible reflections, refraction or scattering because changes in density and velocity are a tenth of a percent or less (air-to-steel difference exceeds 99.9 %).

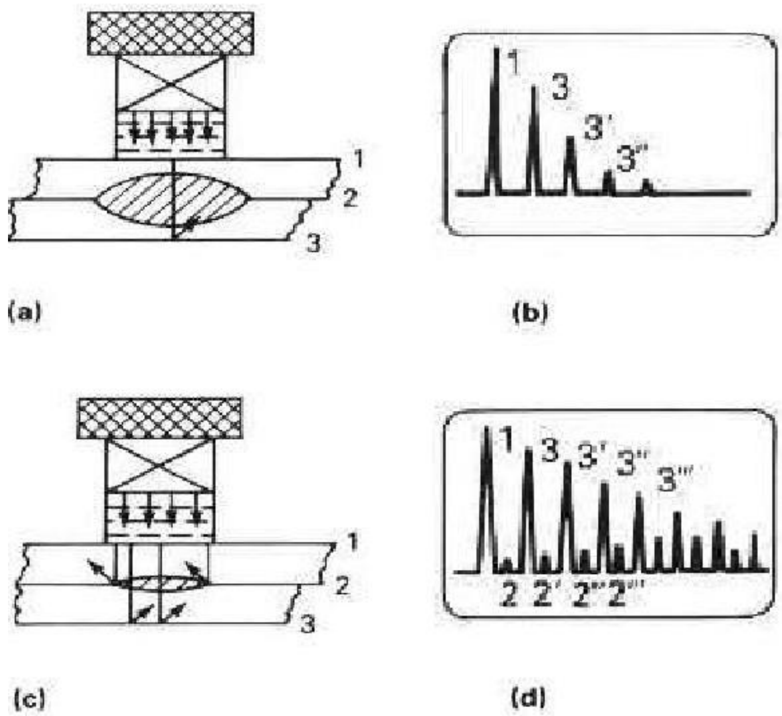

Figure 4.1 Ultrasonic pulse echo spot weld tests : (a) wave paths in a satisfactory weld, (b) echoes from the satisfactory weld, (c) wave paths in an undersized weld and (d) echoes from the undersized weld

Theoretically, one potential problem with testing spot welds is the slight curvature in the metal surfaces left by champing the welding electrodes. Emprically, this is found to have little effect on ultrasonic test result.

Typical oscilloscope displays showing the pulse-echo patterns for the two nugget-to-beam diameter ratios are shown in Figure 4.1b (ultrasonic beam narrower than the weld) and Fig. 4.1d (ultrasonic beam wider than the weld). The difference in these echo patterns permits the ultrasonic method to distinguish between adequate and undersize welds [2].

4.3.6.3 ATTENUATION

Measuring the thickness of a weld nugget can only be done indirectly because the thickness gaging function determines just the thickness between the outher faces in the nugget area. The nugget itself is measured by the effect of its grain structure on the attenuation of the ultrasonic wave. As the wave reflects back and forth between the outer faces the weld sheets, its amplitude A is attenuated approximately exponentially with distance as :

$$A = Ao \exp(-2\alpha x) \qquad (4.1)$$

The attenuation (rate of decay) α of the ultrasonic wave depends on the microstructure of the metal in the beam. In spot welds, the attenuation is caused principally by grain altering. The grains scattering ultrasonic energy out of the coherent beam causing the echoes to die away. In most metals, coarse grains scatter more strongly than the fine grains. For the Rayleigh scattering of interest here, the attenuation coefficient α attributable to scattering is approximated by :

$$\alpha = B\, V\, f^{4} \qquad (4.2)$$

Where :

f = frequency (megahertz) ;
V = a variable approximately proportional to grain volume ;and
B = a coefficient accounting for factors such as prefered orientation of grains and anisotropy of individual grains.

A weld nugget is a cast microstructure with coarser grains than the adjacent cold rolled parent metal (still, though, in the Rayleigh region). For this reason, a nugget scatters more strongly than the remaining parent metal. It follows that a nugget produces higher attenuation than the parent metal and that a thick nugget produces higher attenuation than a thin nugget. Therefore, a thin nugget can be distinguished from a thick nugget by the echoes rate of decay for nuggets of equal diameter [2].

A stick weld is zero reflectivity interface with minimal prior melting and effectively zero thickness nugget. It can be distinguished from a thicker nugget by the ultrasonic pulse echo rate of attenuation observed on an oscilloscope. Typical echoes from a good weld nugget and from a stick weld are compared in Figure 4.2.

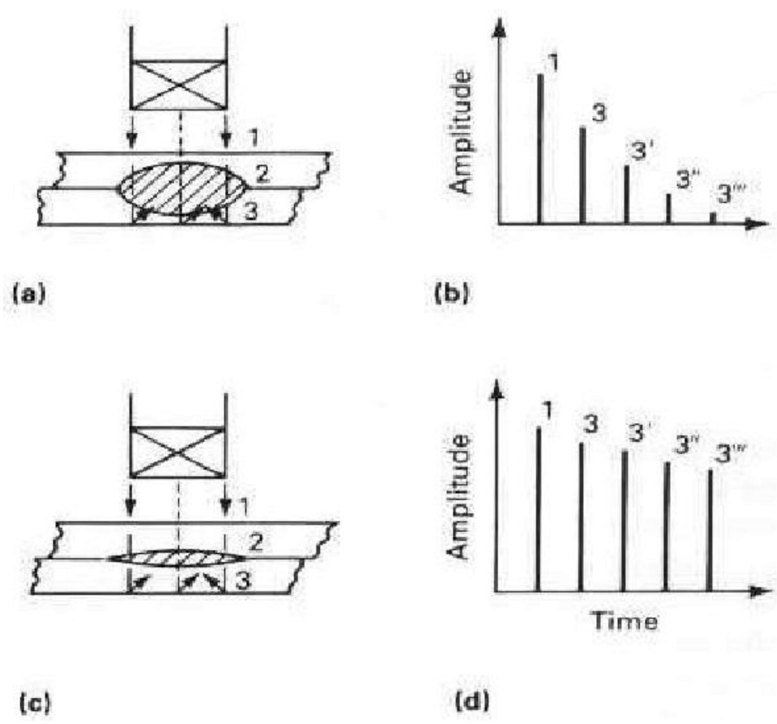

Figure 4.2 Ultrasonic attenuation from two spot welds : (a) diagram of a satisfactory weld, (b) echo pattern from the satisfactory weld, (c) diagram of a stick weld and (d) echo pattern from the stick weld.

It is possible to differentiate between the two welds on the basis of decay patterns. For this reason, the pulse echo ultrasonic method at normal incidence can be expected to perform the required measurements on spot welds in metals with coarse grained nuggets and fine grained parent sheet metal.

4.3.6.4 LIMITATIONS OF ULTRASONIC TESTING

The information obtained from ultrasonic tests only refers to those parts of the test object which are covered by the sound beam of the probe used. The sound beam can be completely reflected from boundary surfaces within the test object so that flaws and reflection points lying deeper remain undetected. It is therefore important to make sure that all areas to be tested in the test object are covered by the sound beam.

In present-day test practice, there are principally two different methods of flaw evaluation :

If the diameter of the sound beam is smaller than the extent of flaw, then the beam can be used to explore the boundaries of the flaw and thus determinate its area. In this method, the smaller the diameter of the probe's sound beam, the more accurately the boundaries (and therefore the flaw area) can be determined. Care should therefore be taken to select a probe which will give a sufficiently narrow beam at the position of the flaw.

If, however, the diameter of the sound beam is larger than the size of the flaw, the maximum echo response from the flaw must be compared with the the maximum echo response from an artificial flaw provided for comparison purposes. In this method, the echo from a small, natural flaw is usually smaller than the echo from an artificial comparison flaw, e.g. circular disc flaw of the same size. This is due, for instance, to the roughness of the surface of a natural flaw, or to the fact that the beam does not impinge on it at right angles. If this fact is not taken into account when evaluating natural flaws, there is a danger of underestimating their magnitude.

In the case of very jagged or fissured flaws, e.g. shrink holes in castings, it may be that the sound scattering occuring at the boundary surface of the flaw is so strong that no echo at all is produced. In such cases, a different evaluation method should be chosen, e.g. by using the backwall echo attenuation in the evaluation. The distance sensitivity of the flaw echo plays an important part when testing large components.

Attention should be paid here to choosing artificial comparison flaws which are as far as possible governed by the same “distance laws” as the natural flaws to be evaluated.

The ultrasonic wave is attenuated in any material. This sound evaluation is very low, e.g. in parts made of fine-grained steel, likewise in many small parts of other materials. However, if the sound wave travels larger distances thrugh the material, a high cumulative sound attenuation can result even with small attenuation coefficients. There is then a danger that echoes from natural flaws appear too small. For this reason, an estimate must always be made of the effects of the attenuation on the evaluation result and taken into account is applicable. If the test object has a rough surface, part of the incident sound energy will be scattered at its surface and is not available for the test. The larger this initial scattering, the smaller the flaw echoes appear, and the more errors occur in the evaluation result. It is therefore important to take the effect of the test object’s surfaces on the height of the echo into account (transfer correction).

All ultrasonic wall thickness measurements are based on a time-of-flight

(TOF) measurement. Accurate measurement results require a constant sound velocity in the test object. In test objects made of steel, even with varying alloying constituents, this condition is mostly fulfilled: the variation in sound velocity is so slight that it is only for importance for high-precision measurements. In other materials, the sound velocity variations may be even larger and thus affect the measuring accuracy.

If the test object's material is not homogeneous, the sound may propagate at different sound velocities in different parts of the test objects [29]. In this case, an average sound velocity should be taken into account for the range calibration. This is achieved by means of a reference block whose sound velocity corresponds to the average sound velocity of the test object. If substantial sound velocity variations are to be expected, then the instrument calibration should be readjusted to the actual sound velocity values at shorter time intervals. Failure to do so may lead to false thickness readings.

The sound velocity within the test object also varies as a function of the material's temperature. This can cause appreciable errors in measurements if the instrument has been calibrated on a cold reference block and is then used on a warm or hot test object. Such measurement errors can be avoided either by warming the reference block to the same temperature before calibrating, or by using a correction factor obtained from tables.

The measurement of the remaining wall thickness on plant components, e.g. pipes, tanks and reaction vessels of all types which are corroded or eroded from the inside, requires a perfectly suitable gauge and special care in handling the probe. The inspectors should always be informed about the corresponding nominal wall thickness and the likely amount of wall thickness losses.

CHAPTER 5

EXPERIMENTAL STUDY

5.1 SAMPLE PREPARATION AND THE TEST PLAN

The experimental study for this study began just after the theoretical information was gathered. 100 torsional test pieces with the dimensions 39 mm x 60 mm for the torsional test set-up were prepared from St 37 steel sheetsl with a thickness of 2 mm. Then, these are mechanicaly shot blasted, chemically cleaned, spot welded and inspected during the study.

The NIMAK PMP 6-1 model spot welding machine (Fig. 5.1) which is available in METU Welding Technology Center Laboratories was used for manufacturing the spot welding specimens.

All of the spot weld specimens of the chosen set were named from SWS-01 to SWS-100. The spot welding parameters and the inspection results for these specimens are given in Table 5.1.

At the beginning, four types of tests one of which was a destructive torsional test to determine the weld quality were planned and they were completed successfully on these specimens.

In recent years, some exciting developments have occured in NDI techniques for the weld inspection. Major advances have been made in several fields, particularly in visual testing, ultrasonics and radiography for in-line monitoring of the welding process. This study utulizes from the latest products of this methods. Digital video microscope with a magnification of 50 to 200X magnification is used for visual inspection. Moreover, a modern real-time radiography system is used for the volumetric inspection. Finally, a universal notebook computer with the integrated ultrasonic feature is utilized with its special probe for spot weld inspections. Especially in the detection of the spot welded joints, this computer system with its special program for this purpose is excellently suitable for checking the weld quality and in this way giving an early chance to correct and adjust the welding parameters accordingly.

Figure 5.1 NIMAK PMP-1 model spot welding machine

Table 5.1 The spot welding parameters and inspection results for the specimens

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-01	2+2	4.8	15	30	8.7	OK	OK	OK	OK	6	8	OK
SWS-02	2+2	4.8	15	20	6.9	OK	Loose (Stick)	Loose (Stick)	OK	0	5	Stick Weld
SWS-03	2+2	4.8	15	25	7.7	OK	OK	Stick Weld	OK	4	7	OK
SWS-04	2+2	4.8	15	35	9.9	Microholes	OK	Stick Weld	OK	6	8	OK
SWS-05	2+2	4.8	15	40	11.3	Burnt	Burnt	Burnt	Burnt & Expulsion	6	8	Microcrack & Expulsion
SWS-06	2+2	4.8	10	40	10.7	Burnt	Bad Through	OK	OK	5	8	OK
SWS-07	2+2	4.8	10	35	9.9	OK	Bad Through	OK	OK	5	8	OK
SWS-08	2+2	4.8	20	25	8.0	Geometric Faults	OK	OK	OK	5	8	OK
SWS-09	2+2	4.8	15	15	6.0	Stick Weld	Stick Weld	Loose (Stick)	Unvisible Nugget	4	6	Stick Weld
SWS-10	2+2	4.8	10	30	8.9	Weak HAZ (LR)	OK	OK	Unsymmetry	3	6	Small Nugget
SWS-11	2+2	4.8	20	30	9.2	Geometric Faults	OK	OK	Unsymmetry	6	8	OK

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-12	2+2	4.8	10	20	6.9	Weak HAZ (LL)	Stick Weld	Stick Weld	Unvisible Nugget	5	6	Stick Weld
SWS-13	2+2	4.8	10	25	7.8	Weak HAZ (LL)	Stick Weld	OK	Unvisible Nugget	2	6	Stick Weld & Small Nugget
SWS-14	2+2	4.8	20	15	5.9	Weak HAZ (LL)	Stick Weld	Loose (Stick)	Unvisible Nugget	4	5	Stick Weld
SWS-15	2+2	4.8	20	20	6.9	OK	OK	OK	OK	4	7	Microholes & Small Nugget
SWS-16	2+2	4.8	20	35	10.2	Burnt & Large HAZ	Burnt	Burnt	Burnt	8	10	Hole & Microcrack
SWS-17	2+2	4.8	20	40	11.7	Burnt & Large HAZ	Burnt	Burnt	Burnt & Expulsion	5	9	Expulsion & Hole
SWS-18	2+2	4.8	25	15	6.1	Burnt & Large HAZ	Stick Weld	Stick Weld	Unvisible Nugget	2	6	Stick Weld
SWS-19	2+2	4.8	25	20	6.9	Geometric Faults	OK	OK	Unsymmetry	5	8	OK
SWS-20	2+2	4.8	25	25	8.1	Large HAZ & Geometric	Small Nugget	Small Nugget	OK	6	8	Hole
SWS-21	2+2	4.8	25	30	9.4	Burnt & Large HAZ	Burnt	Burnt	Burnt	7	10	Hole
SWS-22	2+2	4.8	25	35	10.6	Burnt & Large HAZ	Burnt	Burnt	Burnt	8	10	Burnt

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-23	2+2	4.8	30	15	6.0	OK	Stick Weld	Stick Weld	Unvisible Nugget	3	6	Small Nugget
SWS-24	2+2	4.8	30	20	7.1	Burnt Spot & Geometric	Burnt	OK	Burnt	5	8	Small Hole
SWS-25	2+2	4.8	30	25	8.3	Burnt & Large HAZ	Burnt	Burnt	Burnt	7	9	Burnt
SWS-26	2+2	4.8	30	30	9.5	Burnt & Large HAZ	Burnt	Burnt	Burnt	8	10	Hole & Burnt
SWS-27	2+2	4.8	30	35	10.7	Burnt & Large HAZ	Burnt	Burnt	Burnt & Small Nugget	8	10	Hole & Microcrack
SWS-28	2+2	4.8	30	10	4.9	Stick Weld	Stick Weld	Loose (Stick)	Unvisible Nugget	0	5	Stick Weld
SWS-29	2+2	4.8	15	15	6.0	Stick Weld	Stick Weld	Stick Weld	Unvisible Nugget	0	5	Stick Weld
SWS-30	2+2	4.8	15	20	7.0	Stick Weld	Stick Weld	Stick Weld	OK	3	7	Small Nugget
SWS-31	2+2	4.8	15	25	8.0	OK	OK	OK	OK	5	8	OK
SWS-32	2+2	3.4	15	25	7.2	Grains on HAZ	Bad Through	Stick Weld	Burnt	5	7	OK
SWS-33	2+2	3.4	15	40	11.1	Burnt & Large HAZ	Small Nugget	Burnt	Burnt & Expulsion	6	8	Expulsion & Hole
SWS-34	2+2	3.4	20	20	6.4	OK	OK	OK	Gas Cavity	5	7	OK

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-35	2+2	3.4	20	25	7.5	Burnt & Large HAZ	OK	OK	Unsymmetry & Burnt	5	7	Burnt & Hole
SWS-36	2+2	3.4	20	30	9.0	Burnt & Large HAZ	Small Nugget	Small Nugget	Burnt & Expulsion	5	8	Expulsion & Wide Hole
SWS-37	2+2	3.4	25	20	6.7	Burnt & Large HAZ	Burnt	OK	Gas Cavity	5	7	Hole & Unsymmetry
SWS-38	2+2	3.4	25	25	7.7	Burnt & Large HAZ	Burnt	Small Nugget	Burnt & Small Nugget	5	8	Hole
SWS-39	2+2	4.1	15	30	8.7	Burnt & Microcrack	OK	OK	Gas Cavity	5	7	Hole
SWS-40	2+2	4.1	15	35	9.9	Burnt & Large HAZ	Burnt	Small Nugget	Burnt & Small Nugget	7	9	Wide Hole & Unsymmetry
SWS-41	2+2	4.1	20	15	5.8	Weak HAZ	Stick Weld	Stick Weld	Unvisible Nugget	3	6	Small Nugget
SWS-42	2+2	4.1	20	20	6.9	OK	OK	OK	Gas Cavity	5	7	OK
SWS-43	2+2	4.1	20	25	7.9	Burnt	OK	OK	Weak HAZ	6	8	OK
SWS-44	2+2	4.1	20	30	9.0	Burnt & Large HAZ	Burnt	Small Nugget	Burnt	6	8	Microhole
SWS-45	2+2	4.1	20	35	9.0	Burnt & Large HAZ	Burnt	Burnt	Burnt	6	8	Large Hole & Burnt HAZ

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-46	2+2	4.1	25	15	5.9	Microholes	Stick Weld	Stick Weld	Unvisible Nugget	3	6	Small Nugget
SWS-47	2+2	4.1	25	20	6.9	OK	OK	OK	OK	5	7	OK
SWS-48	2+2	4.1	25	25	8.2	Micrograins on Spot	OK	OK	Gas Cavity	6	8	Small Hole
SWS-49	2+2	4.1	25	30	9.4	Microcrack in Burnt Area	Small Nugget	Burnt	Gas Cavity	6	9	Large Hole
SWS-50	2+2	4.1	25	35	10.8	Burnt & Large HAZ	Loose (Stick)	Burnt	Burnt & Expulsion	4	10	Expulsion & Small Nugget
SWS-51	2+2	6.2	15	30	8.8	OK	OK	Stick Weld	OK	5	8	OK
SWS-52	2+2	6.2	15	25	8.0	OK	Stick Weld	Stick Weld	OK	4	7	Stick Weld
SWS-53	2+2	6.2	15	20	7.2	OK	Stick Weld	Stick Weld	Unvisible Nugget	0	6	Stick Weld
SWS-54	2+2	6.2	15	35	9.9	Burnt & Large HAZ	OK	Stick Weld	Gas Cavity	6	8	OK
SWS-55	2+2	6.2	20	20	7.0	Geometric Faults	Stick Weld	Stick Weld	OK	3	7	Stick Weld
SWS-56	2+2	6.2	20	25	8.0	OK	OK	OK	Gas Cavity	5	8	OK

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-57	2+2	6.2	20	30	9.1	Burnt & Large HAZ	Burnt	Burnt	Gas Cavity	6	8	Small Hole
SWS-58	2+2	6.2	20	35	10.1	Burnt & Large HAZ	Burnt	Burnt	Gas Cavity	8	9	Hole & Burnt
SWS-59	2+2	6.2	25	15	6.3	Pores & Weak HAZ	Stick Weld	Stick Weld	OK	0	6	Stick Weld (No Nugget)
SWS-60	2+2	6.2	25	20	7.1	OK	OK	OK	OK	4	7	Stick Weld & Small Nugget
SWS-61	2+2	6.2	25	25	8.2	Pores & Wide HAZ	OK	OK	OK	6	8	OK
SWS-62	2+2	6.2	25	30	9.2	Microcrack& WideHAZ&Cu	Burnt	Burnt	Wide HAZ & Gas Cavity	7	9	Holes & Burnt
SWS-63	2+2	6.2	30	15	6.1	OK	Stick Weld	Stick Weld	OK	0	7	Stick Weld (No Nugget)
SWS-64	2+2	6.2	30	20	7.2	Pores	OK	OK	OK	4	7	OK
SWS-65	2+2	6.2	30	25	8.3	Burnt & Large HAZ	Burnt	Burnt	Gas Cavity	6	8	Hole & Burnt
SWS-66	2+2	6.2	30	30	9.4	Burnt & Large HAZ	Burnt	Burnt	Wide HAZ & Gas Cavity	7	9	Hole & Burnt
SWS-67	2+2	5.5	15	35	9.9	Burnt & Large HAZ	Stick Weld	Stick Weld	Burnt & Small Holes	6	8	Hole & Burnt

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-68	2+2	5.5	15	30	9.0	Geometric Faults	OK	OK	OK	5	8	OK
SWS-69	2+2	5.5	15	25	8.0	Geometric Faults	Stick Weld	Stick Weld	OK	4	7	Holes & Stick Weld
SWS-70	2+2	5.5	15	20	7.1	Micropores & Weak HAZ	Stick Weld	Stick Weld	Unvisible Nugget	0	6	Stick Weld (No Nugget)
SWS-71	2+2	5.5	20	20	7.1	OK	Stick Weld	Loose (Stick)	Unvisible Nugget	3	7	Stick Weld
SWS-72	2+2	5.5	20	25	8.1	OK	OK	OK	OK	5	7	OK
SWS-73	2+2	5.5	20	30	9.1	Burnt Spot	Burnt	Bad Through	Gas Cavity	6	8	Holes & Burnt
SWS-74	2+2	5.5	20	35	10.2	OK	Burnt	Bad Through	Wide HAZ & Gas Cavity	8	9	Holes & Burnt
SWS-75	2+2	5.5	25	15	6.3	Pores & Weak HAZ	Stick Weld	Stick Weld	Unvisible Nugget	0	5	Stick Weld (No Nugget)
SWS-76	2+2	5.5	25	20	7.1	OK	OK	OK	OK	4	7	OK
SWS-77	2+2	5.5	25	25	8.0	Burnt Spot & Wide HAZ	Burnt	Burnt	Wide HAZ & Gas Cavity	6	8	Holes & Burnt
SWS-78	2+2	5.5	25	30	9.2	Burnt Spot	Burnt	Burnt	Wide HAZ	7	9	Large Hole & Burnt

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-79	2+2	5.5	30	15	6.2	OK	Stick Weld	Stick Weld	Unvisible Nugget	0	6	Stick Weld (No Nugget)
SWS-80	2+2	5.5	30	20	7.1	OK	OK	OK	OK	4	7	OK
SWS-81	2+2	5.5	30	25	8.2	Burnt Spot	Burnt	Small Nugget	Burnt & Wide HAZ	6	8	Holes & Burnt
SWS-82	2+2	5.5	30	30	9.3	Burnt & Large HAZ	Burnt	Burnt	Burnt & Wide HAZ	7	9	Holes & Burnt
SWS-83	2+2	4.8	15	25	7.8	OK	OK	OK	Unvisible Nugget	4	7	Stick Weld & Small Nugget
SWS-84	2+2	4.8	15	30	8.7	Geometric Faults	OK	OK	Gas Cavity	6	8	OK
SWS-85	2+2	4.8	20	25	6.8	Geometry & Weak HAZ	Stick Weld	Stick Weld	Unvisible Nugget	3	7	Stick Weld & Small Nugget
SWS-86	2+2	4.8	20	30	7.9	OK	OK	OK	Small Gas Cavity	5	7	OK
SWS-87	2+2	4.8	25	20	6.9	Pores	OK	OK	Gas Cavity	4	7	Stick Weld
SWS-88	2+2	4.8	25	25	7.9	Burnt Spot	OK	OK	Unsymmetry	6	8	OK
SWS-89	2+2	4.8	30	15	6.0	OK	OK	Stick Weld	Unvisible Nugget	0	6	Stick Weld (No Nugget)

Table 5.1 The spot welding parameters and inspection results for the specimens (continued)

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)	Visual Inspection Results	Ultrasonic Results (with 3.6 mm probe)	Ultrasonic Results (with 8.0 mm probe)	Radiographic Inspection Results	Weld Button Diameter (mm)	Nugget Diameter with HAZ (mm)	Destructive Inspection Results
SWS-90	2+2	4.8	30	20	6.9	Large HAZ	OK	OK	Gas Cavity	5	8	Small Hole
SWS-91	2+2	4.8	30	25	8.0	Burnt Spot	Bad Through	Burnt	OK	6	8	Holes & Burnt
SWS-92	2+2	4.8	20	30	8.9	Microcracks & Large HAZ	Burnt	Burnt	Small Gas Cavity	6	8	Holes & Burnt
SWS-93	2+2	4.8	25	30	8.9	Burnt Spot	Bad Through	Burnt	Gas Cavity	7	9	Large Holes & Burnt
SWS-94	2+2	4.8	30	30	9.2	Burnt Spot	Burnt	Small Nugget	OK	7	9	Large Holes & Burnt
SWS-95	2+2	6.9	15	30	9.3	Pores	Stick Weld	Stick Weld	OK	4	7	Stick Weld
SWS-96	2+2	6.9	20	30	9.3	OK	OK	OK	OK	6	8	OK
SWS-97	2+2	6.9	20	25	8.4	OK	OK	OK	OK	5	7	OK
SWS-98	2+2	6.9	25	30	9.4	Burnt & Large HAZ	Burnt	Burnt	Small Gas Cavity	7	9	OK
SWS-99	2+2	6.9	25	25	8.5	Burnt	OK	OK	OK	5	8	OK
SWS-100	2+2	6.9	25	20	7.4	OK	Stick Weld	Stick Weld	OK	3	7	Stick Weld

5.2 VISUAL INSPECTION OF THE SPOT WELDED SPECIMENS

In our experimental study, all of the spot welding specimens were visually inspected during the welding process. Afterwards, they were inspected with the Olympus DVM-1 model digital video microscope set (Figure 5.2). This set includes a camera, light source and floppy disk driver in a well designed metal case. Its camera has 50 to 200X magnification feature and the images are tansferred to a 8 inches screen from the camera. The resolution of the image taken from the camera is 350 x 470 lines. The scanning area of the camera is minimum 1.37 x 1.03 mm (at 200X) and maximum 5.47 x 4.1 mm (at 50X).

The set has an internal memory of 20 images. The live images taken from the camera can be frozen and stored with this feature and these stored images can be transferred into a computer with the connection cable or by means of floppy disks. The complete set is portable and less than 10 kg in weight, so that it can be used easily in the field applications.

Figure 5.2 Olympus DVM-1 model digital video microscope set

The figures given in Appendix A represents the images taken from specimens with the video microscope. The defects in test pieces can be seen easily (Table 5.1) and give some information about the insufficiency of the spot welds to fullfill the required properties of the product.

When inspected visually with a high magnification video microscope, the microstructure of the spot weld area can be easily compared with the surrounding surfaces. The spot weld area is separated from the surrounding with a heat affected zone (HAZ) and it consists considerably coarser grains than the parent metal.

5.3 RADIOGRAPHIC INSPECTION OF SPOT WELDED SPECIMENS

Radiographic testing together with the real-time radiography is not an economical and practical method for determining the spot weld quality as it requires film processing which is expensive and takes long time to accomplish. This method is not efficient in parts having complex shapes.

Despite of its disadvantages in mass production, radiography and real-time radioscopy can be used to detect volumetric defects after the welding procedure in order to determine the following welding parameters. Hence, both methods were used to determine the defects in our test specimens.

Yxlon model x-ray system (Fig 5.3) established in X-Ray Department of 5 th Main Maintenance Center Command (Güvercinlik/ANKARA) was used in our radiographic studies. The system is capable of both film radiography and real-time radioscopy with interchangeable 160 kV and 320 kV x-ray tubes. The real-time images of all spot weld specimens were monitored and saved. The radiographic test parameters and results for these real-time images are given in Table 5.2.

Table 5.2 Test parameters and results for the real-time images of the specimens

SPOT WELD NO.	ENERGY (kV)	CURRENT (mA)	FOCUS (mm)	COMMENTS
SWS-01	85.0	5.00	0.8	OK
SWS-02	84.4	5.00	0.8	OK
SWS-03	82.6	5.00	0.8	OK
SWS-04	79.0	5.00	0.8	OK
SWS-05	74.8	5.00	0.8	BURNT, EXPULSION OF METAL
SWS-06	86.0	5.00	0.8	OK
SWS-07	82.4	5.00	0.8	OK
SWS-08	85.2	5.00	0.8	OK
SWS-09	80.2	5.00	0.8	UNVISIBLE NUGGET
SWS-10	93.4	5.00	0.8	UNSYMMETRY
SWS-11	80.8	5.00	0.8	UNSYMMETRY
SWS-12	86.8	5.00	0.8	UNVISIBLE NUGGET
SWS-13	86.8	5.00	0.8	UNVISIBLE NUGGET E
SWS-14	87.2	5.00	0.8	UNVISIBLE NUGGET
SWS-15	90.6	5.00	0.8	OK
SWS-16	93.4	5.00	0.8	BURNT
SWS-17	99.2	5.00	0.8	BURNT, EXPULSION OF METAL
SWS-18	100.4	5.00	0.8	NOT VISIBLE
SWS-19	95.4	5.00	0.8	GEOMETRY
SWS-20	93.8	5.00	0.8	OK
SWS-21	95.0	5.00	0.8	BURNT
SWS-22	95.6	5.00	0.8	BURNT
SWS-23	92.8	5.00	0.8	UNVISIBLE NUGGET
SWS-24	98.4	5.00	0.8	BURNT
SWS-25	95.0	5.00	0.8	BURNT
SWS-26	95.0	5.00	0.8	BURNT
SWS-27	93.2	5.00	0.8	BURNT, SMALL NUGGET
SWS-28	96.8	5.00	0.8	UNVISIBLE NUGGET
SWS-29	92.0	5.00	0.8	UNVISIBLE NUGGET
SWS-30	94.4	5.00	0.8	OK
SWS-31	95.0	5.00	0.8	OK
SWS-32	95.0	5.00	0.8	BURNT
SWS-33	95.0	5.00	0.8	BURNT, EXPULSION OF METAL
SWS-34	92.8	5.00	0.8	POROSITY
SWS-35	93.4	5.00	0.8	GEOMETRY, BURNT
SWS-36	93.4	5.00	0.8	BURNT, EXPULSION OF METAL

Table 5.2 Test parameters and results for the real-time images (continued)

SPOT WELD NO.	ENERGY (kV)	CURRENT (mA)	FOCUS (mm)	COMMENTS
SWS-37	88.8	5.00	0.8	POROSITY
SWS-38	88.8	5.00	0.8	BURNT, SMALL NUGGET
SWS-39	94.6	3.35	0.8	POROSITY
SWS-40	99.4	3.30	0.8	BURNT, SMALL NUGGET
SWS-41	95.8	3.70	0.8	UNVISIBLE NUGGET
SWS-42	94.0	4.15	0.8	POROSITY
SWS-43	94.6	4.70	0.8	WEAK HAZ
SWS-44	91.0	4.60	0.8	BURNT
SWS-45	94.8	4.60	0.8	BURNT
SWS-46	94.8	4.60	0.8	UNVISIBLE NUGGET
SWS-47	101.4	3.20	0.8	OK
SWS-48	98.4	3.55	0.8	POROSITY
SWS-49	103.8	2.70	0.8	POROSITY
SWS-50	93.4	4.30	0.8	BURNT, EXPULSION OF METAL
SWS-51	97.0	5.00	0.8	OK
SWS-52	96.0	4.50	0.8	OK
SWS-53	95.0	5.00	0.8	UNVISIBLE NUGGET
SWS-54	90.0	4.80	0.8	POROSITY
SWS-55	94.8	4.75	0.8	OK
SWS-56	101.2	4.50	0.8	POROSITY
SWS-57	99.0	4.20	0.8	POROSITY
SWS-58	101.0	4.70	0.8	POROSITY
SWS-59	98.0	4.40	0.8	OK
SWS-60	100.0	5.00	0.8	OK
SWS-61	100.0	5.00	0.8	OK
SWS-62	101.4	4.00	0.8	WIDE HAZ, POROSITY
SWS-63	95.0	5.00	0.8	OK
SWS-64	95.0	4.70	0.8	OK
SWS-65	102.4	4.10	0.8	POROSITY
SWS-66	97.0	4.40	0.8	WIDE HAZ, POROSITY
SWS-67	99.4	3.90	0.8	BURNT SPOT, SMALL HOLES
SWS-68	100.0	4.20	0.8	OK
SWS-69	99.0	4.50	0.8	OK
SWS-70	98.6	4.30	0.8	UNVISIBLE NUGGET
SWS-71	100.8	5.00	0.8	UNVISIBLE NUGGET
SWS-72	99.0	4.80	0.8	OK
SWS-73	100.0	4.50	0.8	POROSITY

Table 5.2 Test parameters and results for the real-time images (continued)

SPOT WELD NO.	ENERGY (kV)	CURRENT (mA)	FOCUS (mm)	COMMENTS
SWS-74	100.0	4.75	0.8	WIDE HAZ, POROSITY
SWS-75	99.0	4.60	0.8	UNVISIBLE NUGGET
SWS-76	102.0	4.20	0.8	OK
SWS-77	102.0	4.20	0.8	WIDE HAZ, POROSITY
SWS-78	100.0	4.50	0.8	WIDE HAZ
SWS-79	98.0	4.75	0.8	UNVISIBLE NUGGET
SWS-80	100.0	4.50	0.8	OK
SWS-81	102.0	4.50	0.8	BURNT SPOT, WIDE HAZ
SWS-82	99.0	4.75	0.8	BURNT SPOT, WIDE HAZ
SWS-83	102.0	4.00	0.8	UNVISIBLE NUGGET, POROSITY
SWS-84	100.0	4.50	0.8	POROSITY
SWS-85	102.0	3.80	0.8	UNVISIBLE NUGGET, POROSITY
SWS-86	100.0	4.50	0.8	POROSITY
SWS-87	98.,8	4.50	0.8	POROSITY
SWS-88	100.0	5.00	0.8	GEOMETRY
SWS-89	102.0	4.20	0.8	UNVISIBLE NUGGET
SWS-90	99.2	5.00	0.8	POROSITY
SWS-91	99.2	5.00	0.8	OK
SWS-92	100.0	4.50	0.8	POROSITY
SWS-93	100.0	4.50	0.8	POROSITY
SWS-94	100.0	5.00	0.8	OK
SWS-95	97.0	5.00	0.8	OK
SWS-96	97.0	5.00	0.8	OK
SWS-97	98.0	4.80	0.8	OK
SWS-98	100.0	4.75	0.8	POROSITY
SWS-99	101.0	4.60	0.8	OK
SWS-100	99.6	4.50	0.8	OK

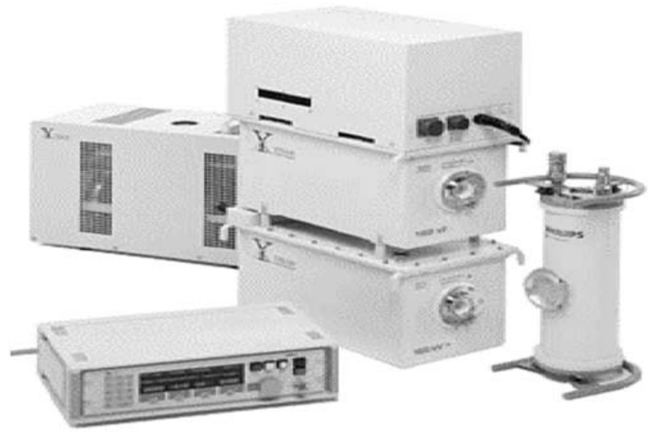

Figure 5.3 The YXLON model x-ray system used in the study

The real-time images taken from specimens are given in Appendix B. Comparing the real time images with IIW (International Institute of Welding) reference radiographs, the comments in Table 5.2 can be attained easily. Here, it should be noted that the real-time images give the negative view of the radiographic films, i.e. the darker parts of a real-time image is equal to the lighter parts of a radiographic film.

The quality of the image can easily be checked by means of hole type image quality indicators. The type of the appropriate IQI (Image Quality Indicators) depends on the type and thickness of the sheet metal. The image quaity indıcators has three holes with diameters 1T, 2T and 4T, where T is the thickness of the indicator. The number of the holes visible on the radiograph determine the quality of the radiograph. In our study, hole with the largest diameter is taken as lower limit and it is easily seen on the real-time images in their original dimensions. Hence, this hole may not be seen on some of the images smaller than their original dimensions given in Appendix B.

5.4 ULTRASONIC INSPECTION OF THE SPOT WELDED SPECIMENS

A typical test system for ultrasonic spot weld examination is mainly composed of two elements; a straight beam probe and a universal ultrasonic instrument. However, both the probe and the ultrasonic instrument should meet some additional criteria which are not required for a standard ultrasonic test.

Special probes are designed and used for inspecting spot welds. They contain a water delay path with flexible rubber membrane. This ensures that the sound wave can be perfectly introduced even with the typically curved surfaces of spot welds without any problem. The sound frequency usually chosen is the highest (20 MHz). The transducer element diameters vary between 3.6 and 10 mm.

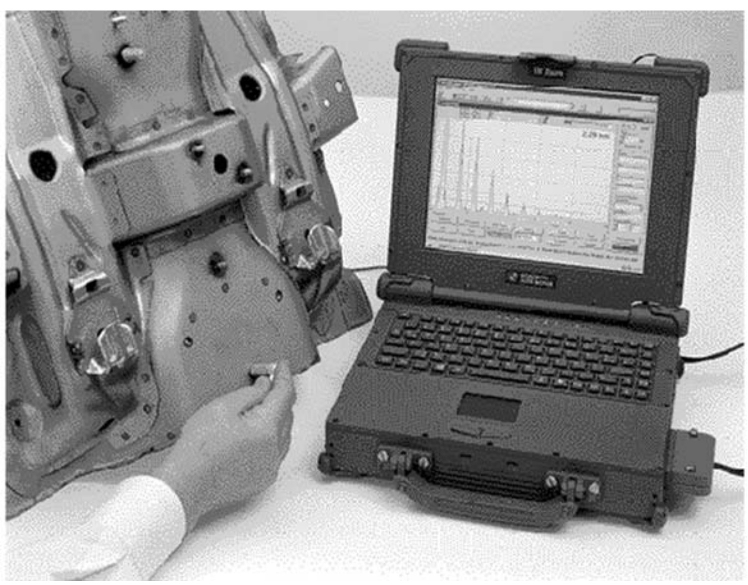

Figure 5.4 The ultrasonic notebook USLT 2000 and spot weld inspection

Krautkramer USLT 2000 used in this study is a universal ultrasonic instrument as a notebook computer design stands for a mobile use (Figure 5.4). Ultrasonic controlling features were added to this industrial-type notebook with a PCMCIA card and an adapter for probe connections [29]. By the clear Windows 98 interface, no problem exists for the system operating. The system is operated via keyboard, an integrated touchpad, or an optionally connected mouse. As the USLT 2000 is a standard PC, installation of other Windows applications such as Microsoft Office and using them for individual applications parallel to the ultrasonic functionality.

The identically named USLT 2000 program coming with the standard instrument allows universal evaluation options for detected indications to meet international test specifications: DGS curves, user friendly recording of a DAC and TCG for both methods. The large color display and the fast echo display together with a high A-scan resolution of 635 x 400 pixels makes USLT 2000 even suitable for applications in which an excellent resolution is important: for example bonding tests and flaw detection on thin workpieces or in particular the inspection of the spot welded joints. Especially in the detection of the spot welded joints, the USLT 2000 with the UltraLOG program is excellently suitable for checking the weld quality and in this way giving an early chance to correct an adjust the welding parameters accordingly.

The UltraLOG and Database Manager programs for spot welding tests enables the complete documentation of inspection processes, the customary shop inspection methods are likewise integrated, such as the tool test using hammer and chisel. Data transfer to quality management systems is also possible without any difficulty thanks to standard interfaces. But access to different program levels is protected by passwords [29].

The Database Manager contains a complete database system for the generation and management of inspection results. Using inspection plans matching with your production process structures and enabling a worldwide distribution, e.g. by e-mail, the inspection can be planned, controlled and documented easily.

5.4.1 SPOT WELD TESTING PROBES

An essential component of ultrasonic testing is the appropriate transducer, or probe. For the inspection of spot welds, special spot welding probes with high frequencies are used. Moreover, to assess the size of the weld nugget, the ultrasonic beam diameter and therefore, the transducer diameter of the probe must be appropriate for the specified nugget diameter of the material thickness involved.

The probe (Fig. 5.5) consists of a small encapsulated transducer with an attached transmission medium which is usually the water column delay line. Water or delay line liquid is kept in its housing which is tightly connected to the transducer housing, with the help of a replaceable rubber membrane placed at the bottom end [30]. The rubber membrane is flexible and it protrudes at the contacting end as a result of water pressure generated during the attachment of the water delay line assembly to the transducer housing. This curved rubber membrane forms a very soft probe tip which provides a good coupling of the probe to the rough and uneven spot weld surfaces with little need for external fluid couplant.

Computer supported spot weld testing with the USLT 2000 offers far reaching possibilities regarding the automation of working sequences and their subsequent documentation. The newest generation of probes for spot weld testing has now been introduced onto the market in order to support these functions, these are: the DIALOG probes G20 MN.X (Fig. 5.5). These probes are straight-beam probes with water delay and exchangeable protection membrane with a frequency of 20 MHz and a bandwidth of 14 MHz to 26 MHz.

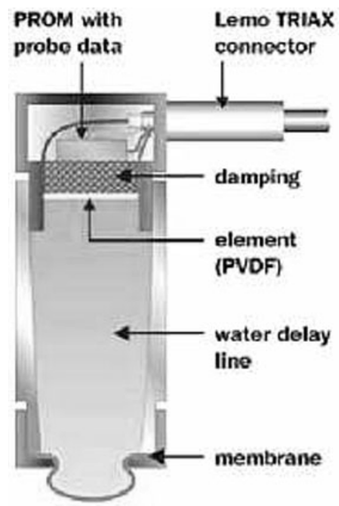

Figure 5.5 The special probe design for spot weld testing

The pulser and receiver electronics is accomodated in a small aluminium box of USLT 2000 standard set. The Krautkramer intelligent dialog probes provides an ease of use because they are automatically recognized by the system, i.e. all important probe data is automatically transferred to the instrument by means of an electronic chip inside the probe.

Special probe designs are available for special tasks, e.g. the snorkel-shaped probes enables to reach even concealed spot welds.

The sound field of the probe should be measured to furnish documented proof of the sound beam properties, i.e. the probe certificate.

5.4.2 COUPLING OF THE PROBE

In order to obtain correct information about the spot weld that is examined, tha appropriate coupling of the probe to the spot weld surface is very important. Therefore, the training in ultrasonic method generally and in spot welding testing specifically is required. Different from other ultrasonic testing techniques, this method is highly operator dependent because correct positioning is very difficult due to the deformation of membrane.

For testing the spot welds, the probe assembly is coupled to the spot weld surface with very little couplant, which in our case is ZG-F of Krautkramer. Correct evaluation of a spot weld is only achieved with the correct positioning of the probe perpendicular to the weld surface. The best method to couple the probe to the surface correctly is to hold the probe assembly between the thumb and the middle finger and to apply the necessary coupling pressure with the forefinger on top of the probe.

5.4.3 CALIBRATION OF THE INSTRUMENT

In our study, for two 2 mm thick sheet metals were welded, hence the total thickness is 4 mm and a calibration range of 30 mm was selected in order to see the desired 7 echoes. As it is already known, for calibration a special calibration block made of the same material as the test object can be used. Here, in our study a calibration block made of the same material, St 37 steel with the thickness of the thinnest of the sheet metals (1.9 mm) was used.

The test parameters such as probe frequency and range should be set to the instruments, and the parameters such as gain, probe delay and sound velocity (5920 m/s for St 37 steel) should be found with calibration of the echoe sequence as follows :

The probe is coupled to the calibration sheet and the echo sequence is maximised on the screen and moved with the probe delay. The first echo should be on the left end of the horizontal screen scale. This first echo on the display should be the entrance echo coming from the membrane and calibration block interface. In order to check this, the probe should be uncoupled very slowly and when the probe is completely removed from the spot weld, the first echo should be the only one left on the screen.

Behind the entrance echo, a sequence of backwall echoes from the sheet metal appears on the screen when the probe is coupled to the metal sheet. After maximising the first backwall echo by certain probe manipulations, the peak of this echo is set to full screen height with the gain controls. After that, as in the case of a standard calibration procedure, the positions of the necessary number of echoes are adjusted by means of the sound velocity, probe delay controls. Now the instrument and the probe is ready for the inspection, but the number and positions of the echoes should be checked just after the probe is coupled to the spot weld before the test.

5.4.4 ULTRASONIC INSPECTION PRACTICE

In our study, all of the spot welding specimens were inspected with the USLT 2000 ultrasonic instrument by means of two different probes available, G20MNX3.6 (20 MHz frequency probe with an element diameter of 3.6 mm) and G15MN8.0 (15 MHz frequency probe with an element diameter of 8.0 mm) regarding to the theoretical basis explained in Chapter 4.

The USLT 2000 ultrasonic instrument includes UltraLOG and Database Manager software for spot welding tests enabling the complete documentation of inspection processes. The Database Manager contains a complete database for the generation and management of inspection reports, i.e. all the inspection parameters, results and displays for each of the probes, G20MNX3.6 and G15MN8.0 were saved as the inspection reports and are given in Appendix C and Appendix D, respectively.

5.5 TORSIONAL TESTS FOR THE SPOT WELDED SPECIMENS

All the spot welded specimens were broken with a simple torsional testing machine that is available in the METU Welding Technology Center Laboratories (Figure 5.6). Then, their weld button and nugget diameters were measured by means of a ruler. These diameters and torsional test results are given in Table 5.1.

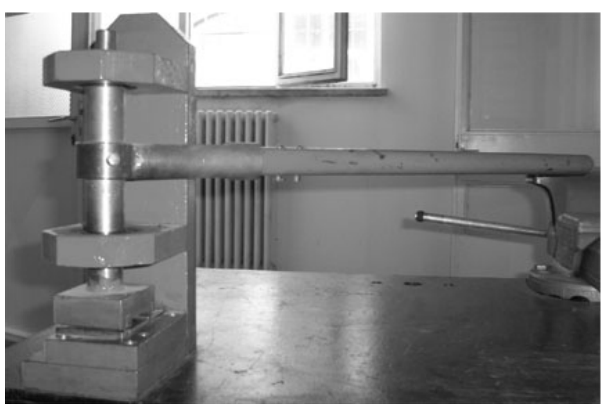

Figure 5.6 Torsional Testing Machine

CHAPTER 6

DISCUSSION AND CONCLUSION

6.1 STATISTICAL CONTROL OF THE EXPERIMENTAL DATA

Evaluating the spot welding parameters and the inspection results for the specimens, i.e. Table 5.1 would take us to many statistical consequences about the spot welding process supporting the theoretical basis. The most considerable ones are given graphically and in brief below.

As seen from the Fig. 6.1, there is a linear relationship between the machine efficiency and the welding current for constant welding pressures and welding times, i.e. the welding current increases linearly with the spot welding machine efficiency (machine performance). Note that, here welding current is determined value, i.e. the output value, measured with a special multimeter capable of measuring the current for a very short time period. On the other hand, welding time do not affect the weld current significantly for constant welding pressure and machine efficiency values (Fig. 6.2).

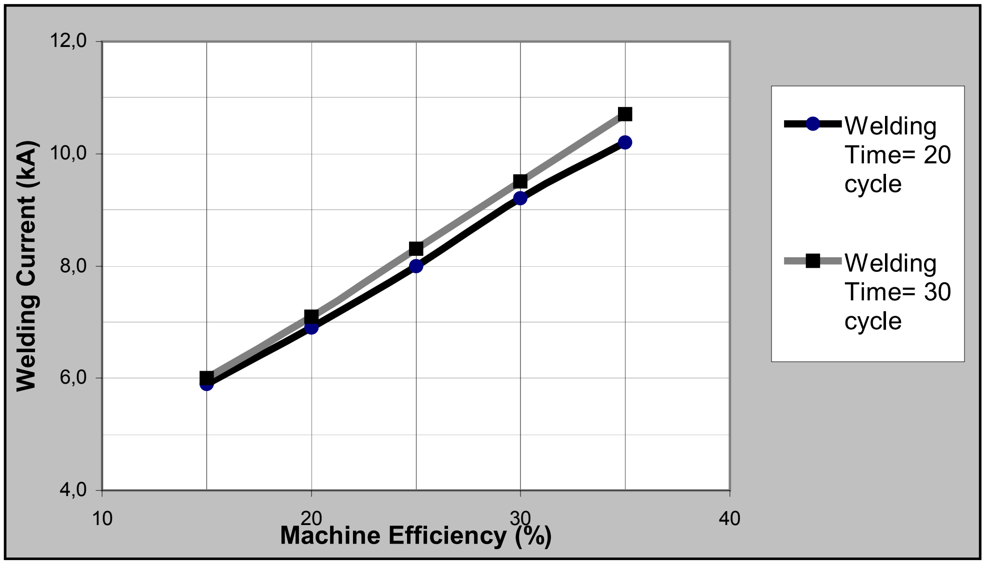

Figure 6.1 Welding current vs machine efficiency for constant welding times (for welding pressure= 4.8 kN)

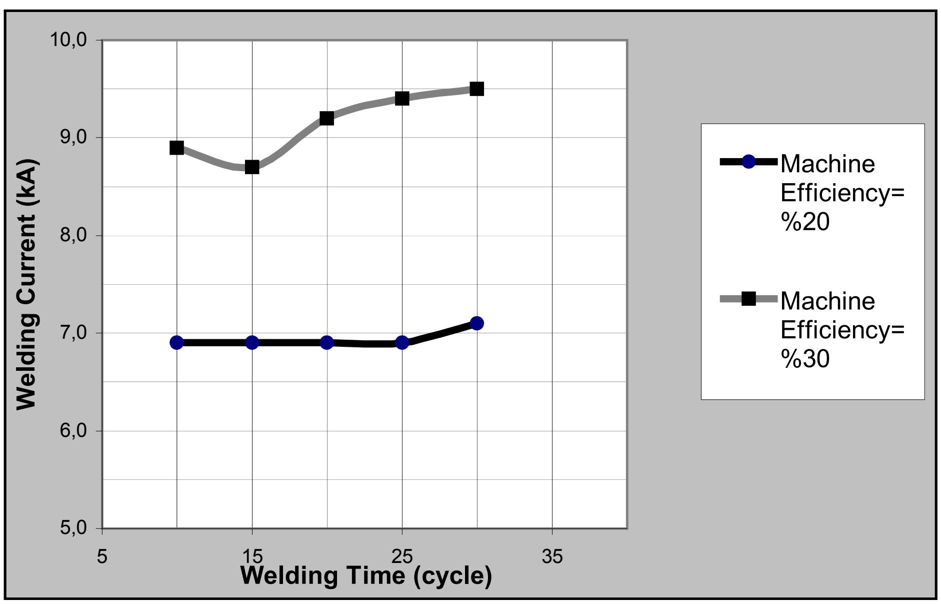

Figure 6.2 Welding current vs welding time for constant machine efficiencies. (for welding pressure= 4.8 kN)

Furthermore, welding pressure also do not affect the determined weld current value significantly for constant welding time and machine efficiency values as seen in Fig. 6.3.

Consequently, it can easily be understood that the welding current is strongly dependent on the machine efficiency not on the welding time or welding pressure, i.e. one can easily predict the output welding current by assigning the machine performance value, or by other words, machine efficiency is the control mechanism of the output welding current. Hence some of the weld defects resulting from the low or high welding currents can be avoided by means of the machine performance control.

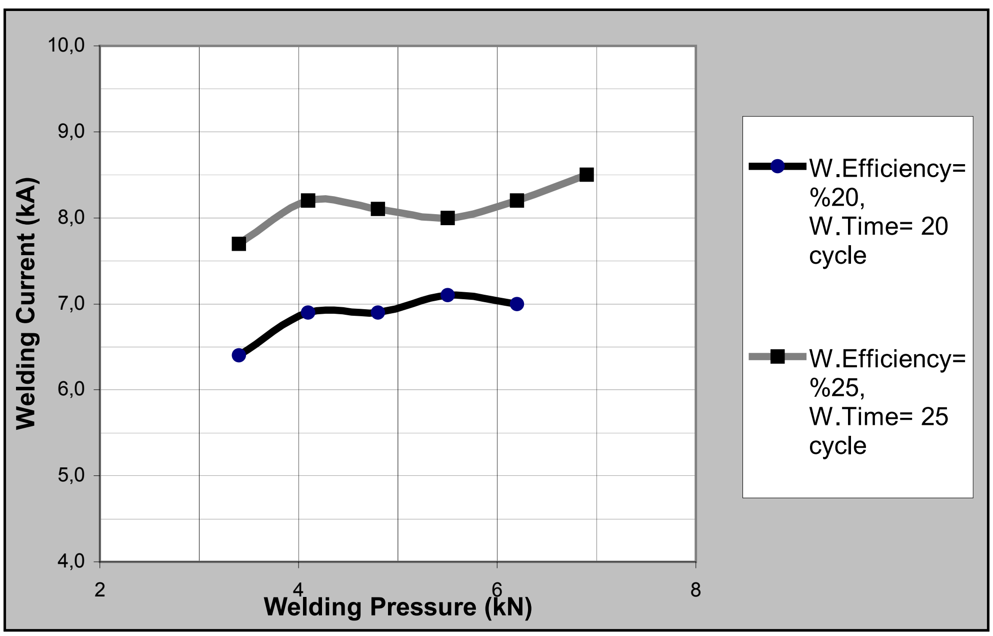

Figure 6.3 Welding current vs welding pressure

In order to understand the effect of welding pressure to quality of spot welding specimens, the statistical study shown graphically in Fig. 6.4 was made. Six different welding pressure values were used during the manufacturing of the spot welding specimens : 3.4, 4.1, 4.8, 5.5, 6.2 and 6.9 kN (Table 5.1).

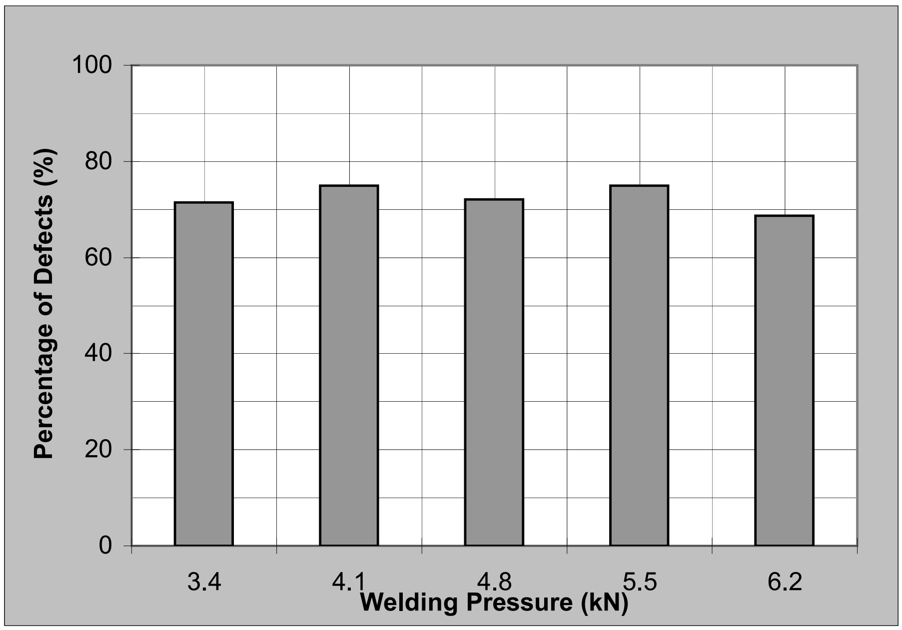

Figure 6.4 Percentage of defective specimens vs welding pressure

As it is explained in Section 2.1.1, a high resistance caused by a low force will generate more heat resulting in expulsion, porous welds and low strength welds while a high weld pressure leads into undersized welds, excessive indentation and inadequate penetration. Thus, looking at the Fig. 6.4, higher percentages of defects are expected for the lower and higher welding pressures. But the experimental data shows that the probability of defective specimens is approximately the same for all of the welding pressure values. This comes from the situation that more specimens were prepared with the average welding pressure values (12 specimen with 4.1 kN, 43 specimen with 4.8 kN and 16 for the 5.5 kN), i.e. the finding different types of defects for different welding time and machine efficiency (welding current) is more probable with a higher number of specimens.

But, from Table 5.1, it is experimentally shown that expulsion is more severe for lower welding pressures (2 of 7 specimen, i.e. 28.6 % for 3.4 kN) as in the theory. On the other hand, stick welds are more probable for higher welding pressures (2 of 6 specimen, i.e. 33.3 % for 6.9 kN and 6 of 16 specimen, i.e. 37.5 % for 6.2 kN).

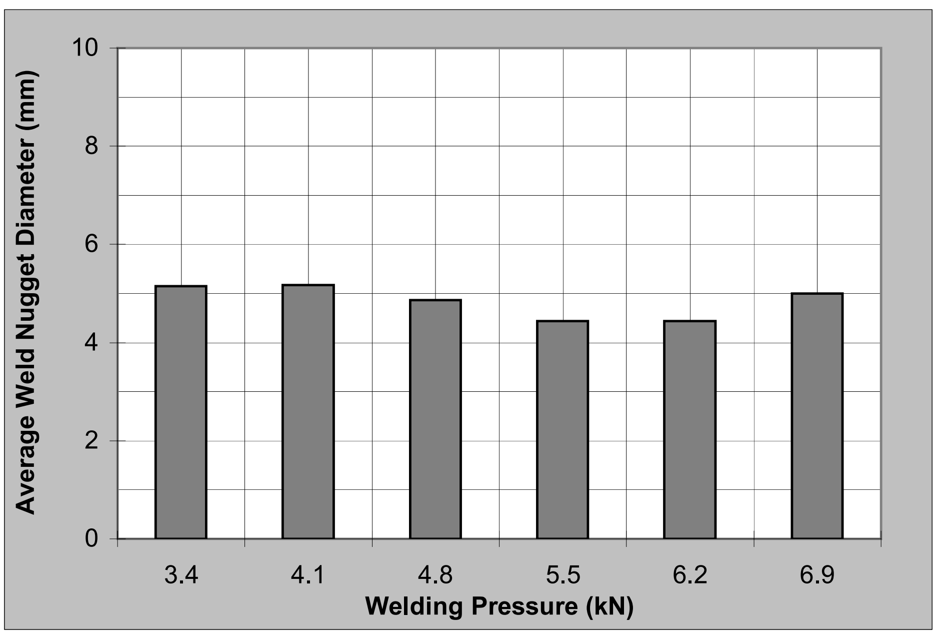

Figure 6.5 Average weld nugget diameter vs welding pressure

Figure 6.5 demonstrates the effect of the welding pressure to average weld nugget diameter. The weld nugget diameter slightly decreases with the increasing welding pressure. Here it should be noted that, for lower welding pressure values, the average weld nugget diameter is slightly less than the expected values because of the expulsion of the metal from the weld nugget.

The decrease in the average weld nugget diameter as the welding pressure increases is also due to the effect of welding pressure on the resistance and by the way the heat generated. As lower welding pressures leads to an increase in the heat generated, an increase in the volume of the metal, the weld nugget, that has undergone heating, melting, fusion and resolidification is expected. But, this effect is not strict as the effect of the welding current, because of the equation $H = I^2 R t$. In this equation heat is directly proportional to resistance itself but to the square of the current. Hence, as the welding current increases, there is a sudden rise in the average weld nugget diameter. This situation is easily seen in Figure 6.6. But, it should be noted that for the welding current range of 11.1 to 12.0 kA, there is a decrease in the average weld nugget diameter due to the expulsion that is most probable for such a high welding current range. Because of the expulsion of the resolidifying material from the weld nugget, the average weld nugget diameter decreases rapidly.

In order to understand the effect of welding current on the quality of spot welded specimens, the statistical study shown graphically in Fig. 6.7 was made. Seven different output welding current ranges were used during this statistical approach. Note that, here the lower and upper limit output welding current values of a range are included to that range when calculating the number of defects for this ranges from Table 5.1.

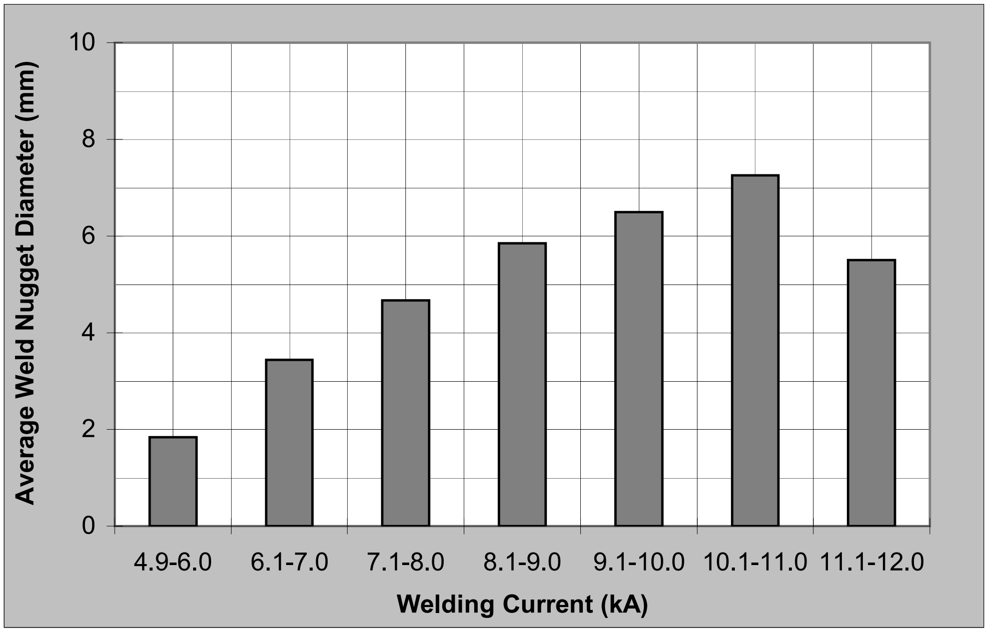

Figure 6.6 Average weld nugget diameter vs welding current (for welding pressure= 4.8 kN)

A high welding current will generate more heat as explained with the Eq. 1.1, resulting in weld issues such as excessive indentation, cracks and holes and expulsion/burn-through. On the other hand, lower welding currents will give rise to the weld issues such as stick welds, undersized welds and poor weld shapes. Thus, looking at the Fig. 6.7, higher percentages of defects are certain for the lower and higher welding pressures as expected by the theory.

Although the least probability of defects is expected for the output welding current range 8.1 to 9.0 kA, a rapid rise in the percentage of defective specimens is seen in for the is seen in Fig. 6.7. This is due to the higher welding times. But, from Table 5.1, it is experimentally shown that expulsion is more severe for higher welding currents (2 of 2 specimen, i.e. 100 % for the range 11.1 to 12.0 kA) as in the theory. On the other hand, stick welds are more probable for lower welding currents (5 of 6 specimen, i.e. 83.3 % for the range 4.9 to 6.0 kA and 5 of 9 specimen, i.e. 55.6 % for the range 6.1 to 7.0 kN).

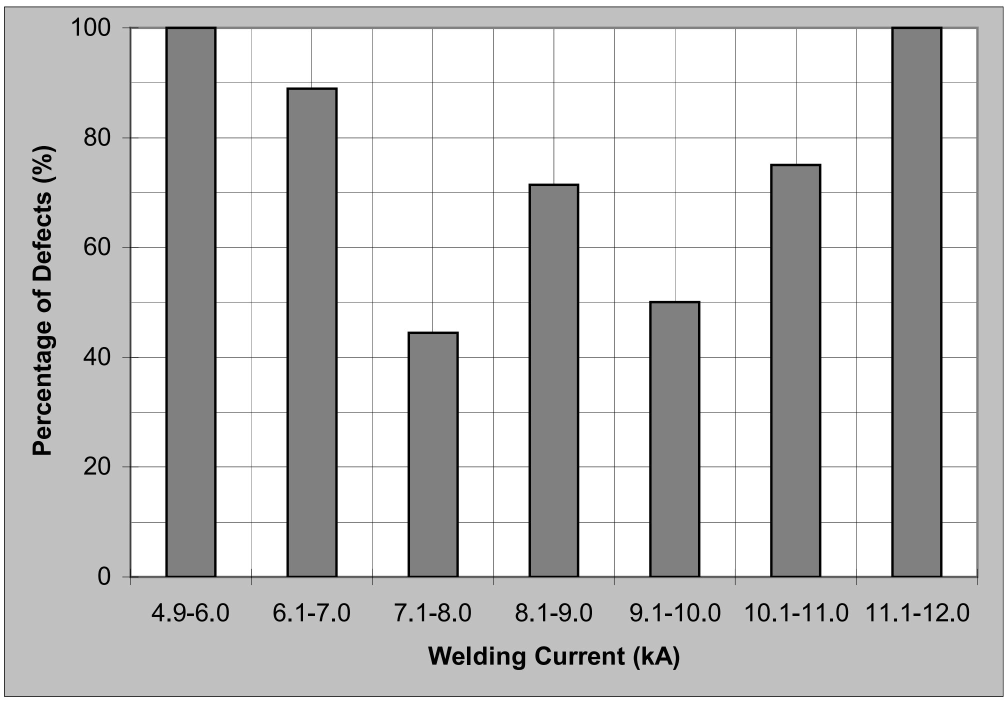

Figure 6.7 Percentage of defective specimens vs welding current (for welding pressure= 4.8 kN)

From the discussion on the statistical data above, the best spot welding parameters suggesting least probability of defective spot welding specimens can be selected from Table 5.1 for the studies on 2 mm thick St 37 steel plates are given Table A.1 of Appendix A.

When we come to the most important statistical analysis for the consistency of the nondestructive inspection methods with the torsional destructive test, the best nondestructive technique on the basis of the consistency can be selected assuming that the results taken from the torsional destructive test are absolute. Fig 6.8 points that the results received from the ultrasonic instrument with the narrower probe, the probe with the element diameter of 3.6 mm is the most consistent with the torsional test results among the other nondestructive methods.

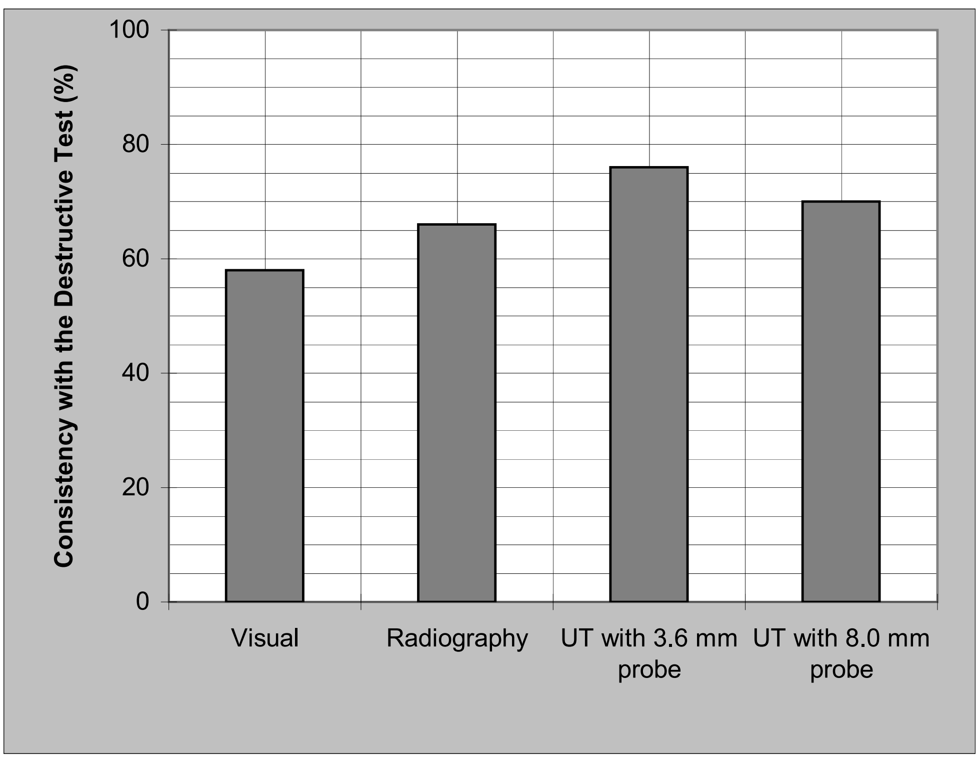

Figure 6.8 Consistency of the applied NDI methods with the torsional destructive test

If the results for all of the specimens with the ultrasonic probes G20MNX3.6 and G15MN8.0 are evaluated seperately with regard to the torsional destructive test, the data from the Table 5.1 gives the statistical data given graphically in Fig. 6.9 and in Fig 6.10, respectively.

With the G20MNX3.6 probe, the ultrasonic test gives an error of 4 defective specimen while the destructive test accepts these specimens as perfect for usage. Although, 4 specimen among a hundred is a minor value, it is considerable for the fact that the ultrasonic test with this probe rejects the part and results in the loss of these specimens by mistake if the test is done under the factory conditions. This may be a severe situation for the budget of a factory producing valuable goods such as automotive parts with spot

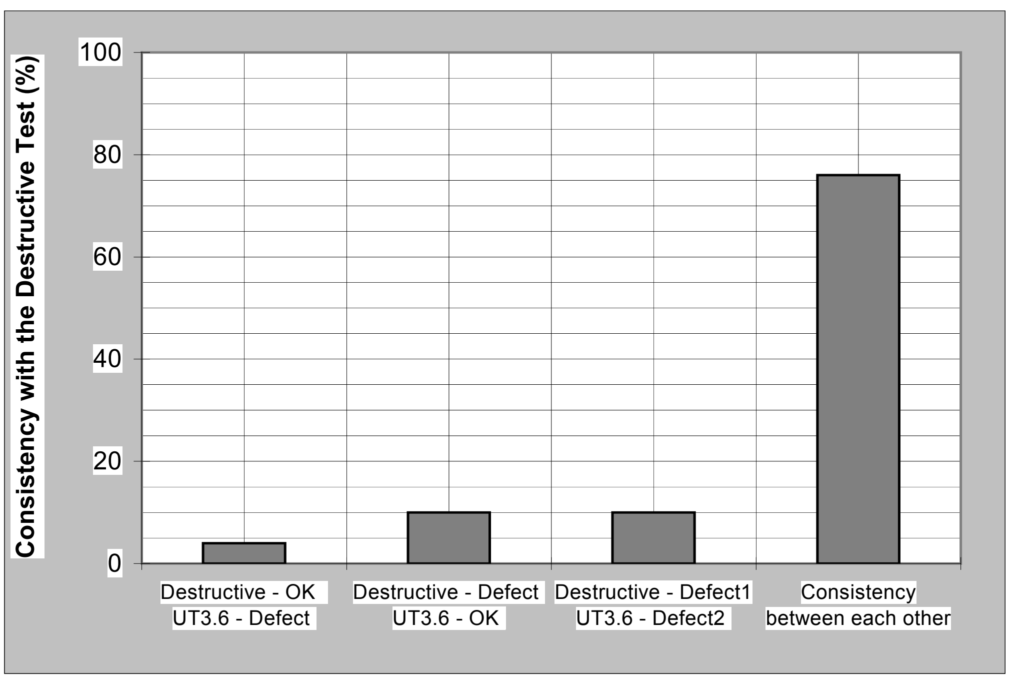

Figure 6.9 Consistency of the ultrasonic test with the probe having the element diameter of 3.6 mm with the torsional test

welding procedures, but may be assumable for a factory using spot welding in the manufacture of wire home storage products.

To the contrary, with the G20MNX3.6 probe, the ultrasonic test gives an error as it is accepting 10 specimens as perfect while the destructive test rejects these specimens. 10 specimen among a hundred is a considerable value for production lines since the acceptance of these specimens may result in the failure of the finished products made of them. Thus, the reasons for this inconsistency should be evaluated. The most important reasons for this situation in our study are :

- The error in 5 (SWS-10, SWS-15, SWS-60, SWS-83 and SWS-87) of these 10 ultrasonically accepted but destructively rejected specimens should be due to the element diameter of the probe since the element diameter of the probe (3.6 mm) is smaller than the expected nugget size of the weld (5 – 6 mm for the thinnest plate thickness of 2 mm). Hence the small nugget determined by the torsional test is not attained with the ulrasonic test with this probe.

- The others should be operator mistakes in coupling the probe or in evaluating the ultrasonic signals.

Moreover, there is another type of inconsistency, with the G20MNX3.6 probe, the ultrasonic test and the torsional destructive test gives different types of defects for 10 spot weld specimens. Although, this situation does not affect the accept/reject crirteria, it should also be considered. The main reasons for this situation are the same as the above since the error in 4 (SWS-23, SWS-30, SWS-41 and SWS-46) of these specimens should be due to the probe's narrower element diameter while the others are operator mistakes. Because for these 4 specimens, ultrasonics with the probe having a element diameter of 3.6 mm gives stick weld as the preliminary defect while the torsional test indicates them as having small nuggets.

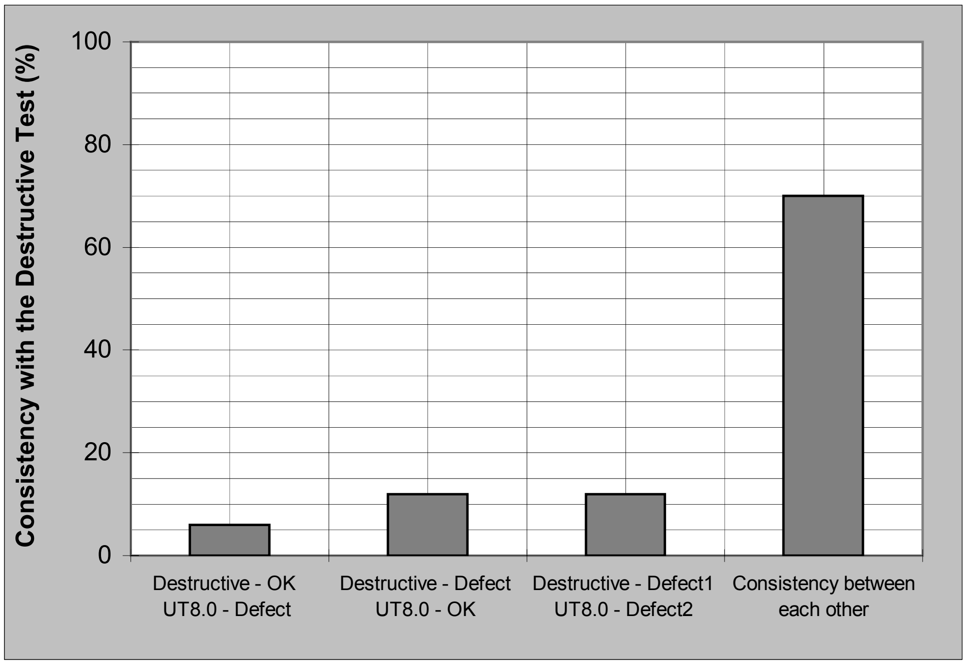

Figure 6.10 Consistency of the ultrasonic test with the probe having the element diameter of 8.0 mm with the torsional test

From the results from Table 5.1, it is clear that the consistency of the ultrasonic test with G15MNX8.0 probe is less than that of the ultrasonic test with G20MNX3.6. This condition arises from the following facts :

- The frequency of G15MN8.0 (15 MHz) is less than the frequency of the G20MNX3.6, i.e. it provides less sensitivity than the other.

- The element diameter and hence the sound beam of the G15MN8.0 probe is wider than the expected nugget size of the weld (5-6 mm), leading to some false indications.

- The coupling of the probe is more difficult and needs more attention to place on the right position of the spot weld indication due to wider diameter.

6.2 CONCLUSION

Obviously, the quality of the spot weld has a direct impact on the quality of the final product. For the successful application of spot weld inspection, the inspection system must be suitable and the operator must be sufficiently trained and experienced. If either of these prerequisities is not met, there is a high potential for gross error in inspection results. For example, with an inadequate equipment or with a poorly trained operator, discontinuities may go undetected or be deemed unimportant. This may cause the loss of the product on the service or more unfortunately the loss of lives, for example in the case of an aircraft part.

In this study, a procedure which is actually a guideline to the nondestructive inspection of spot welds is aimed to be constituted in order to use the nondestructive inspection methods in a correctly, effectively and perfect manner for different kinds of industries. This study is conducting by using commercially available instruments supporting last technologies.

Various technical approaches have been investigated for nondestructively inspecting spot weld quality. The first method is the visual inspection, the oldest one, which is also used in the applicaton of the other approaches. It is very efficient for the visible surface of the spot weld, but can not be used for determining the quality of the weld nugget, alone. Excessive identation, distortion, surface fusion, surface cracks can be detected visually. But, visual inspection is not sufficient for a reliable defect assessment of the spot welds as seen with the 42 % inconsistency with the torsional test in our study.

For the radiographic testing, its reliability was not found too malicious with 66 % consistency with the torsional test, but it is not economical, practical and easily adaptable solution for spot welding lines. It requires film processing which is expensive and takes long time for film treatment. Nowadays, a new radiographic technique called “real-time radiography” introduced using the real-time images in stead of film processing. But this method is not efficient in parts having complex shapes and in spot welding production lines.

Among the others, the leading nondestructive method was found to be ultrasonic pulse-echo technique with at least 70 % consistency (for ultrasonics with the transducer having element diameter of 8.0 mm) with the torsional test. If we add the percentage of spot welded specimens for which torsional and ultrasonic tests give different kinds of defects but both rejects the part, then the consistency will rise to 82 %. Here, it should also be noted that more reliable results can be taken by using a transducer having an element diameter of the desired nugget diameter.

Ultrasonic pulse-echo technique is based upon the transit time and attenuation of the ultrasonic energy. It enables detection of the presence and size adequacy of a weld in the weld zone. Early works point toward the probable success of the ultrasonic pulse-echo method applied through the thickness of the weld nugget. Recent work on transducers will permit extending the method to inspection of thinner spot welds.

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APPENDIX A

Table A.1 Selected spot welded specimens and parameters for the least probability of defects from the study.

Test Piece No.	Plate Thickness (mm)	Welding Pressure (kN)	Welding Time (cycle)	Machine Performance (%)	Welding Current (kA)
SWS-01	2+2	4.8	15	30	8.7
SWS-08	2+2	4.8	20	25	8.0
SWS-19	2+2	4.8	25	20	6.9
SWS-31	2+2	4.8	15	25	8.0
SWS-47	2+2	4.1	25	20	6.9
SWS-64	2+2	6.2	30	20	7.2
SWS-68	2+2	5.5	15	30	9.0
SWS-72	2+2	5.5	20	25	8.1
SWS-76	2+2	5.5	25	20	7.1
SWS-80	2+2	5.5	30	20	7.1
SWS-96	2+2	6.9	20	30	9.3
SWS-97	2+2	6.9	20	25	8.4

Table A.2 Spot welding factors and their explanations (detailed information about the explanation can be found in the section given in paranthesis).

NO.	FACTORS	EXPLANATION
1	**Factors Depending on the Material**	
1.1	Composition of the alloy	Weldability (1.3)
1.2	Coatings	Weldability (1.3) Stick welds and inclusions (2.2.12, 2.2.14)
1.3	Production method	Microstructure (1.2)
1.4	Properties	Weldability according to mechanical and electrical properties (1.3)
1.5	Surface Condition	Some Type of Defects (2.1.5 and 2.2)
1.6	Design	Nugget Diameter (2.2.3) Joint configurations (1.2)
1.7	Electrode/Workpiece Interactions	Face alloying affinity (2.1.5) Mushrooming or pitting of electrodes (2.1.3)
2	**Spot Welding Equipment Factors**	
2.1	Type of RSW machine	Spot weld quality (1.2.2)
2.2	Electrodes	Design and nugget size (1.2 and 1.2.3) Some types of defects (2.1.3 and 2.2)
2.3	Water cooling system	Undersized welds and cracks (2.2)
2.4	Electrical supply	Welding Time (2.1.4)
2.5	Mechanical system	Welding Pressure (2.1.1)

Table A.2 Spot welding factors and their explanations (continued).

3	**Spot Welding Operation Factors**	
3.1	Preweld Preperation	Surface condition (2.1.5 and 2.2) Tempering (1.3.1.1)
3.2	Welding Parameters	Welding pressure (2.1.1) Welding current (2.1.2) Welding time (2.1.4) Defects (2.2)
3.3	Weld Configuration	Direct or series welding (1.2.1) Single or multiple welding (1.2.1)
3.4	Procedure	Standarts and specifications (2.2.3) Design Criteria (1.2)
4	**Operator**	
4.1	Training	Proper training on the theory of RSW, surface preperation, equipment (2.1.6)
4.2	Experience	Experience on the selection of welding parameters (2.1.6)
4.3	Knowledge	Continuous education to preserve the gathered information
4.4	Progress	Looking for the new developments in the industry

APPENDIX B

In the digital video microscope images below, the letter F denotes the front side while the letter B denotes the back side of the spot welded specimen.

Figure B.1 SWS01F- OK

Figure B.2 SWS02F- OK

Figure B.3 SWS03B- OK

Figure B.4 SWS04F- Microholes on the spot

Figure B.5 SWS05B- Burnt and Copper pickup

Figure B.6 SWS06F- OK

Figure B.7 SWS07F- OK

Figure B.8 SWS08B-Unsymmetry on the HAZ border

Figure B.9 SWS09F- Indefinite HAZ Region

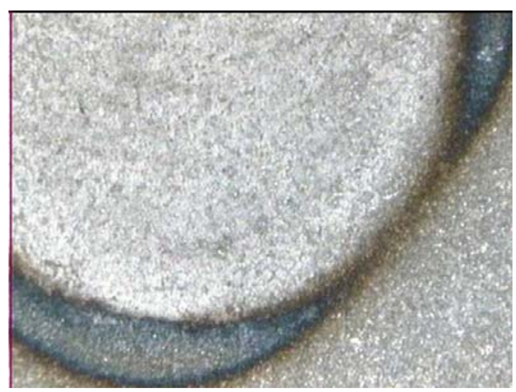


Figure B.10 SWS10B- Weak HAZ

Figure B.11 SWS11B- Unsymmetry on HAZ

Figure B.12 SWS12B- No HAZ in LL portion

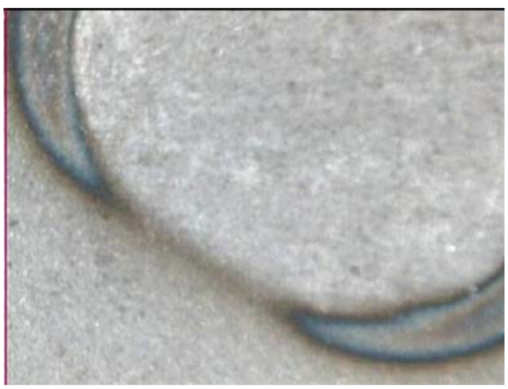


Figure B.13 SWS13B- Weak HAZ

Figure B.14 SWS14B- No HAZ in LL portion

Figure B.15 SWS15F- OK

Figure B.16 SWS16B- Large HAZ & Burnt Spot

Figure B.17 SWS17B- Wide HAZ

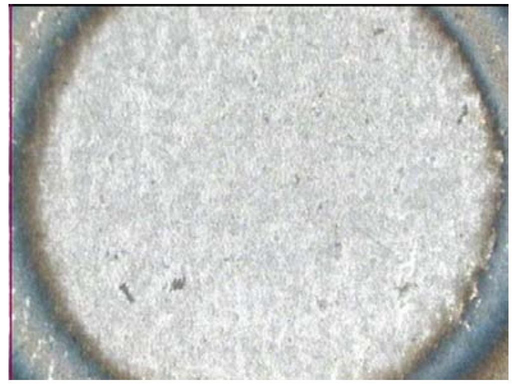


Figure B.18 SWS18F- OK

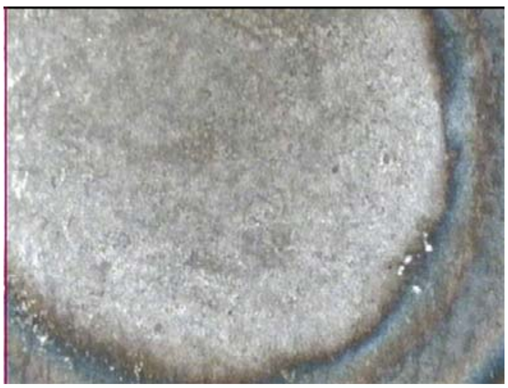


Figure B.19 SWS19B- Geometry

Figure B.20 SWS20B- Wide HAZ & Geometry

Figure B.21 SWS21B- Burnt Spot & Wide HAZ

Figure B.22 SWS22B- Wide HAZ & Geometry & Cu

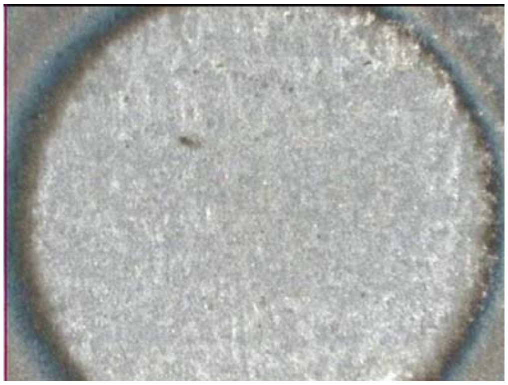


Figure B.23 SWS23F- OK

Figure B.24 SWS24B- Burnt Spot & Geometry

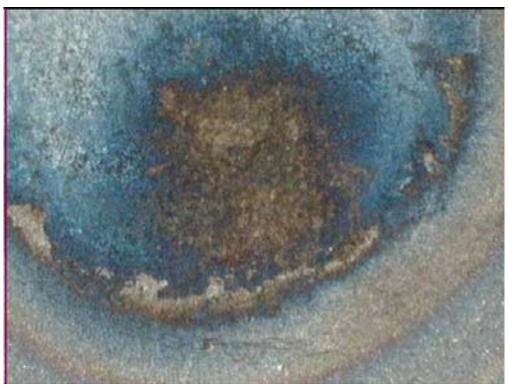


Figure B.25 SWS25B- Burnt Spot Wide HAZ

Figure B.26 SWS26B- Burnt Spot & & Wide HAZ & Cu

Figure B.27 SWS27B- Burnt Spot & Wide HAZ & Cu

Figure B.28 SWS28B- Weak HAZ

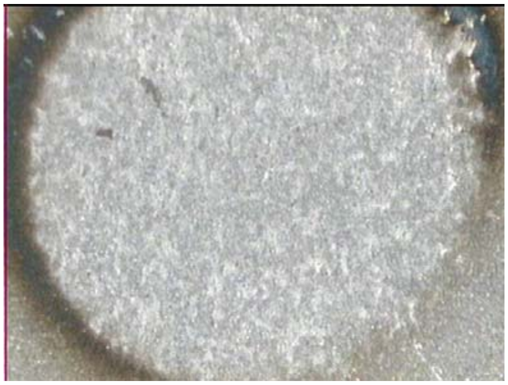


Figure B.29 SWS29F- Weak HAZ

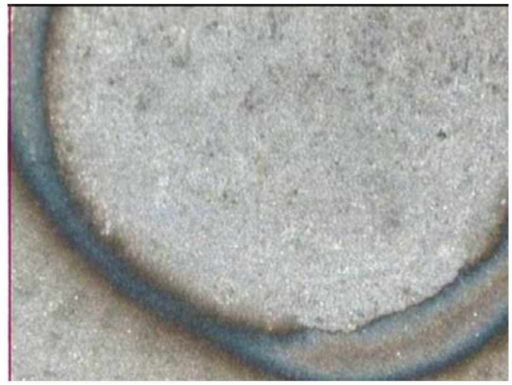


Figure B.30 SWS30B- Weak HAZ

Figure B.31 SWS31F- Narrow HAZ

Figure B.32 SWS32F- Grains on Spot & HAZ

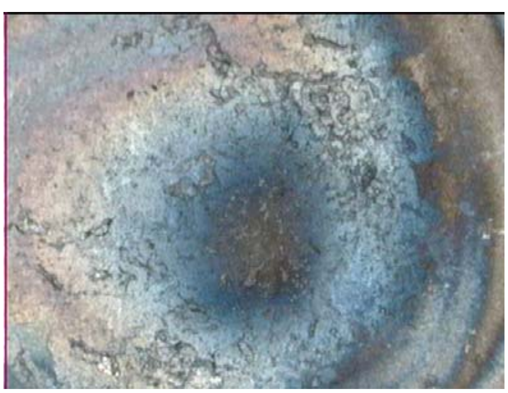


Figure B.33 SWS33B- Burnt Spot & Wide HAZ & Cu

Figure B.34 SWS34F- OK

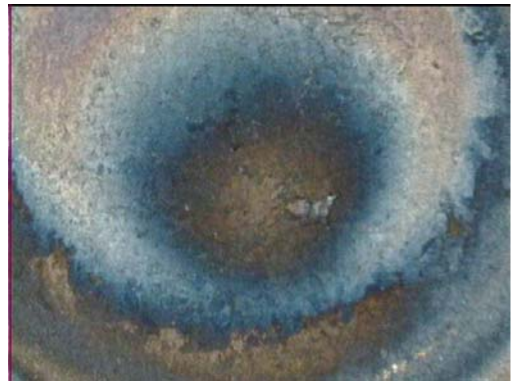


Figure B.35 SWS35F- Burnt Spot & Wide HAZ

Figure B.36 SWS36B- Burnt Spot & Wide HAZ & Cu

Figure B.37 SWS37B- Burnt Spot & Wide HAZ

Figure B.38 SWS38B- Burnt HAZ

Figure B.39 SWS39B- Burnt Spot & Microcrack

Figure B.40 SWS40B- Burnt & Spot&Wide HAZ

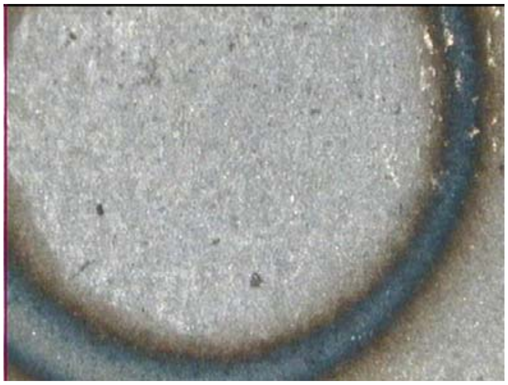


Figure B.41 SWS41F- Weak HAZ

Figure B.42 SWS42B- OK

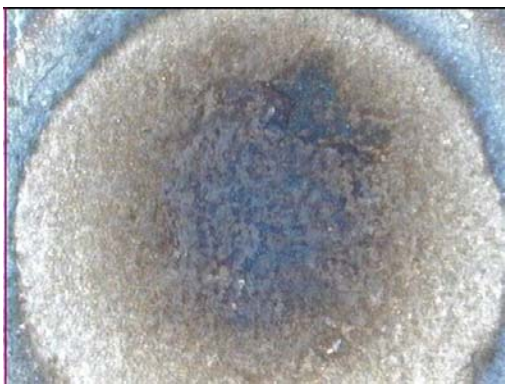


Figure B.43 SWS43B- Burnt Spot & Wide HAZ

Figure B.44 SWS44B- Burnt Spot

Figure B.45 SWS45B- Burnt HAZ

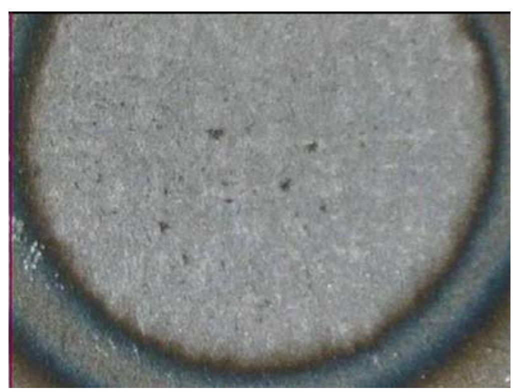


Figure B.46 SWS46F- Microholes

Figure B.47 SWS47F- OK

Figure B.48 SWS48F- Micrograins on the spot

Figure B.49 SWS49B- Microcrack in Burnt Spot

Figure B.50 SWS50B- Wide HAZ & Cu Pickup

Figure B.51 SWS51B- OK

Figure B.52 SWS52F- OK

Figure B.53 SWS53B- OK

Figure B.54 SWS54F- Burnt Spot & Wide HAZ

Figure B.55 SWS55F- Geometry & Narrow HAZ

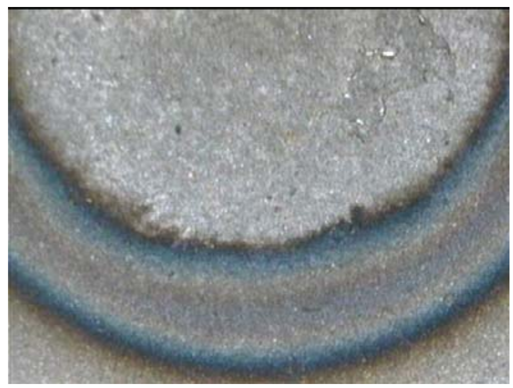


Figure B.56 SWS56B- OK

Figure B.57 SWS57B- Burnt Spot & Wide HAZ

Figure B.58 SWS58B- Burnt Spot &Wide HAZ

Figure B.59 SWS59B- Pores & Narrow HAZ

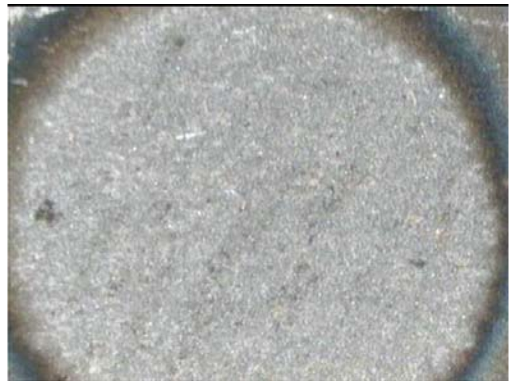


Figure B.60 SWS60F- OK

Figure B.61 SWS61F- Pores & Wide HAZ

Figure B.62 SWS62B- Microcracks & Wide HAZ & Cu

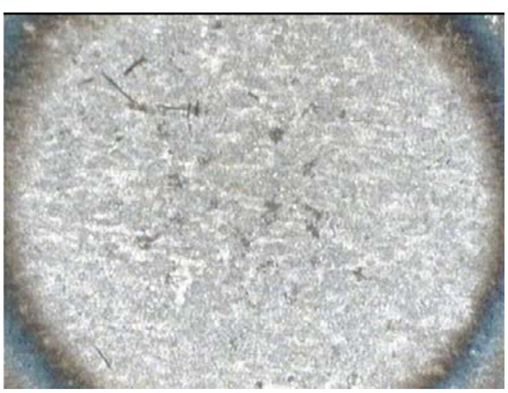


Figure B.63 SWS63B- OK

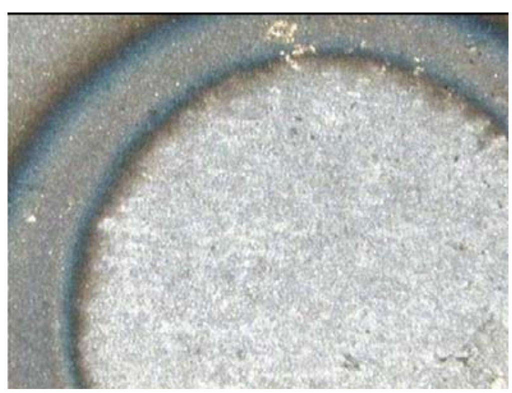


Figure B.64 SWS64F- Pores

Figure B.65 SWS65B- Burnt Spot & Large HAZ

Figure B.66 SWS66B- Burnt Spot & Large HAZ

Figure B.67 SWS67B- Burnt Spot & Large HAZ

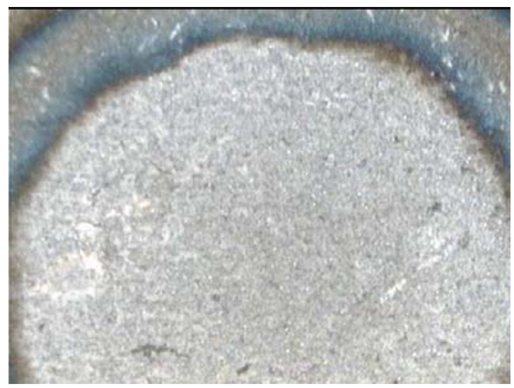


Figure B.68 SWS68B- Unsymmetric HAZ

Figure B.69 SWS69B- Unsymmetric HAZ

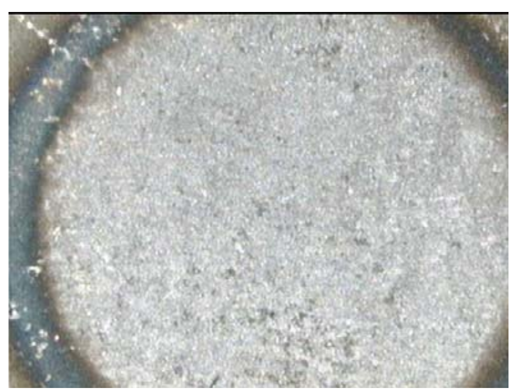


Figure B.70 SWS70F- Micropores

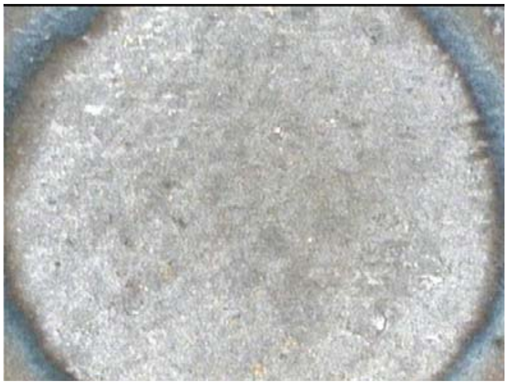


Figure B.71 SWS71F- OK

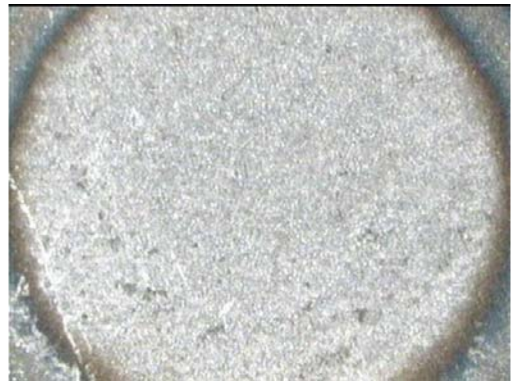


Figure B.72 SWS72B- OK

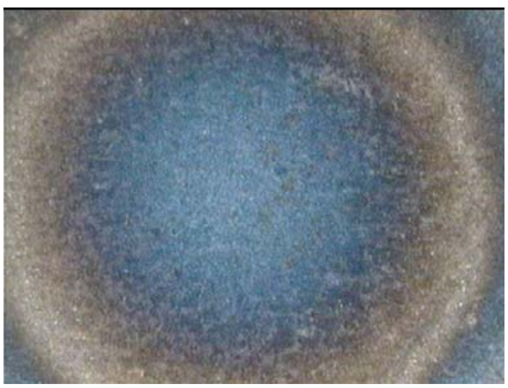


Figure B.73 SWS73F- Burnt Spot

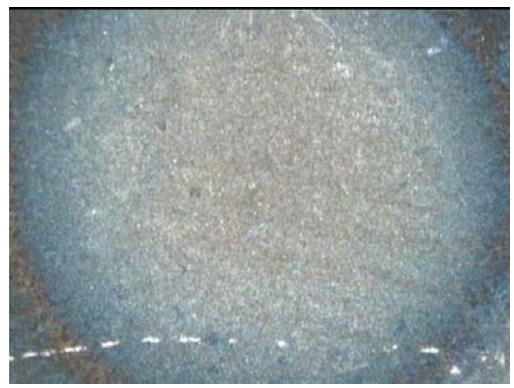


Figure B.74 SWS74B- OK

Figure B.75 SW75B- Pores & Narrow HAZ

Figure B.76 SWS76F- OK

Figure B.77 SWS77B- Burnt Spot & Wide HAZ

Figure B.78 SWS78B- Burnt Spot

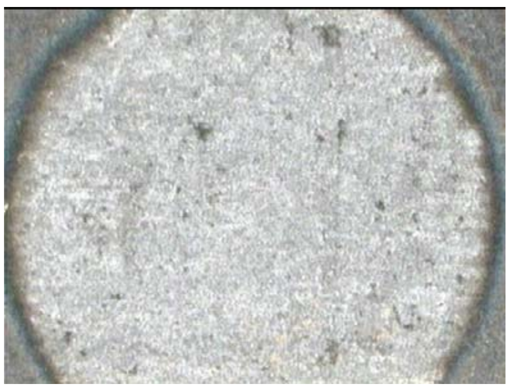


Figure B.79 SWS79B- OK

Figure B.80 SWS80B- OK

Figure B.81 SWS81B- Burnt Spot

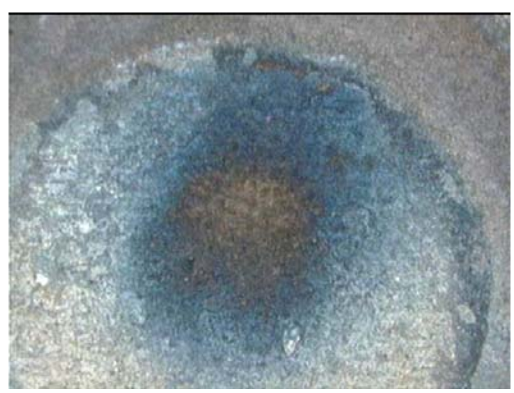


Figure B.82 SWS82B- Burnt Spot & Large HAZ

Figure B.83 SWS83B- OK

Figure B.84 SWS84B-Unsymmetry on HAZ Border

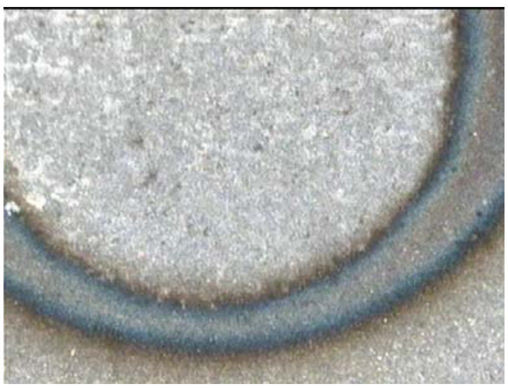


Figure B.85 SWS85B- Narrow HAZ

Figure B.86 SWS86F- OK

Figure B.87 SWS87F- Pores

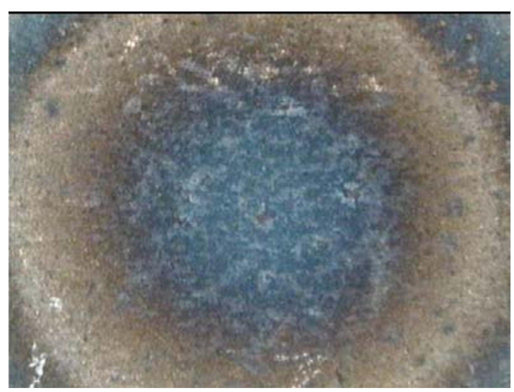


Figure B.88 SWS88F- Burnt Spot

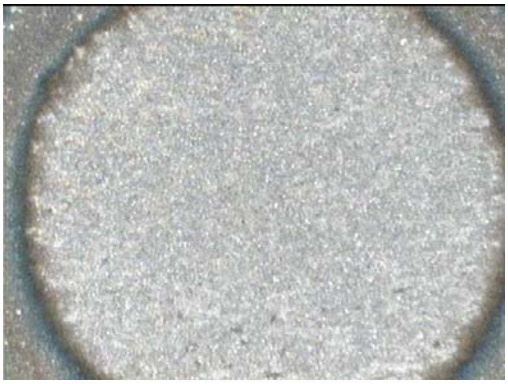
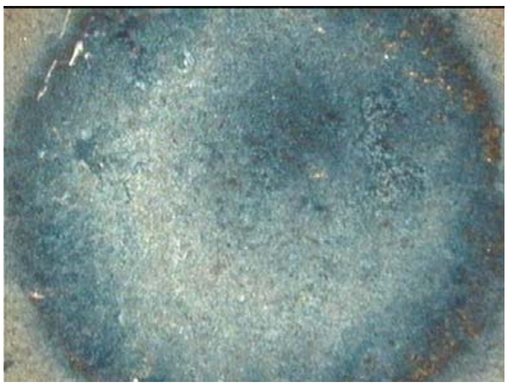


Figure B.89 SWS89F- Narrow HAZ

Figure B.90 SWS90B- Large HAZ



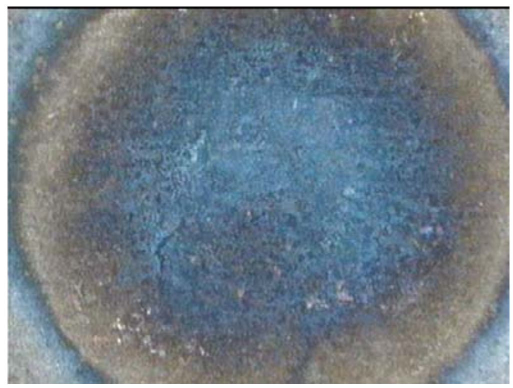


Figure B.91 SWS91F- Burnt Spot

Figure B.92 SWS92B- Microcracks & Large HAZ

Figure B.93 SWS93B- Burnt Spot

Figure B.94 SWS94B- Burnt Spot

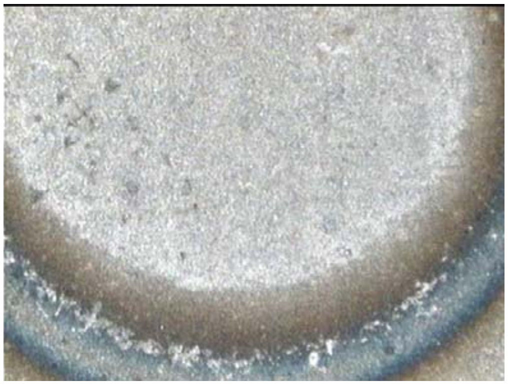


Figure B.95 SWS95F- Pores

Figure B.96 SWS96B- OK

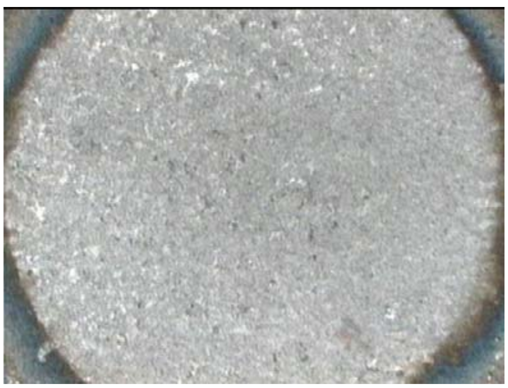


Figure B.97 SWS97B- OK

Figure B.98 SWS98F- Burnt Spot & Large HAZ

Figure B.99 SWS99F- Burnt Spot

Figure B.100 SWS100B- OK

APPENDIX C

Figure C.1 SWS01- OK

Figure C.2 SWS02- OK

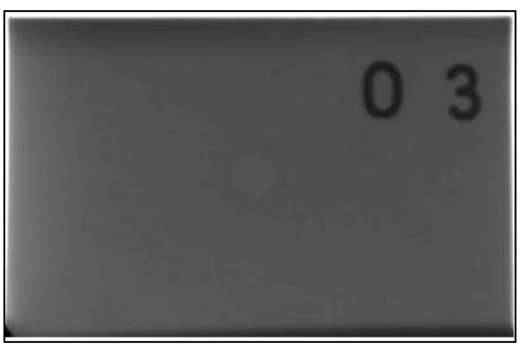


Figure C.3 SWS03- OK

Figure C.4 SWS04- OK

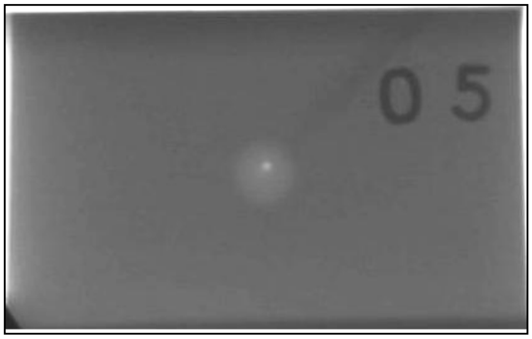


Figure C.5 SWS05- Burnt, Expulsion

Figure C.6 SWS06- OK

Figure C.7 SWS07- OK

Figure C.8 SWS08- OK

Figure C.9 SWS09- Spot not visible

Figure C.10 SWS10- Unsymmetry

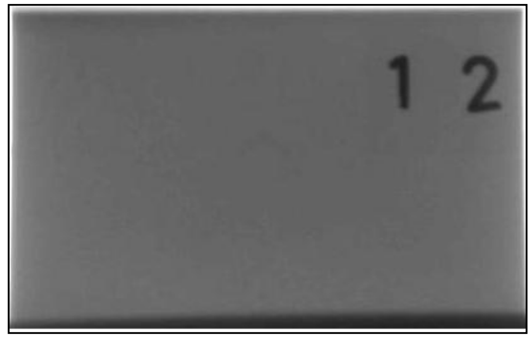


Figure C.11 SWS11- Unsymmetry

Figure C.12 SWS12- Unvisible nugget

Figure C.13 SWS13-Unvisible nugget

Figure C.14 SWS14-Spot not visible

Figure C.15 SWS15- OK

Figure C.16 SWS16- Burnt Spot & Wide HAZ

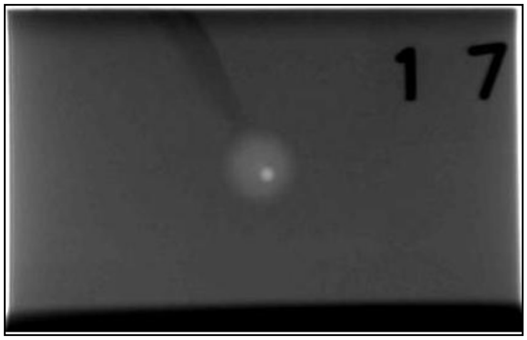


Figure C.17 SWS17- Burnt Spot & Expulsion

Figure C.18 SWS18- Spot not visible

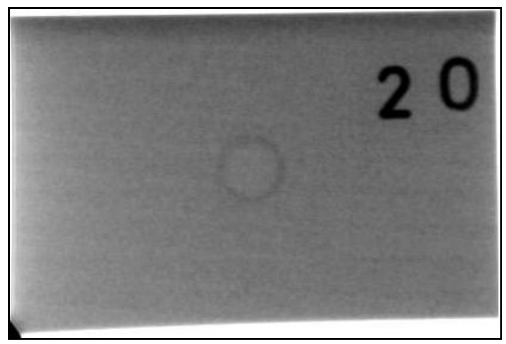


Figure C.19 SWS19- Unsymmetry

Figure C.20 SWS20- OK

Figure C.21 SWS21- Burnt Spot

Figure C.22 SWS22- Burnt Spot

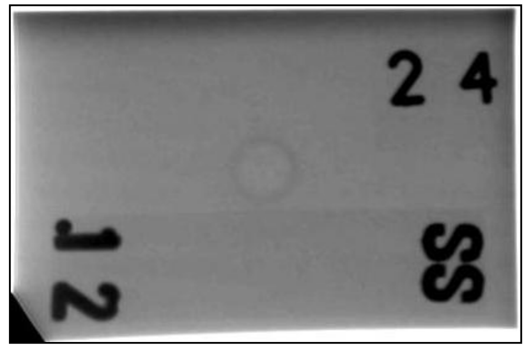
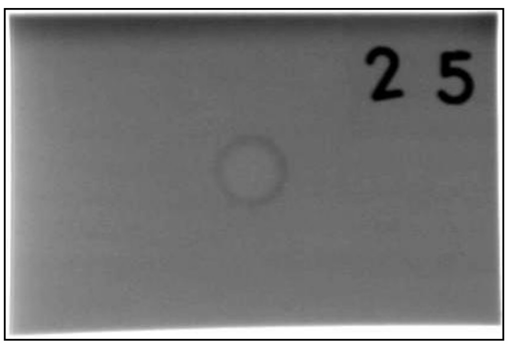


Figure C.23 SWS23-Unvisible nugget **Figure C.24** SWS24- Burnt Spot



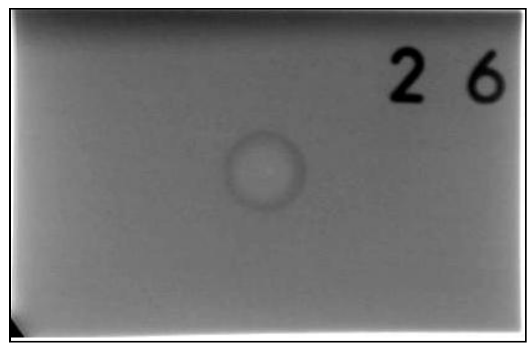


Figure C.25 SWS25- Burnt Spot **Figure C.26** SWS26- Burnt Spot

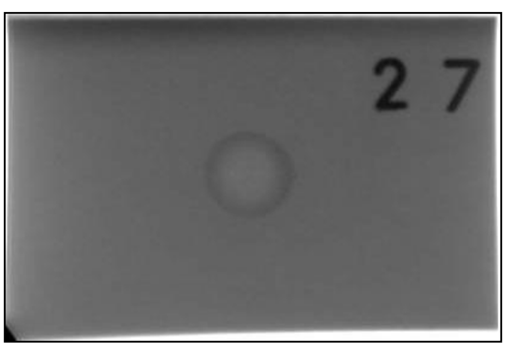


Figure C.27 SWS27- Burnt Spot & Wide HAZ **Figure C.28** SWS28- Spot not visible

Figure C.29 SWS29-Unvisible nugget **Figure C.30** SWS30- OK

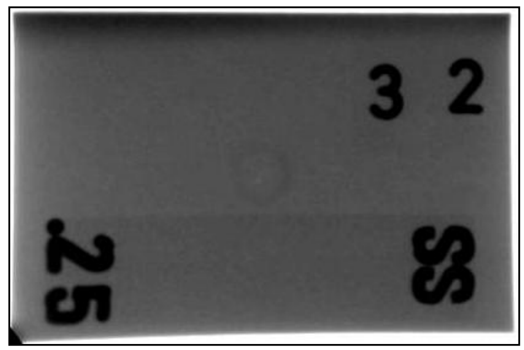


Figure C.31 SWS31- OK

Figure C.32 SWS32- Burnt Spot

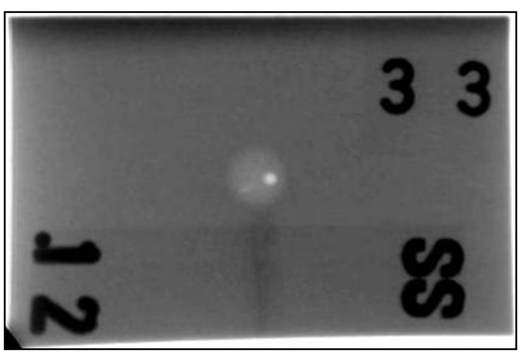


Figure C.33 SWS33- Burnt Spot & Expulsion (Holes)

Figure C.34 SWS34- Gas Cavity

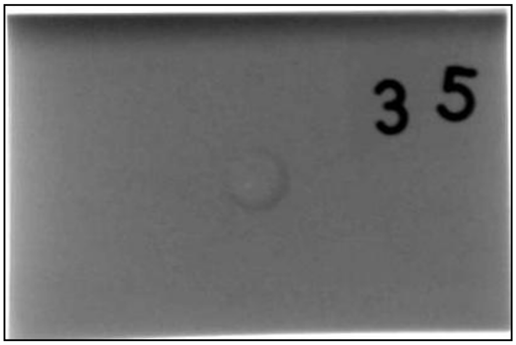


Figure C.35- Burnt Spot & Weak HAZ

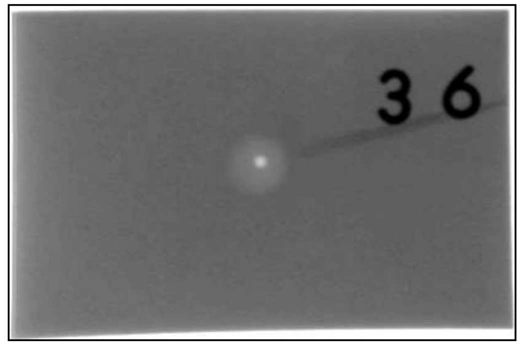


Figure C.36 SWS36- Burnt Spot & Expulsion

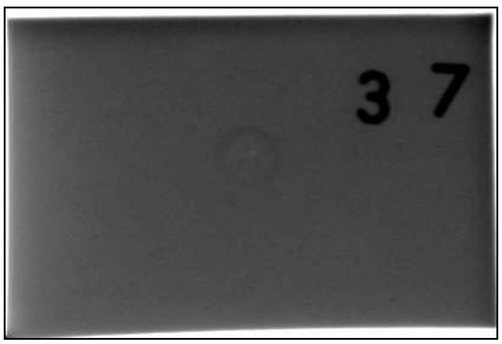


Figure C.37 SWS37- Gas Cavity

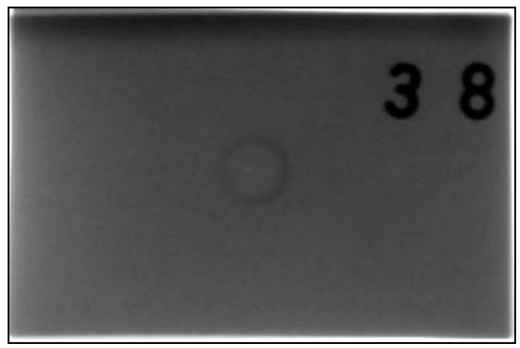
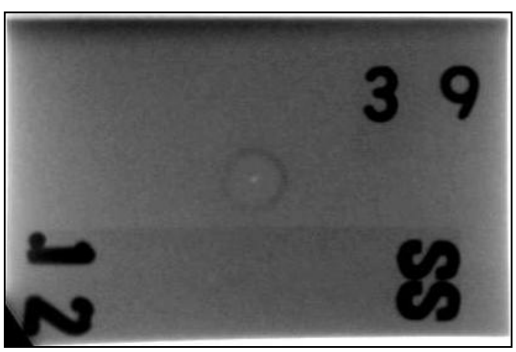


Figure C.38 SWS38- Burnt Spot (Small Hole)



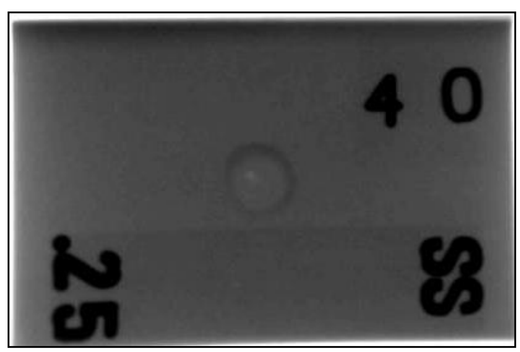


Figure C.39 SWS39- Gas Cavity

Figure C.40 SWS40- Burnt Spot

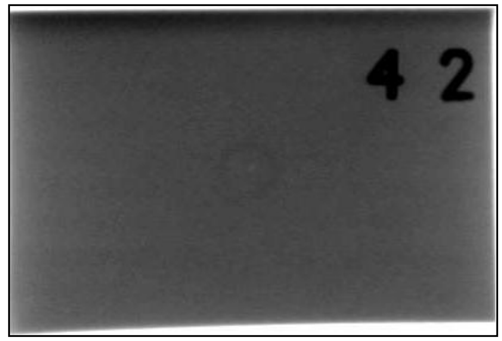
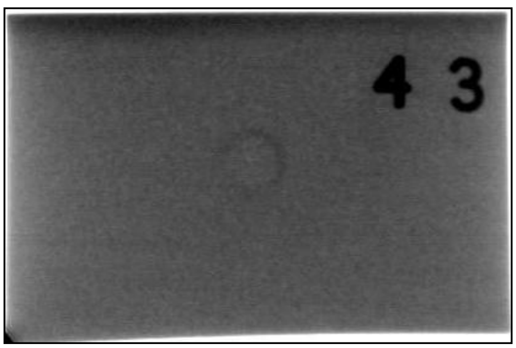


Figure C.41 SWS41- Spot not visible

Figure C.42 SWS42- Gas Cavity



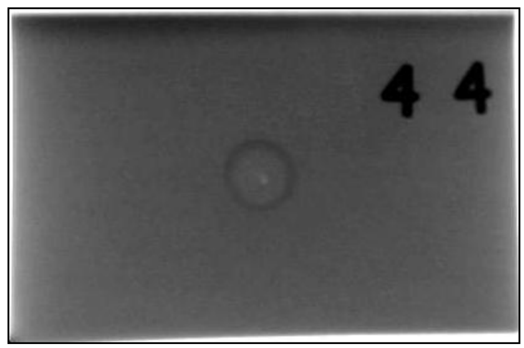


Figure C.43 SWS43- Weak HAZ

Figure C.44 SWS44- Burnt Spot

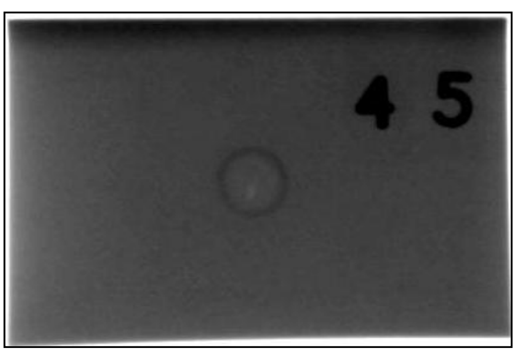


Figure C.45 SWS45- Burnt Spot

Figure C.46 SWS46-Spot not visible

(Large Hole)

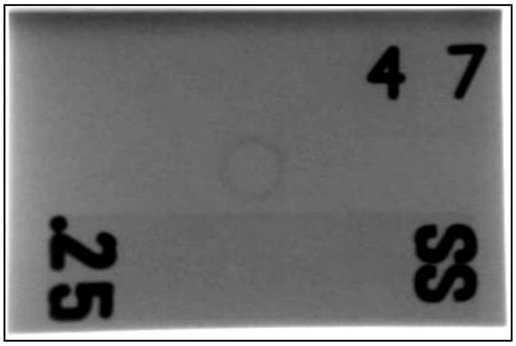


Figure C.47 SWS47- OK

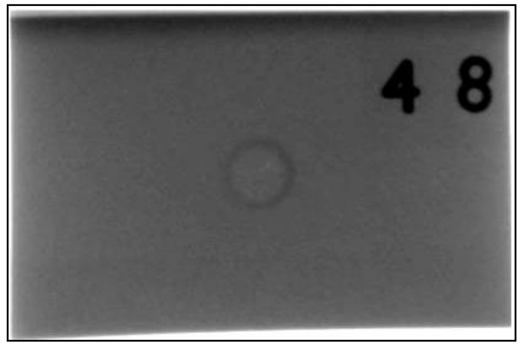


Figure C.48 SWS48- Gas Cavity

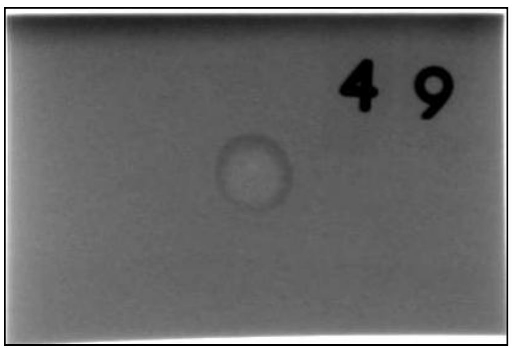


Figure C.49 SWS49- Gas Cavity

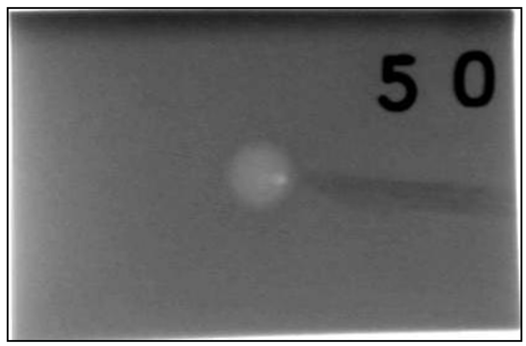
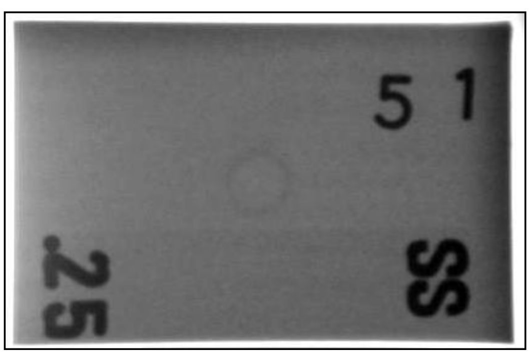


Figure C.50 SWS50- Burnt Spot & Expulsion (Large Hole)



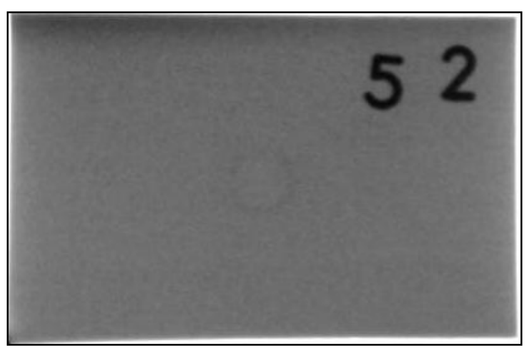


Figure C.51 SWS51- OK

Figure C.52 SWS52- OK

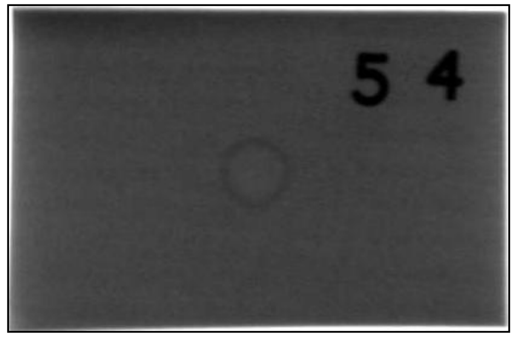
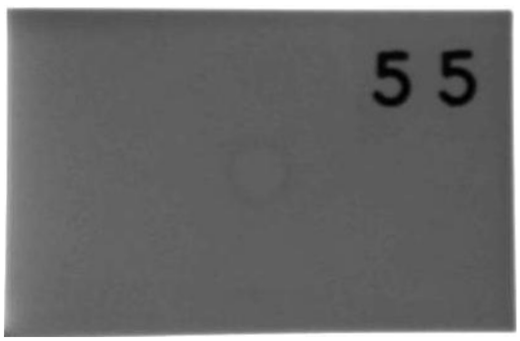


Figure C.53 SWS53- Spot not visible

Figure C.54 SWS54- Gas Cavity



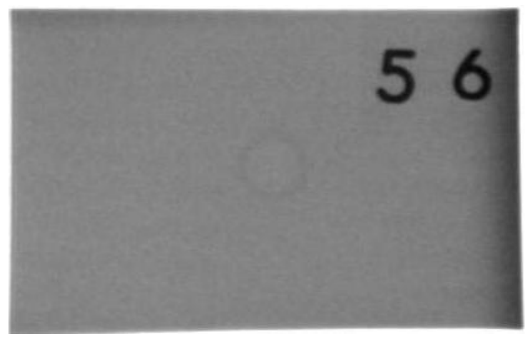
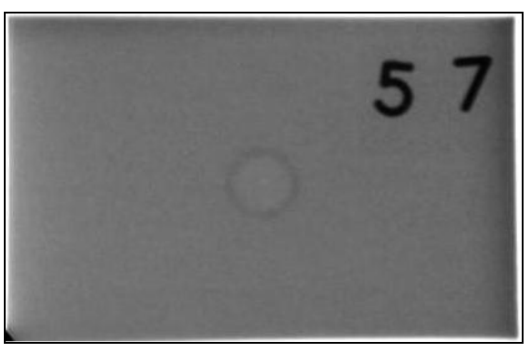


Figure C.55 SWS55- OK

Figure C.56 SWS56- Gas Cavity



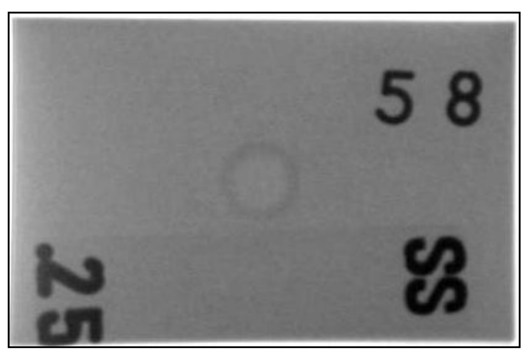
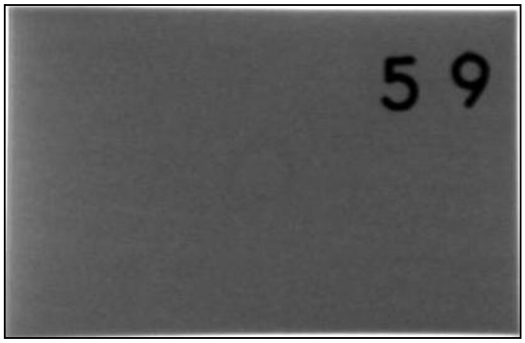


Figure C.57 SWS57- Gas Cavity

Figure C.58 SWS58- Gas Cavity



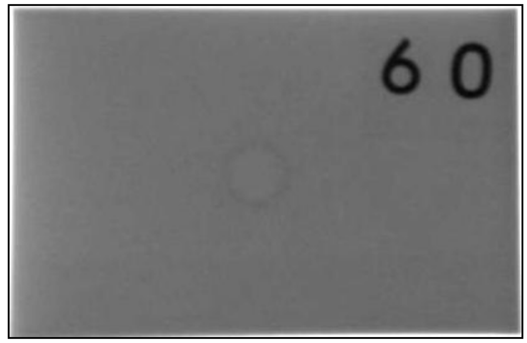
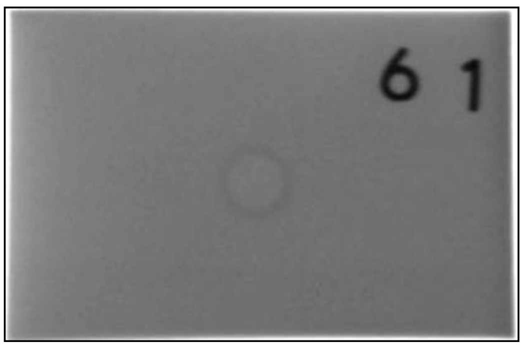


Figure C.59 SWS59- OK

Figure C.60 SWS60- OK



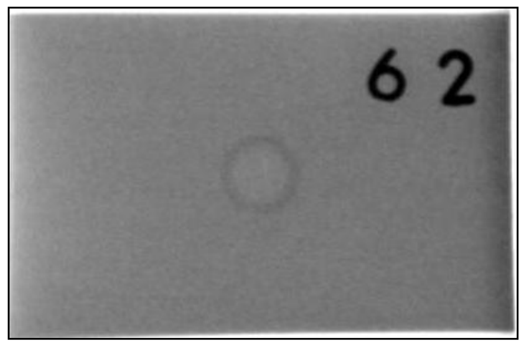
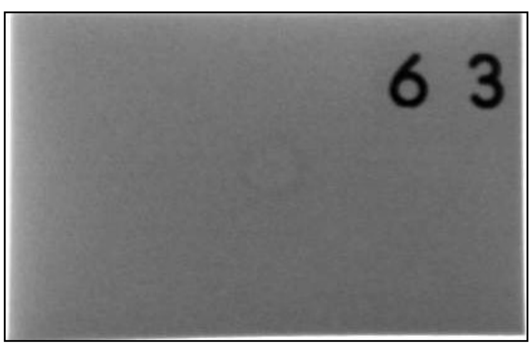


Figure C.61 SWS61- OK

Figure C.62 SWS62- Wide HAZ & Gas Cavity



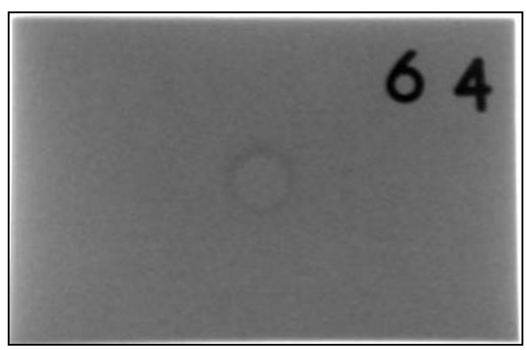
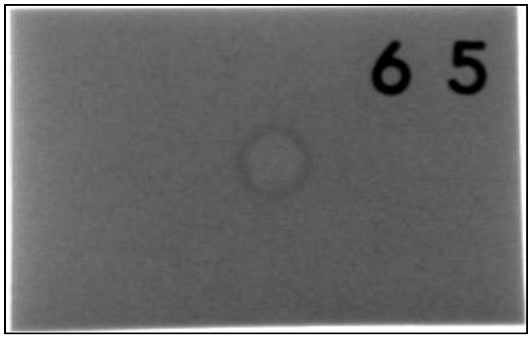


Figure C.63 SWS63- OK

Figure C.64 SWS64- OK



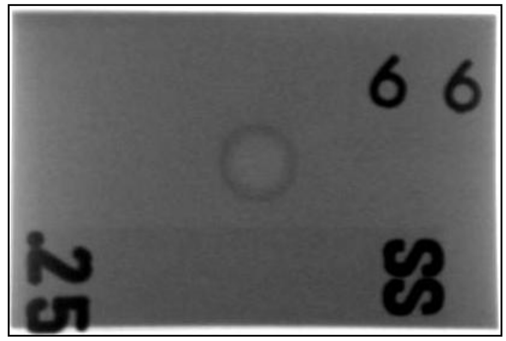
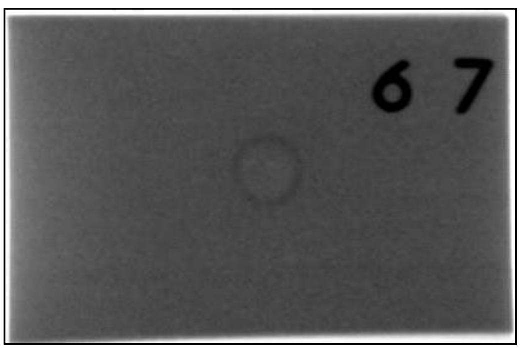


Figure C.65 SWS65- Gas Cavity

Figure C.66 SWS66- Wide HAZ & Gas Cavity



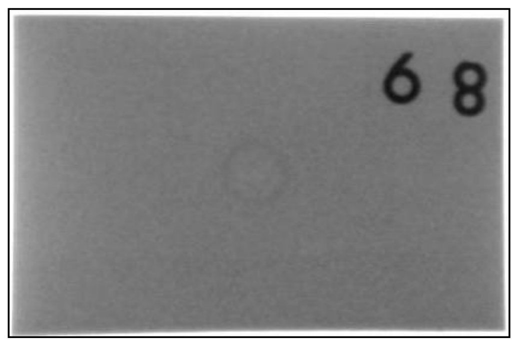


Figure C.67 SWS67- Burnt Spot

Figure C.68 SWS68- OK

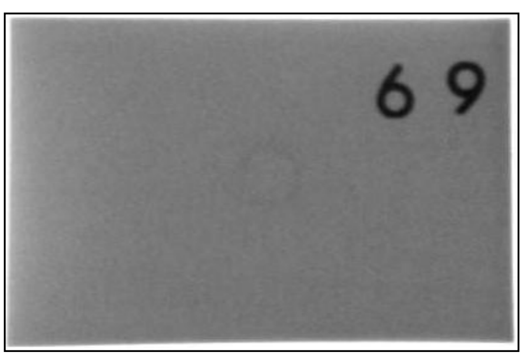


Figure C.69 SWS69- OK

Figure C.70 SWS70-Spot not visible

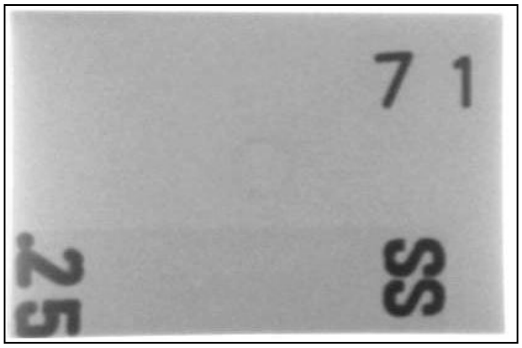
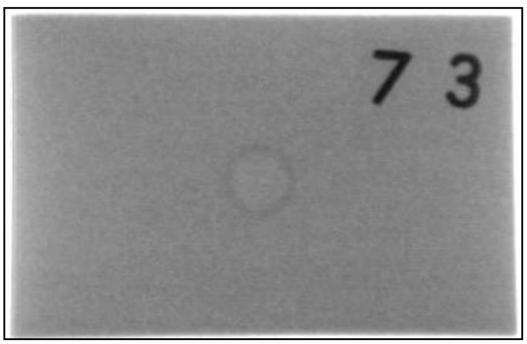


Figure C.71 SWS71- Spot not visible

Figure C.72 SWS72- OK



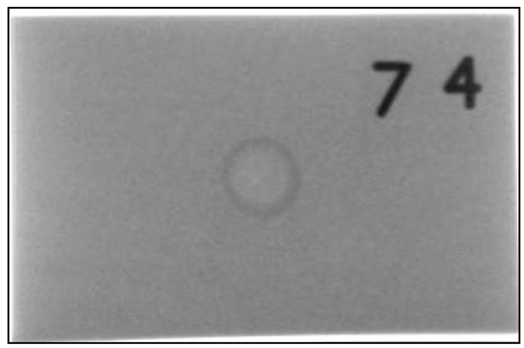
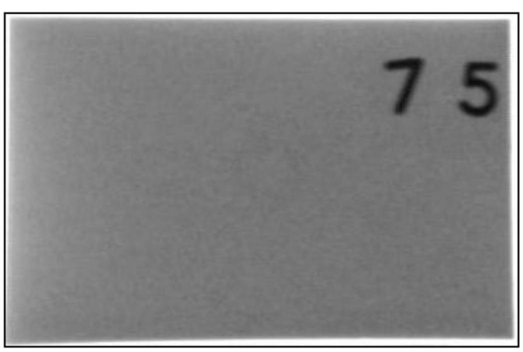


Figure C.73 SWS73- Gas Cavity

Figure C.74 SWS74- Wide HAZ & Gas Cavity



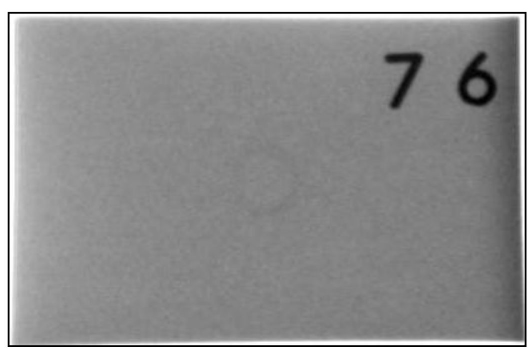


Figure C.75 SWS75- Spot not visible

Figure C.76 SWS76- OK

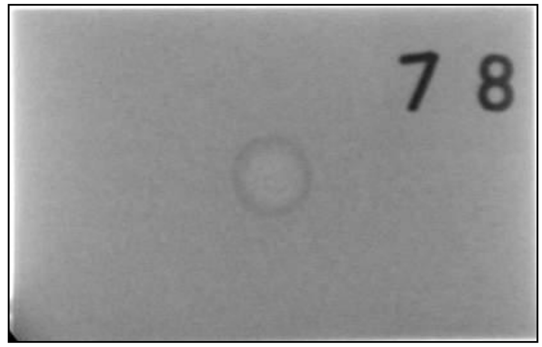
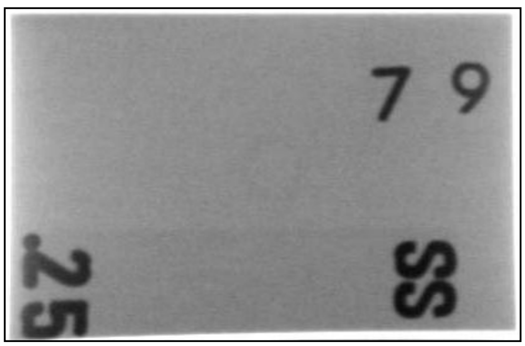


Figure C.77 SWS77- Burnt Spot & Wide HAZ

Figure C.78 SWS78- Wide HAZ



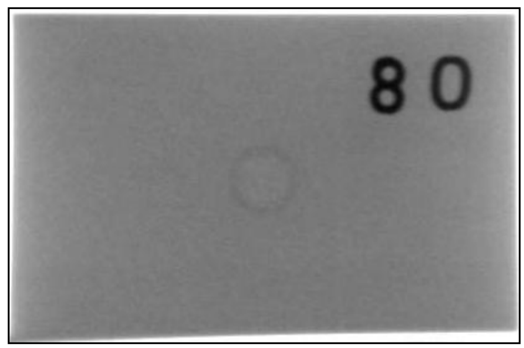
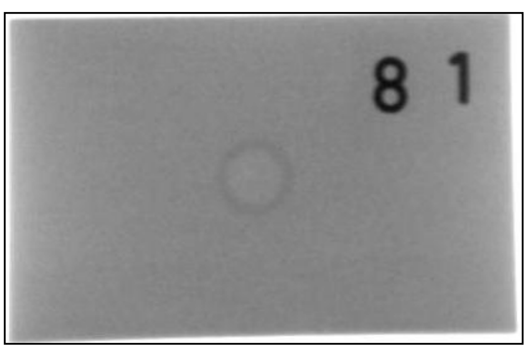


Figure C.79 SWS79-Nugget not visible

Figure C.80 SWS80- OK



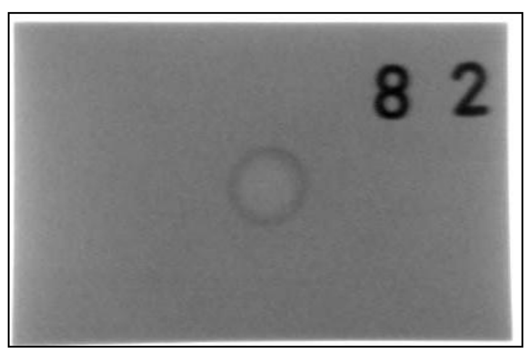


Figure C.81 SWS81- Burnt Spot

Figure C.82 SWS82- Burnt Spot &

& Wide HAZ

Wide HAZ

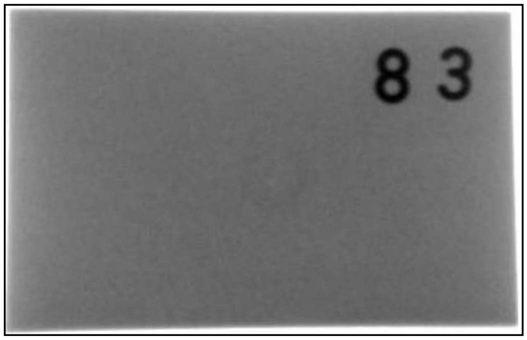


Figure C.83 SWS83-Spot not visible

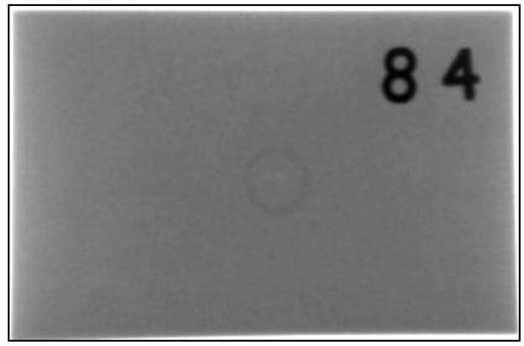


Figure C.84 SWS84- Gas Cavity

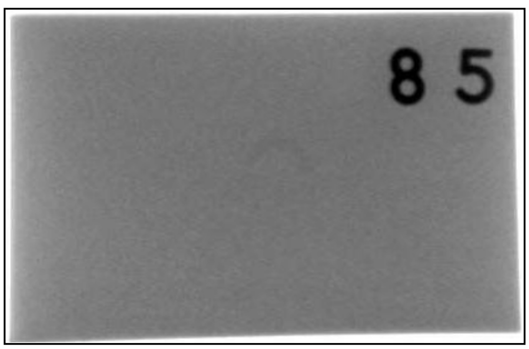


Figure C.85 SWS85-Unvisible nugget

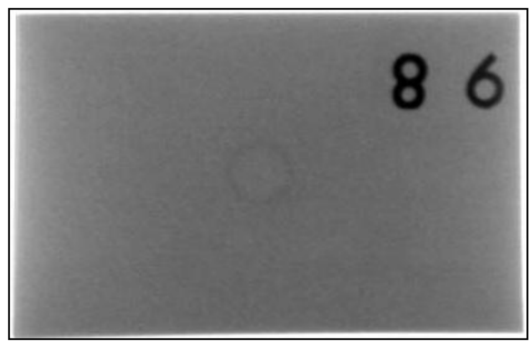


Figure C.86 SWS86- Gas Cavity

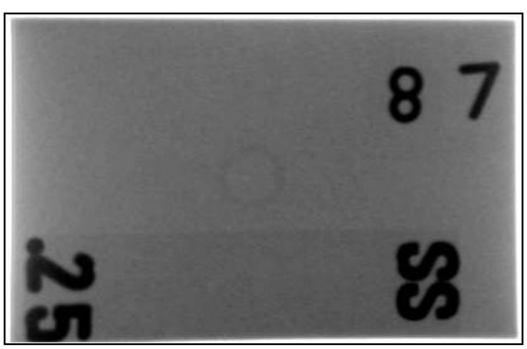


Figure C.87 SWS87- Gas Cavity

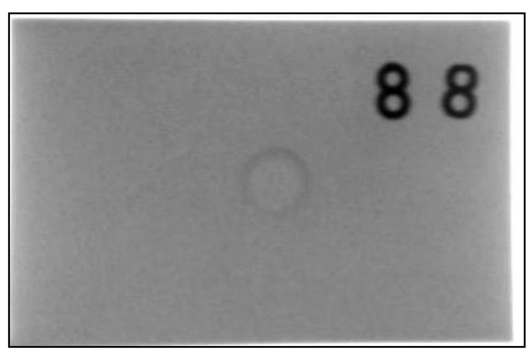


Figure C.88 SWS88- Weak HAZ

İn lower portion

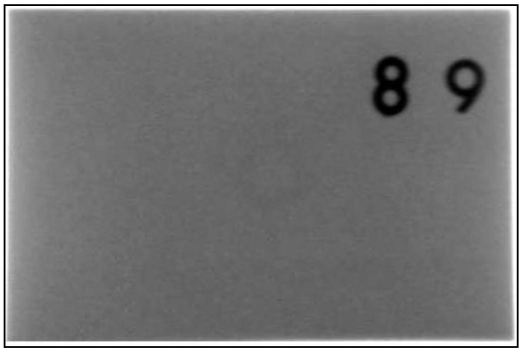


Figure C.89 SWS89-Unvisible nugget

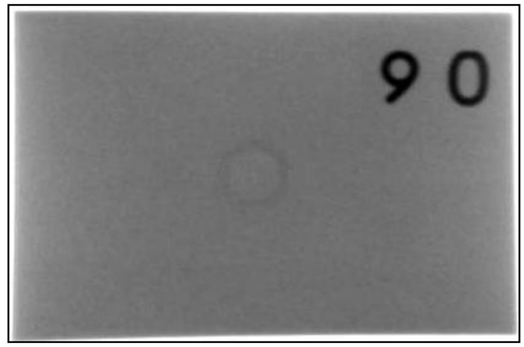


Figure C.90 SWS90- Gas Cavity

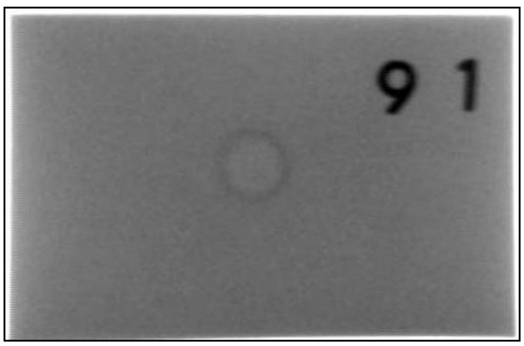


Figure C.91 SWS91- OK

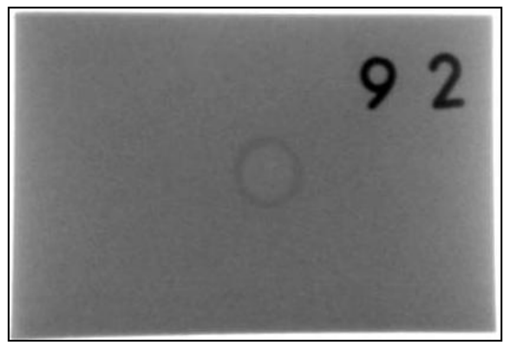


Figure C.92 SWS92- Gas Cavity

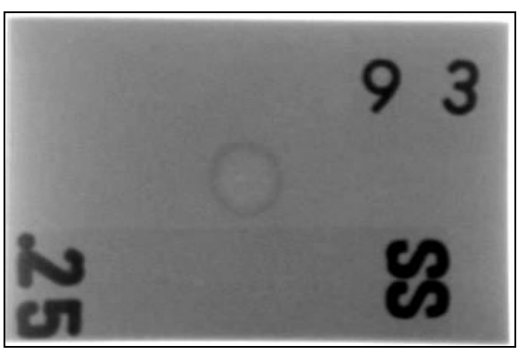


Figure C.93 SWS93- Gas Cavity

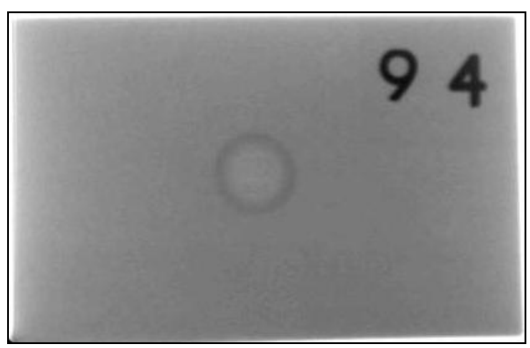


Figure C.94 SWS94- OK

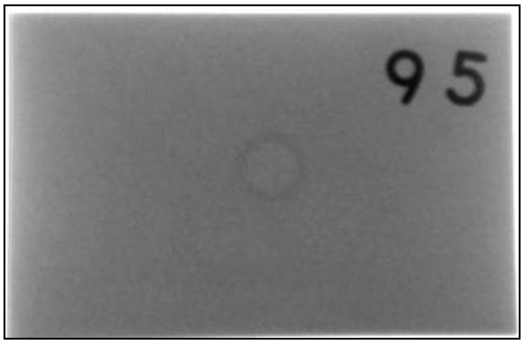


Figure C.95 SWS95- OK

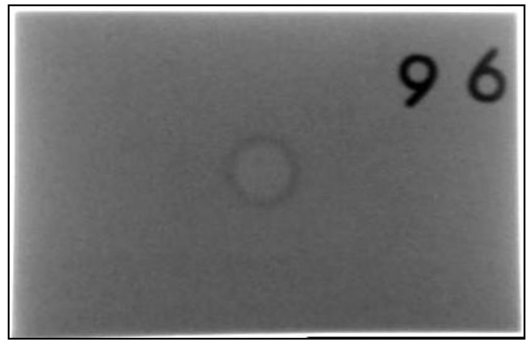


Figure C.96 SWS96- OK

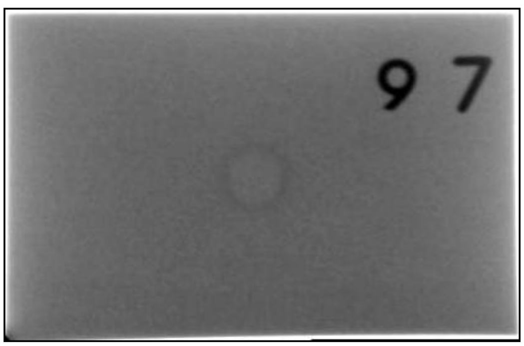


Figure C.97 SWS97- OK

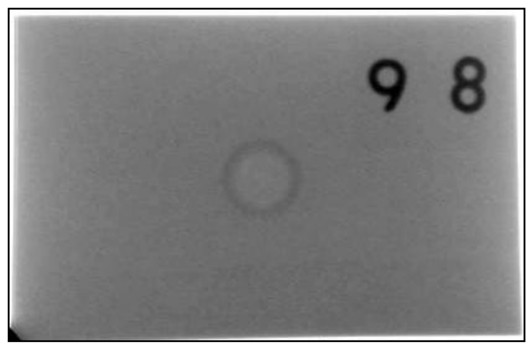


Figure C.98 SWS98- Gas Cavity

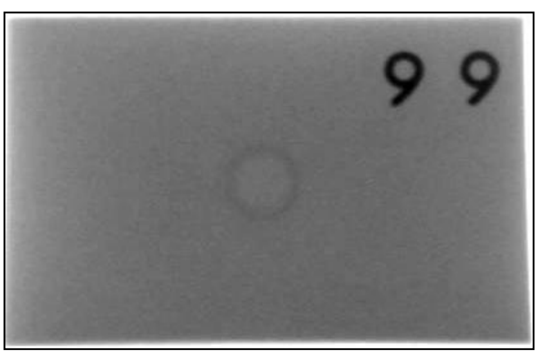


Figure C.99 SWS99- OK

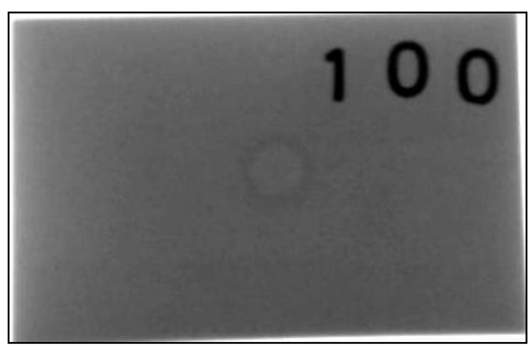
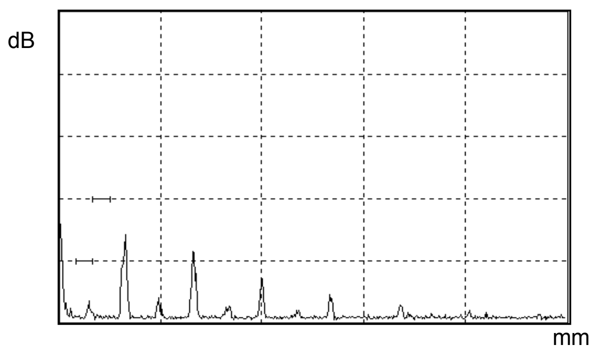


Figure C.100 SWS100- OK

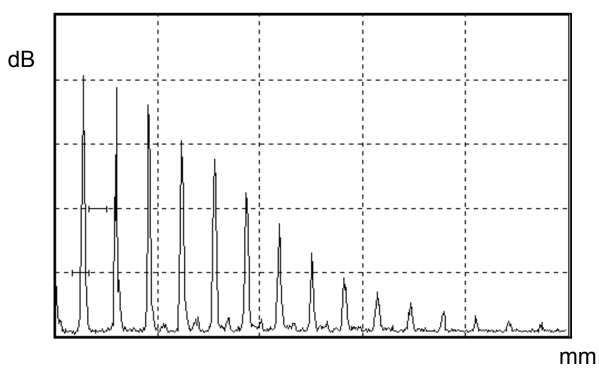
APPENDIX D

Inspection Plan :	SWS-3.6		Inspector:	Okan Okay KOÇAK	
Probe name:	SW PROBE		Probe number:	G20MNX3.6	
Probe diameter:	3.6	mm	Probe frequency:	20	MHz
Evaluation Threshold:	10	%	Tolerance of electrode mark:	10	%
Plate Thickness 1:	2	mm	Sofware Version:	Ultralog Version 2.1	
Plate Thickness 2:	2	mm	Surface:	Without coating	



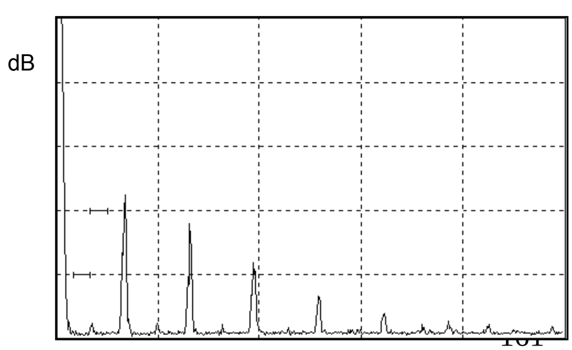
Group of spots:	SWS-3.6mm
Spot name:	SWS-01
Date:	13.04.2003
Time:	4:05:25 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.1 A-Scan of SWS-01 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-02
Date:	13.04.2003
Time:	4:07:04 PM
Number of plates:	2
Result:	loose
Plate thickness:	1,89 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.2 A-Scan of SWS-02 with 3.6 mm probe

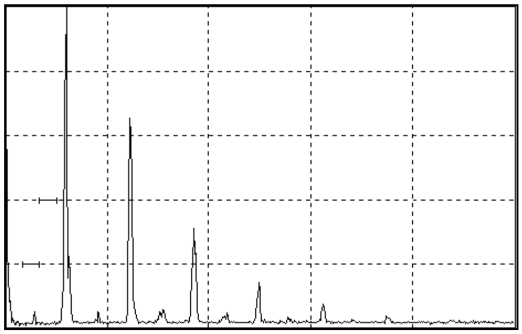


Group of spots:	SWS-3.6mm
Spot name:	SWS-03
Date:	13.04.2003
Time:	4:08:15 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs

Range:	30 mm

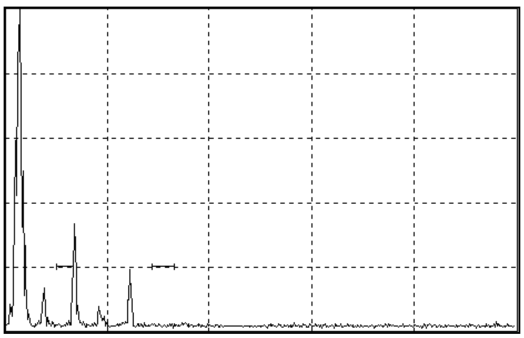
mm

Figure D.3 A-Scan of SWS-03 with 3.6 mm probe



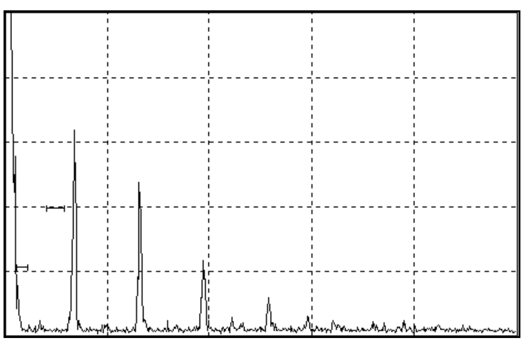
Group of spots:	SWS-3.6mm
Spot name:	SWS-04
Date:	13.04.2003
Time:	4:12:29 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	72 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.4 A-Scan of SWS-04 with 3.6 mm probe



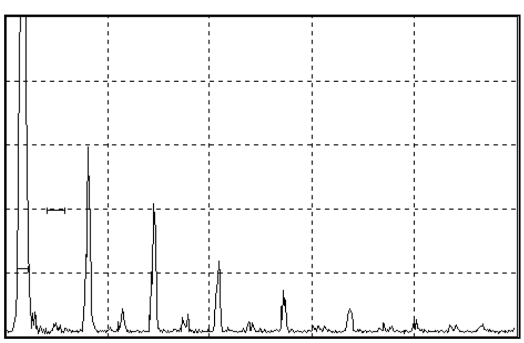
Group of spots:	SWS-3.6mm
Spot name:	SWS-05
Date:	13.04.2003
Time:	4:25:59 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,28 mm
Sound velocity:	5920 m/s
Gain:	75 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.5 A-Scan of SWS-05 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-06
Date:	13.04.2003
Time:	4:33:30 PM
Number of plates:	2
Result:	bad through-weld.
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	75 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.6 A-Scan of SWS-06 with 3.6 mm probe

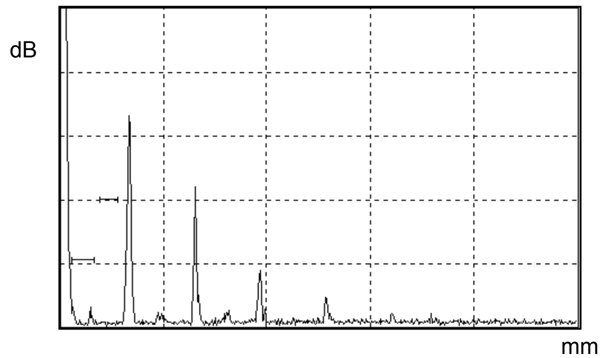


Group of spots:	SWS-3.6mm
Spot name:	SWS-07
Date:	13.04.2003
Time:	4:35:58 PM
Number of plates:	2
Result:	bad through
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	74 dB
Probe delay:	21 µs

Range:	30 mm

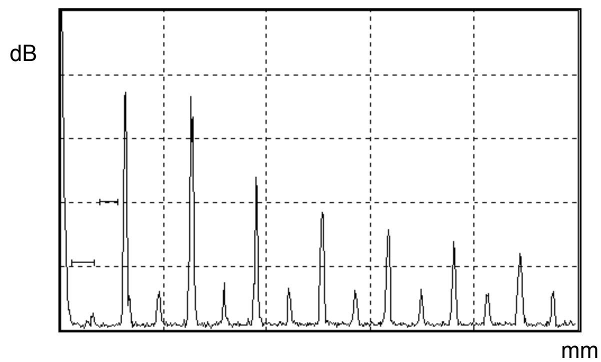
mm

Figure D.7 A-Scan of SWS-07 with 3.6 mm probe



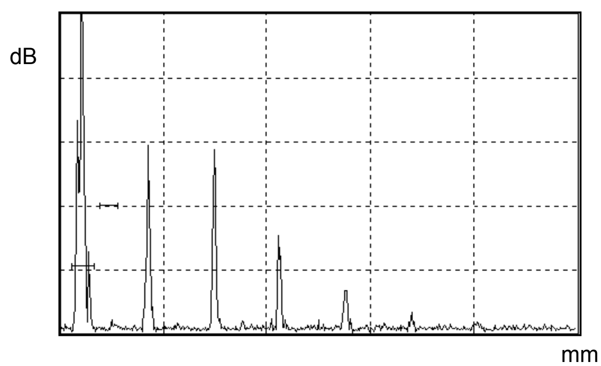
Group of spots:	SWS-3.6mm
Spot name:	SWS-08
Date:	13.04.2003
Time:	4:41:10 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.8 A-Scan of SWS-08 with 3.6 mm probe



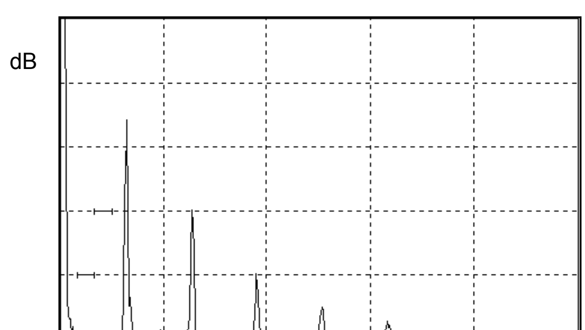
Group of spots:	SWS-3.6mm
Spot name:	SWS-09
Date:	13.04.2003
Time:	4:43:32 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	75 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.9 A-Scan of SWS-09 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-10
Date:	13.04.2003
Time:	4:48:38 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.10 A-Scan of SWS-10 with 3.6 mm probe

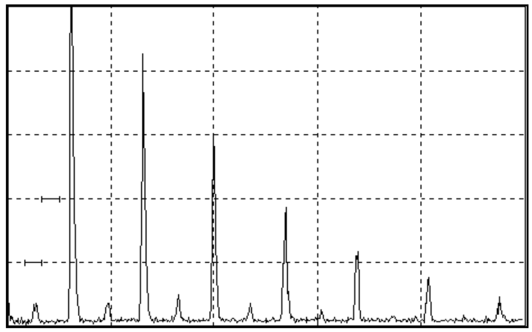


Group of spots:	SWS-3.6mm
Spot name:	SWS-11
Date:	13.04.2003
Time:	5:08:30 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	21 µs

Range: 30 mm

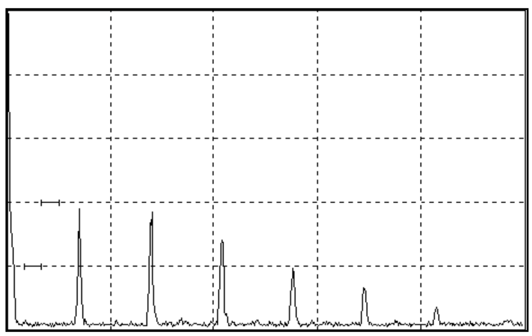
mm

Figure D.11 A-Scan of SWS-11 with 3.6 mm probe



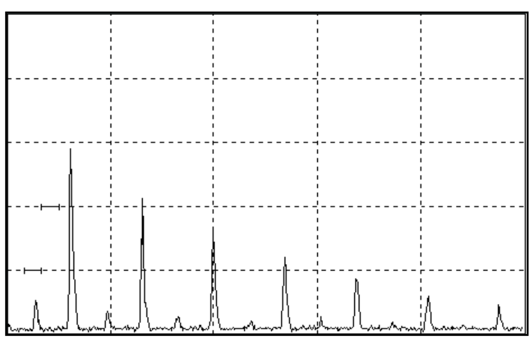
Group of spots:	SWS-3.6mm
Spot name:	SWS-12
Date:	13.04.2003
Time:	5:16:32 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.12 A-Scan of SWS-12 with 3.6 mm probe



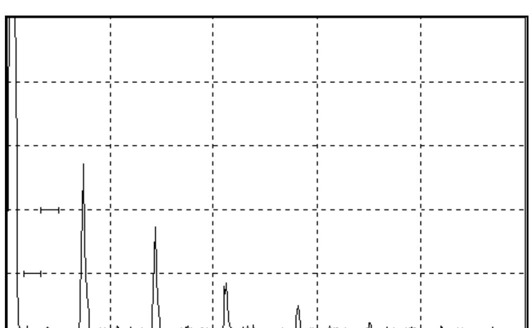
Group of spots:	SWS-3.6mm
Spot name:	SWS-13
Date:	13.04.2003
Time:	5:18:03 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.13 A-Scan of SWS-13 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-14
Date:	13.04.2003
Time:	5:20:16 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.14 A-Scan of SWS-14 with 3.6 mm probe

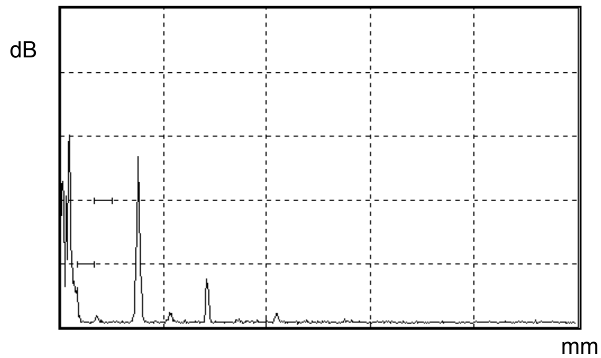


Group of spots:	SWS-3.6mm
Spot name:	SWS-15
Date:	13.04.2003
Time:	5:24:42 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	21 µs

Range:	30 mm

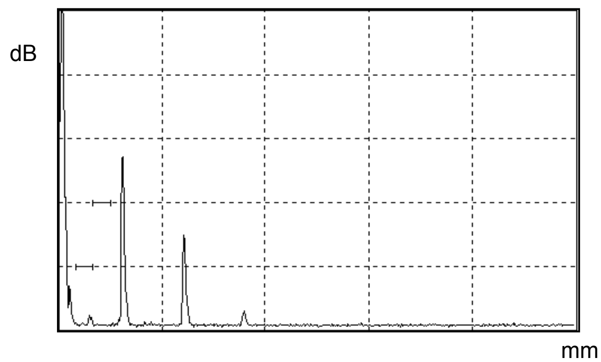
mm

Figure D.15 A-Scan of SWS-15 with 3.6 mm probe



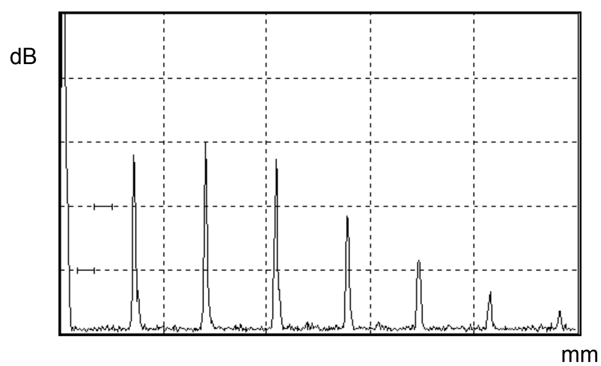
Group of spots:	SWS-3.6mm
Spot name:	SWS-16
Date:	13.04.2003
Time:	5:31:36 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.16 A-Scan of SWS-16 with 3.6 mm probe



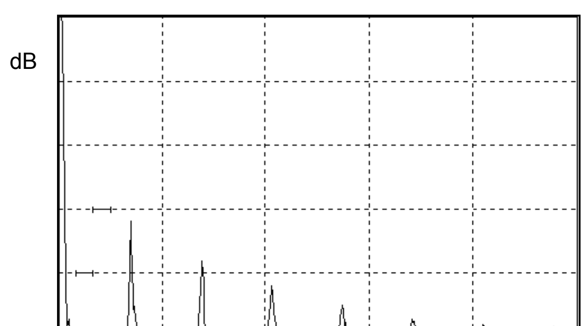
Group of spots:	SWS-3.6mm
Spot name:	SWS-17
Date:	13.04.2003
Time:	5:35:20 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,52 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.17 A-Scan of SWS-17 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-18
Date:	13.04.2003
Time:	5:40:08 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.18 A-Scan of SWS-18 with 3.6 mm probe

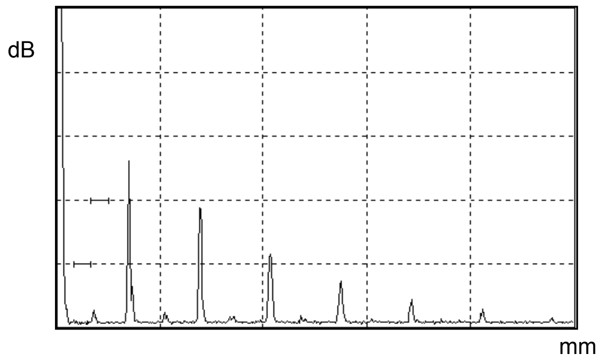


Group of spots:	SWS-3.6mm
Spot name:	SWS-19
Date:	13.04.2003
Time:	5:42:48 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	21 µs

Range:	30 mm

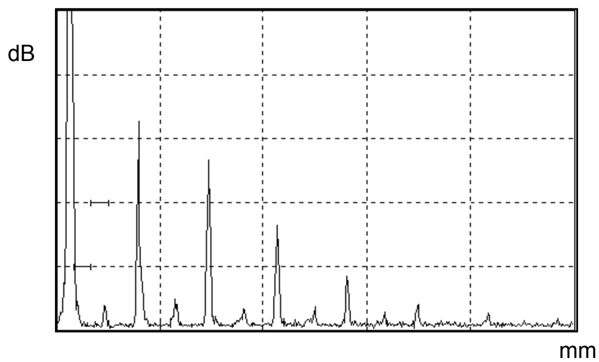
mm

Figure D.19 A-Scan of SWS-19 with 3.6 mm probe



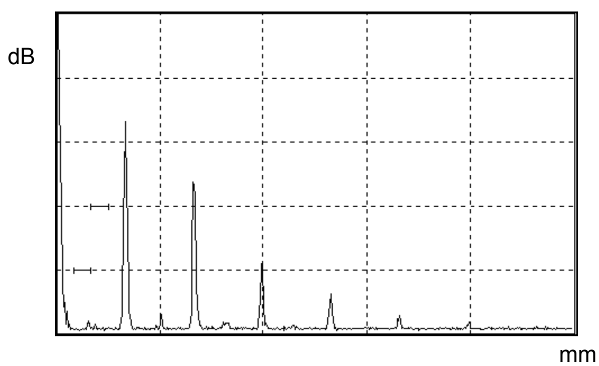
Group of spots:	SWS-3.6mm
Spot name:	SWS-20
Date:	13.04.2003
Time:	5:45:53 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.20 A-Scan of SWS-20 with 3.6 mm probe



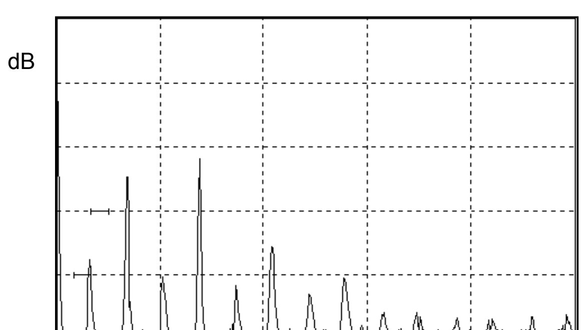
Group of spots:	SWS-3.6mm
Spot name:	SWS-21
Date:	13.04.2003
Time:	5:57:31 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.21 A-Scan of SWS-21 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-22
Date:	13.04.2003
Time:	6:01:18 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.22 A-Scan of SWS-22 with 3.6 mm probe

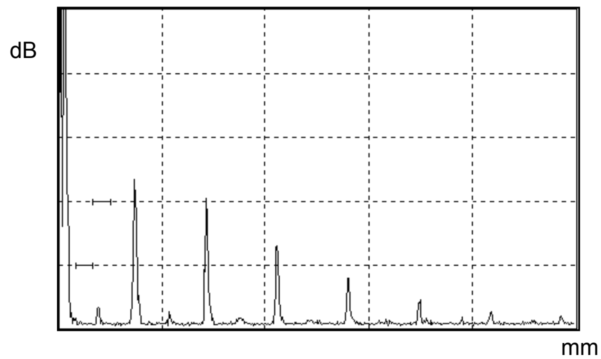


Group of spots:	SWS-3.6mm
Spot name:	SWS-23
Date:	13.04.2003
Time:	6:04:39 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	21 µs

Range:	30 mm

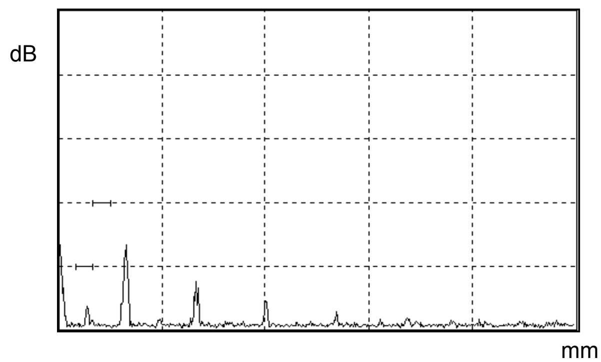
mm

Figure D.23 A-Scan of SWS-23 with 3.6 mm probe



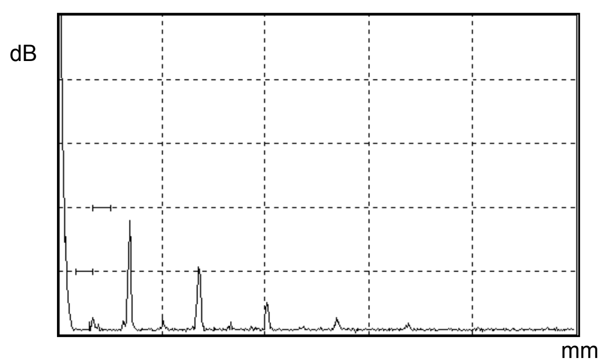
Group of spots:	SWS-3.6mm
Spot name:	SWS-24
Date:	13.04.2003
Time:	6:09:23 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.24 A-Scan of SWS-24 with 3.6 mm probe



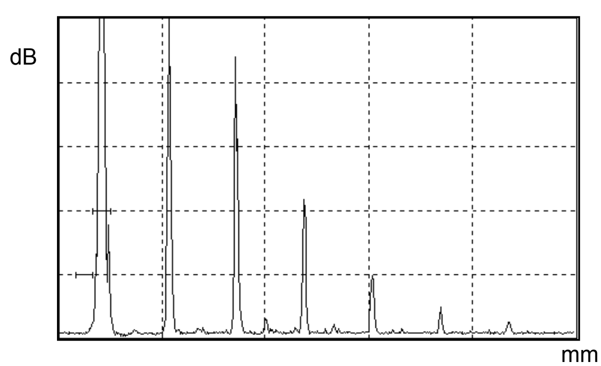
Group of spots:	SWS-3.6mm
Spot name:	SWS-25
Date:	13.04.2003
Time:	6:17:45 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.25 A-Scan of SWS-25 with 3.6 mm probe



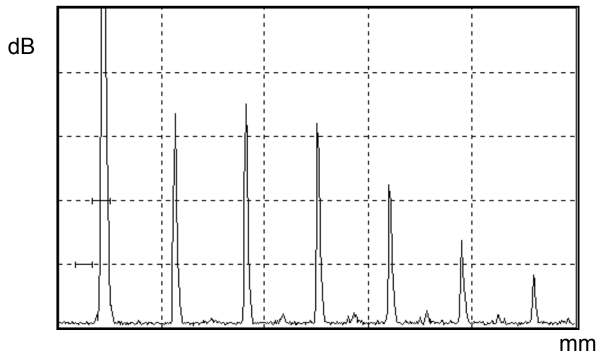
Group of spots:	SWS-3.6mm
Spot name:	SWS-26
Date:	13.04.2003
Time:	6:44:00 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	73 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.26 A-Scan of SWS-26 with 3.6 mm probe



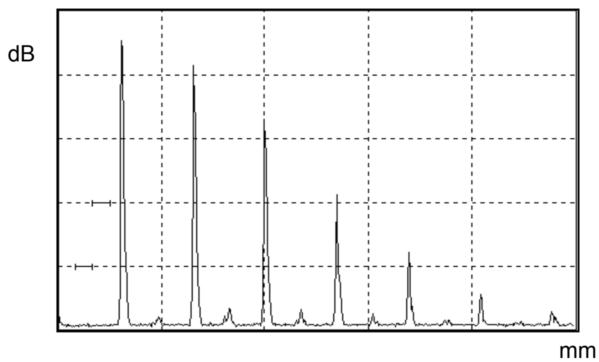
Group of spots:	SWS-3.6mm
Spot name:	SWS-27
Date:	13.04.2003
Time:	6:46:26 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	72 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.27 A-Scan of SWS-27 with 3.6 mm probe



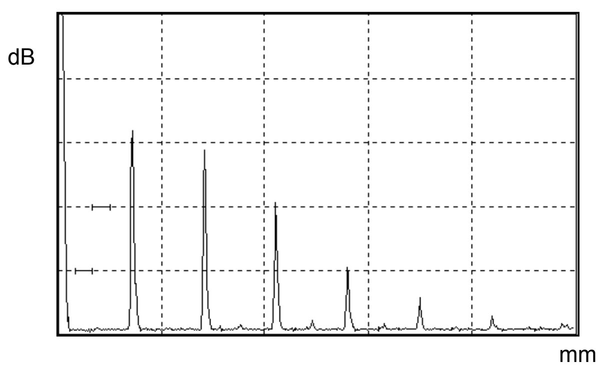
Group of spots:	SWS-3.6mm
Spot name:	SWS-28
Date:	13.04.2003
Time:	6:48:41 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	20 µs
Range:	30 mm

Figure D.28 A-Scan of SWS-28 with 3.6 mm probe



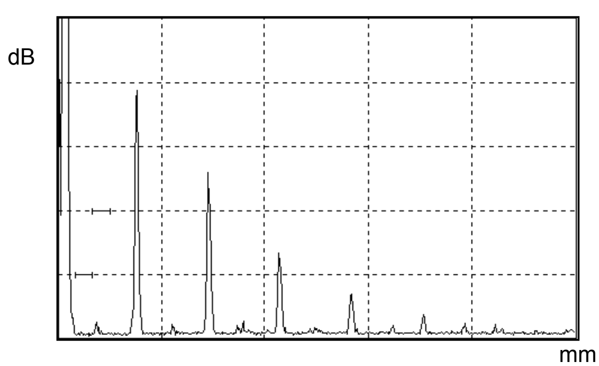
Group of spots:	SWS-3.6mm
Spot name:	SWS-29
Date:	13.04.2003
Time:	6:50:04 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.29 A-Scan of SWS-29 with 3.6 mm probe



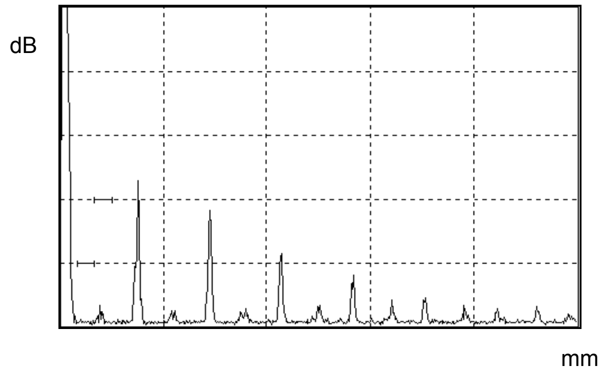
Group of spots:	SWS-3.6mm
Spot name:	SWS-30
Date:	13.04.2003
Time:	6:51:18 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	63 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.30 A-Scan of SWS-30 with 3.6 mm probe



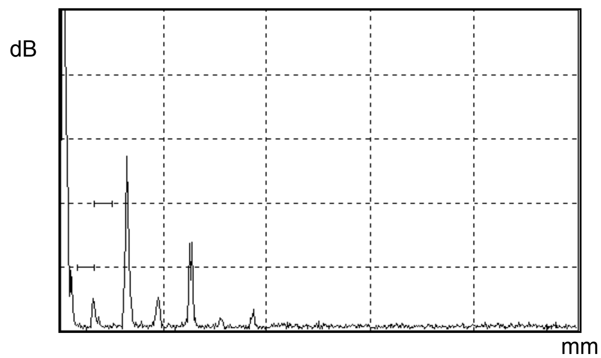
Group of spots:	SWS-3.6mm
Spot name:	SWS-31
Date:	13.04.2003
Time:	6:56:39 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.31 A-Scan of SWS-31 with 3.6 mm probe



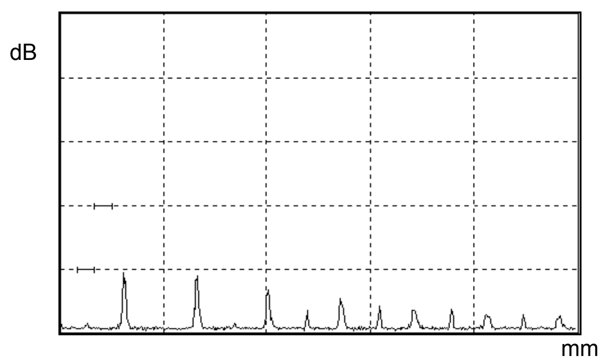
Group of spots:	SWS-3.6mm
Spot name:	SWS-32
Date:	13.04.2003
Time:	7:59:49 PM
Number of plates:	2
Result:	bad through-weld.
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.32 A-Scan of SWS-32 with 3.6 mm probe



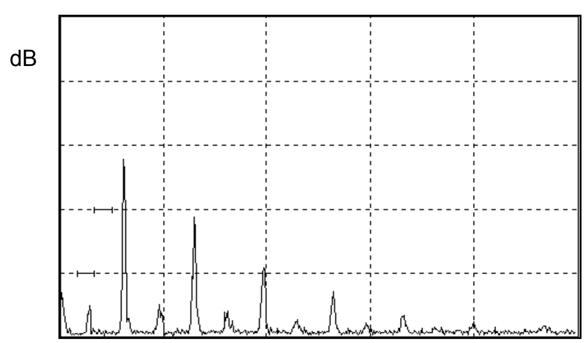
Group of spots:	SWS-3.6mm
Spot name:	SWS-33
Date:	13.04.2003
Time:	8:01:12 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.33 A-Scan of SWS-33 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-34
Date:	13.04.2003
Time:	8:03:43 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	21 µs
Range:	30 mm

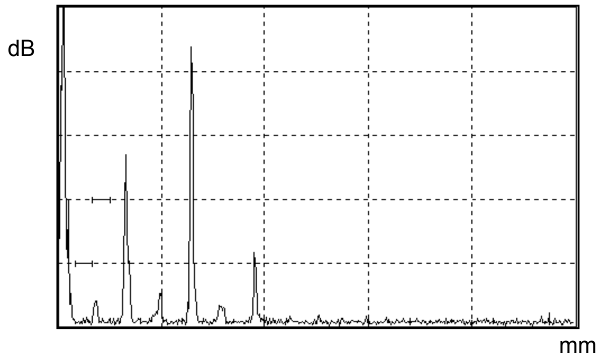
Figure D.34 A-Scan of SWS-34 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-35
Date:	13.04.2003
Time:	8:04:25 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

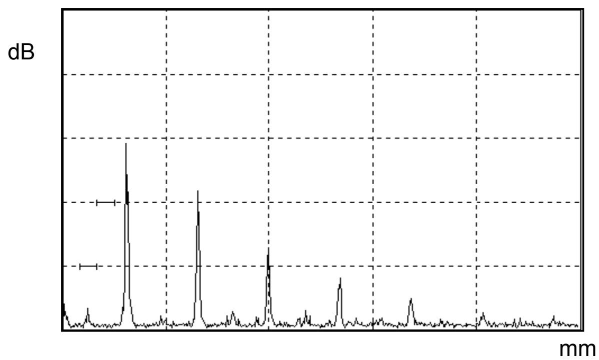
mm

Figure D.35 A-Scan of SWS-35 with 3.6 mm probe



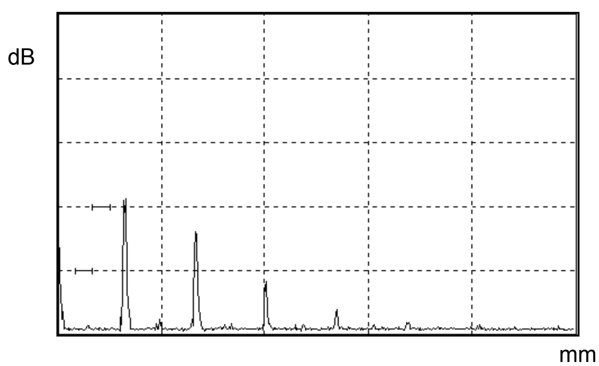
Group of spots:	SWS-3.6mm
Spot name:	SWS-36
Date:	13.04.2003
Time:	8:06:33 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	73 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.36 A-Scan of SWS-36 with 3.6 mm probe



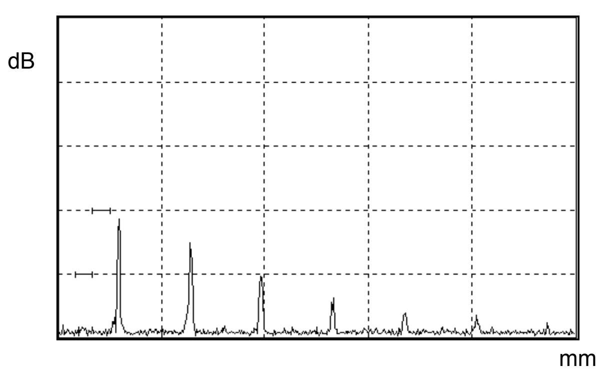
Group of spots:	SWS-3.6mm
Spot name:	SWS-37
Date:	13.04.2003
Time:	8:08:37 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	69 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.37 A-Scan of SWS-37 with 3.6 mm probe



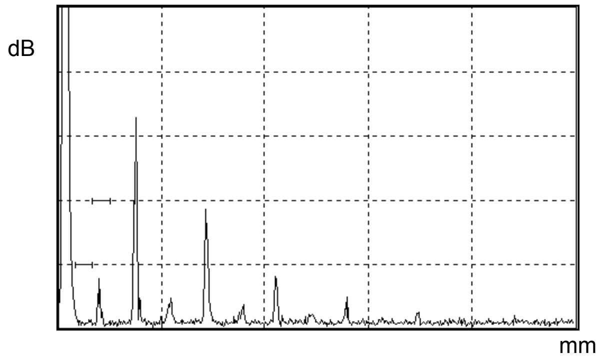
Group of spots:	SWS-3.6mm
Spot name:	SWS-38
Date:	13.04.2003
Time:	8:19:56 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.38 A-Scan of SWS-38 with 3.6 mm probe



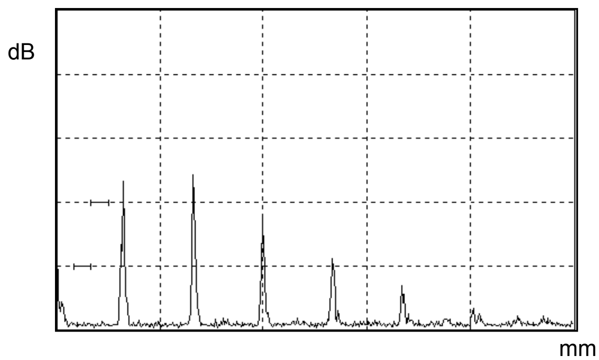
Group of spots:	SWS-3.6mm
Spot name:	SWS-39
Date:	13.04.2003
Time:	8:22:31 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.39 A-Scan of SWS-39 with 3.6 mm probe



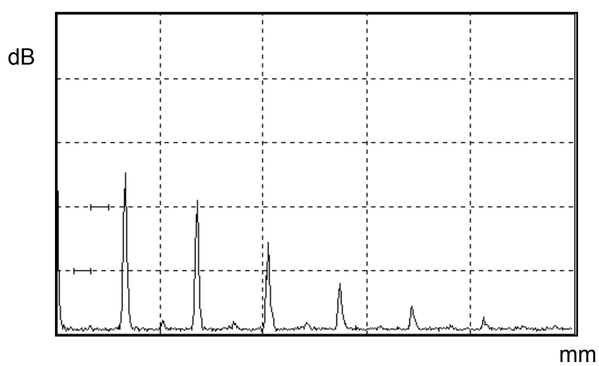
Group of spots:	SWS-3.6mm
Spot name:	SWS-40
Date:	13.04.2003
Time:	8:26:45 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	71 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.40 A-Scan of SWS-40 with 3.6 mm probe



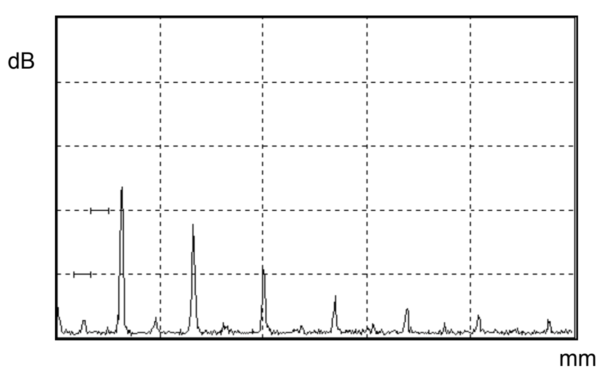
Group of spots:	SWS-3.6mm
Spot name:	SWS-41
Date:	13.04.2003
Time:	8:29:13 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.41 A-Scan of SWS-41 with 3.6 mm probe



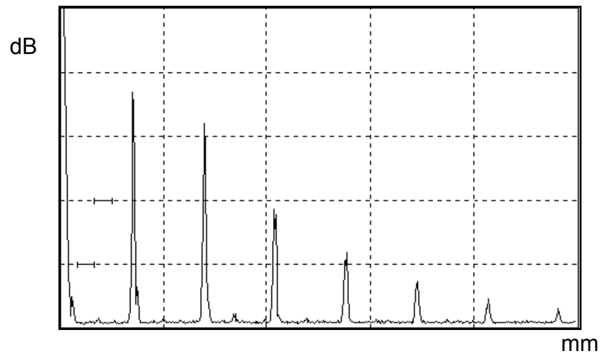
Group of spots:	SWS-3.6mm
Spot name:	SWS-42
Date:	13.04.2003
Time:	8:31:45 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.42 A-Scan of SWS-42 with 3.6 mm probe



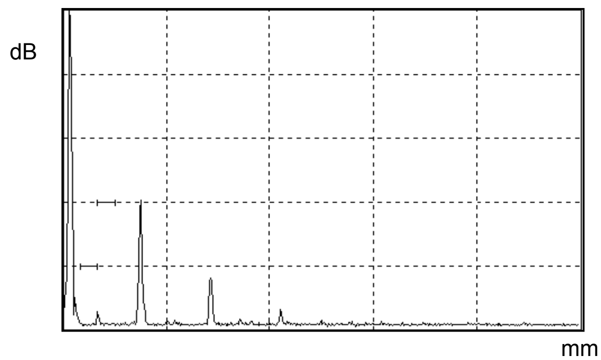
Group of spots:	SWS-3.6mm
Spot name:	SWS-43
Date:	13.04.2003
Time:	8:32:46 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.43 A-Scan of SWS-43 with 3.6 mm probe



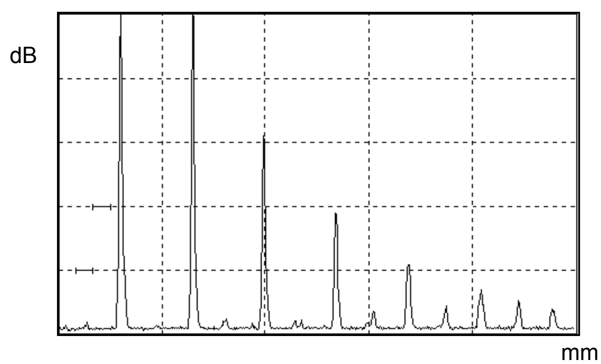
Group of spots:	SWS-3.6mm
Spot name:	SWS-44
Date:	13.04.2003
Time:	8:35:40 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.44 A-Scan of SWS-44 with 3.6 mm probe



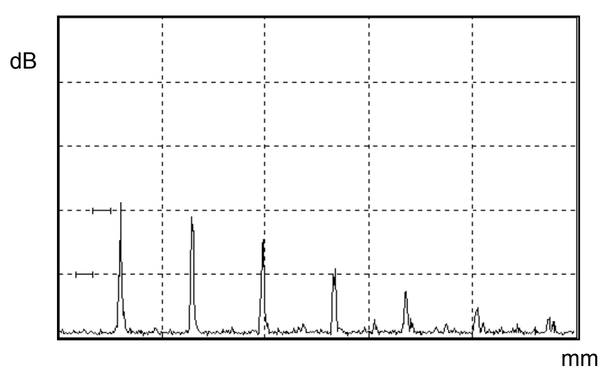
Group of spots:	SWS-3.6mm
Spot name:	SWS-45
Date:	13.04.2003
Time:	8:39:50 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.45 A-Scan of SWS-45 with 3.6 mm probe



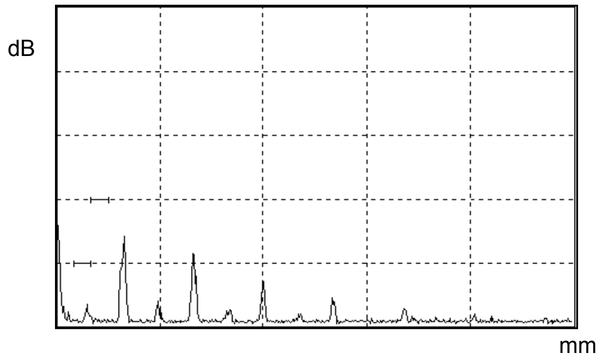
Group of spots:	SWS-3.6mm
Spot name:	SWS-46
Date:	13.04.2003
Time:	8:40:38 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.46 A-Scan of SWS-46 with 3.6 mm probe



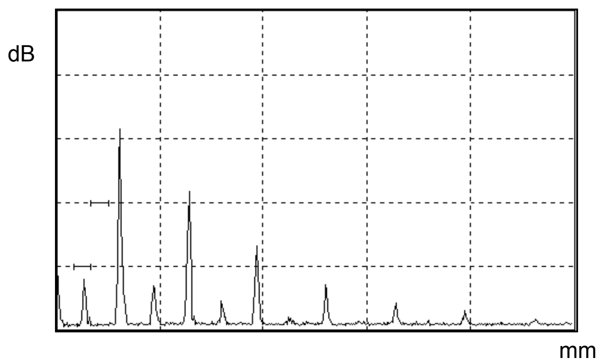
Group of spots:	SWS-3.6mm
Spot name:	SWS-47
Date:	13.04.2003
Time:	8:42:50 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.47 A-Scan of SWS-47 with 3.6 mm probe



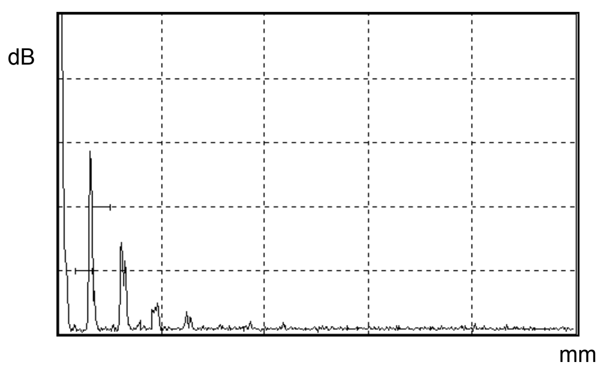
Group of spots:	SWS-3.6mm
Spot name:	SWS-48
Date:	13.04.2003
Time:	8:43:59 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	70 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.48 A-Scan of SWS-48 with 3.6 mm probe



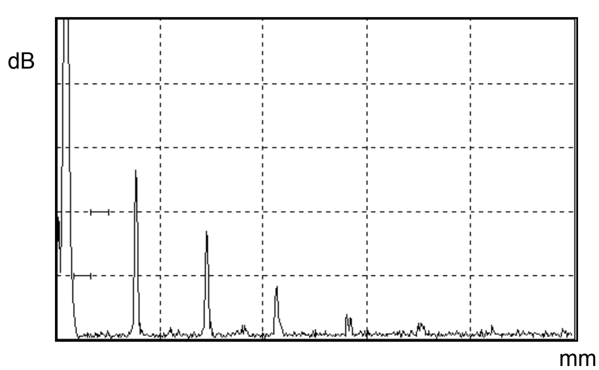
Group of spots:	SWS-3.6mm
Spot name:	SWS-49
Date:	13.04.2003
Time:	8:45:14 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	72 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.49 A-Scan of SWS-49 with 3.6 mm probe



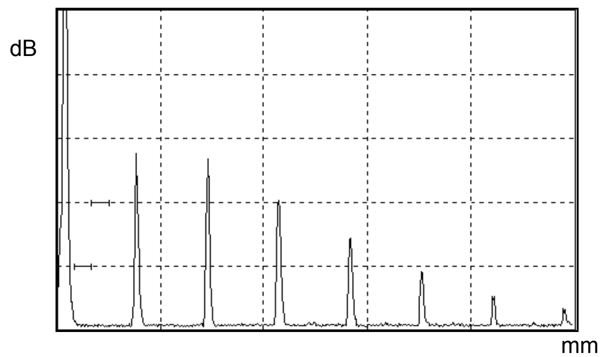
Group of spots:	SWS-3.6mm
Spot name:	SWS-50
Date:	13.04.2003
Time:	8:48:06 PM
Number of plates:	2
Result:	loose
Plate thickness:	1,82 mm
Sound velocity:	5920 m/s
Gain:	72 dB
Probe delay:	21 µs
Range:	30 mm

Figure D.50 A-Scan of SWS-50 with 3.6 mm probe



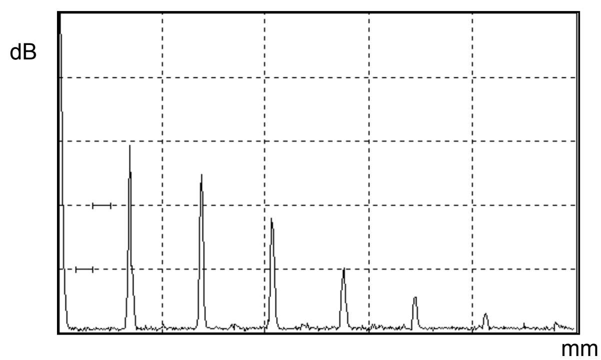
Group of spots:	SWS-3.6mm
Spot name:	SWS-51
Date:	29.05.2003
Time:	2:28:55 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.51 A-Scan of SWS-51 with 3.6 mm probe



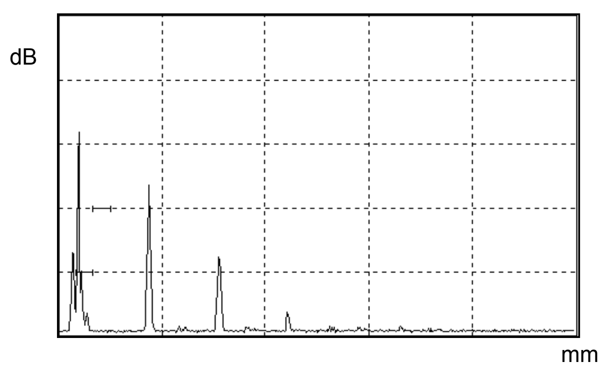
Group of spots:	SWS-3.6mm
Spot name:	SWS-52
Date:	29.05.2003
Time:	2:33:09 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.52 A-Scan of SWS-52 with 3.6 mm probe



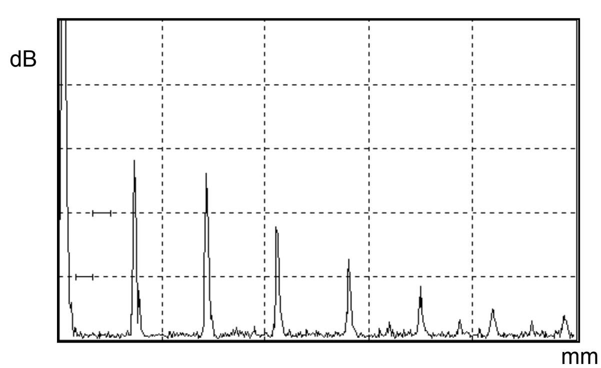
Group of spots:	SWS-3.6mm
Spot name:	SWS-53
Date:	29.05.2003
Time:	2:36:20 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.53 A-Scan of SWS-53 with 3.6 mm probe



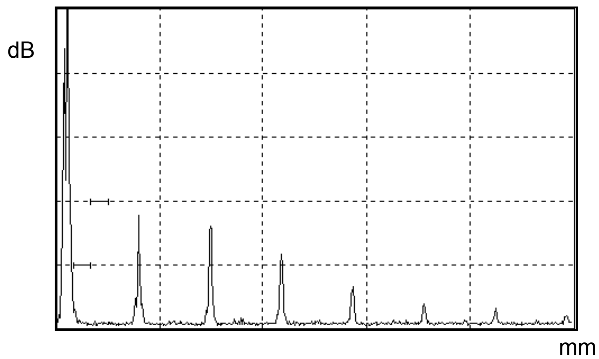
Group of spots:	SWS-3.6mm
Spot name:	SWS-54
Date:	29.05.2003
Time:	2:43:49 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.54 A-Scan of SWS-54 with 3.6 mm probe



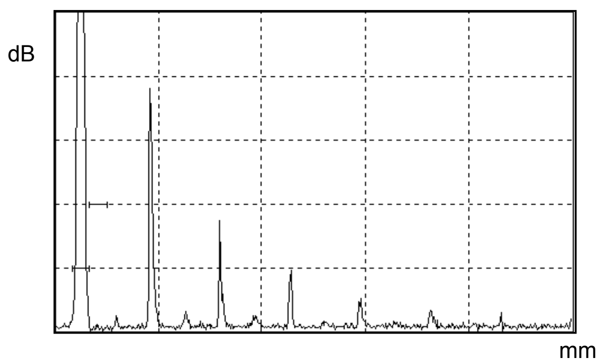
Group of spots:	SWS-3.6mm
Spot name:	SWS-55
Date:	29.05.2003
Time:	2:45:56 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.55 A-Scan of SWS-55 with 3.6 mm probe



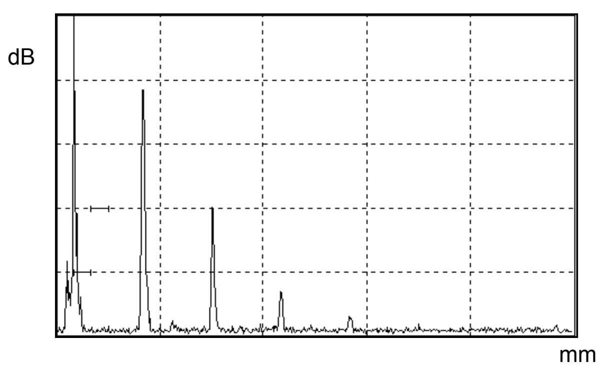
Group of spots:	SWS-3.6mm
Spot name:	SWS-56
Date:	29.05.2003
Time:	2:49:29 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.56 A-Scan of SWS-56 with 3.6 mm probe



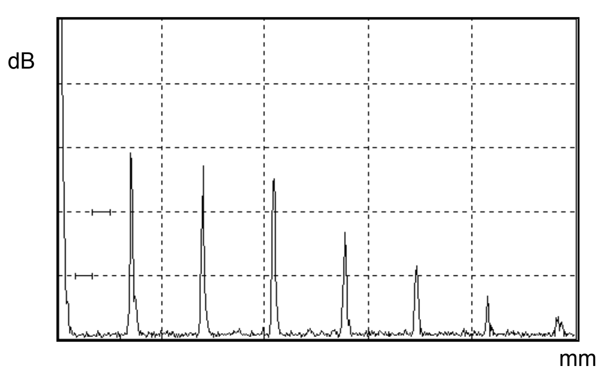
Group of spots:	SWS-3.6mm
Spot name:	SWS-57
Date:	29.05.2003
Time:	2:50:56 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.57 A-Scan of SWS-57 with 3.6 mm probe



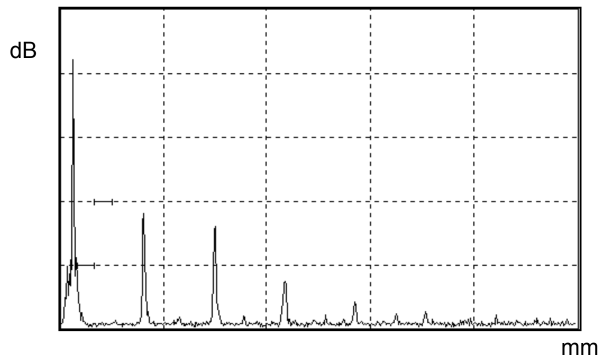
Group of spots:	SWS-3.6mm
Spot name:	SWS-58
Date:	29.05.2003
Time:	2:53:43 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	72 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.58 A-Scan of SWS-58 with 3.6 mm probe



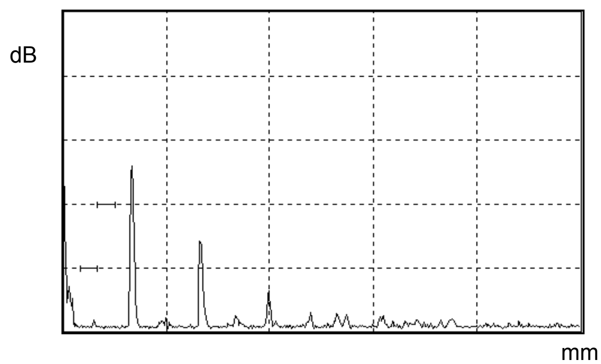
Group of spots:	SWS-3.6mm
Spot name:	SWS-59
Date:	29.05.2003
Time:	2:56:54 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.59 A-Scan of SWS-59 with 3.6 mm probe



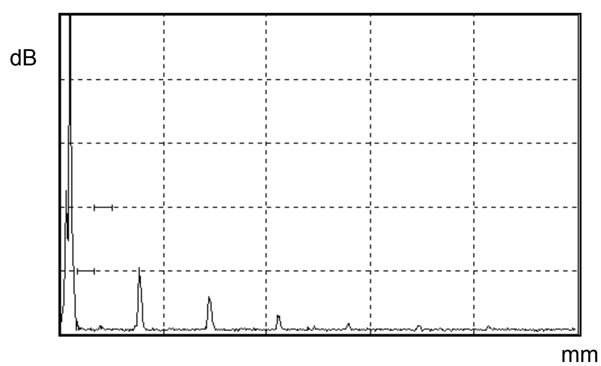
Group of spots:	SWS-3.6mm
Spot name:	SWS-60
Date:	29.05.2003
Time:	2:58:41 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.60 A-Scan of SWS-60 with 3.6 mm probe



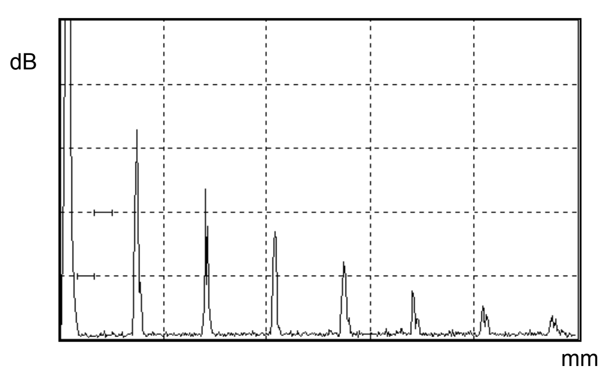
Group of spots:	SWS-3.6mm
Spot name:	SWS-61
Date:	29.05.2003
Time:	3:15:25 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	68 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.61 A-Scan of SWS-61 with 3.6 mm probe



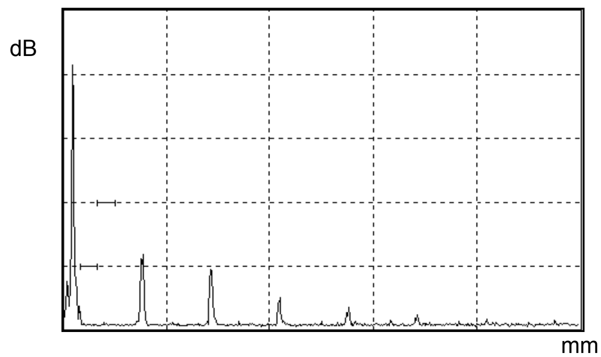
Group of spots:	SWS-3.6mm
Spot name:	SWS-62
Date:	29.05.2003
Time:	3:19:04 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.62 A-Scan of SWS-627 with 3.6 mm probe



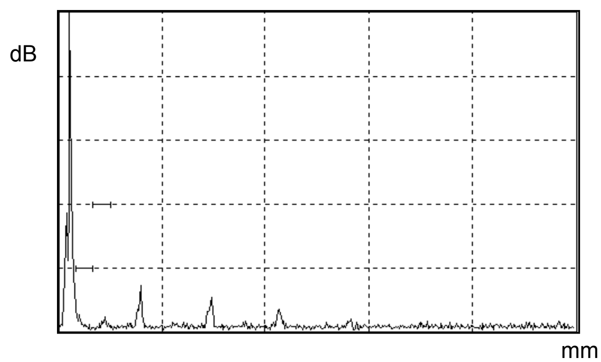
Group of spots:	SWS-3.6mm
Spot name:	SWS-63
Date:	29.05.2003
Time:	3:19:56 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.63 A-Scan of SWS-63 with 3.6 mm probe



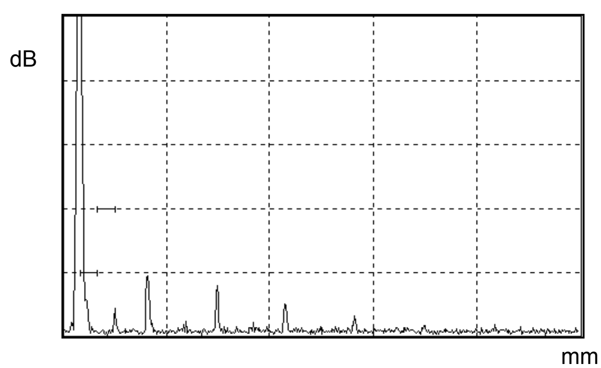
Group of spots:	SWS-3.6mm
Spot name:	SWS-64
Date:	29.05.2003
Time:	3:20:37 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.64 A-Scan of SWS-64 with 3.6 mm probe



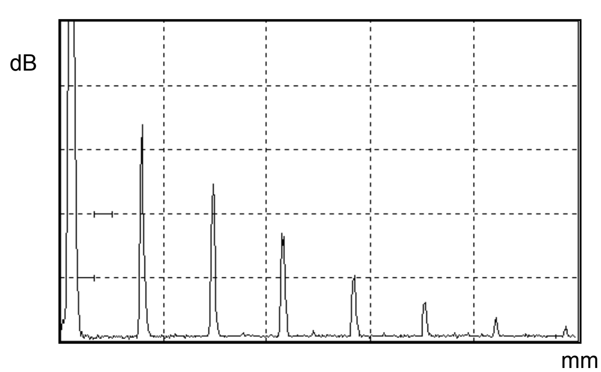
Group of spots:	SWS-3.6mm
Spot name:	SWS-65
Date:	29.05.2003
Time:	3:21:45 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.65 A-Scan of SWS-65 with 3.6 mm probe



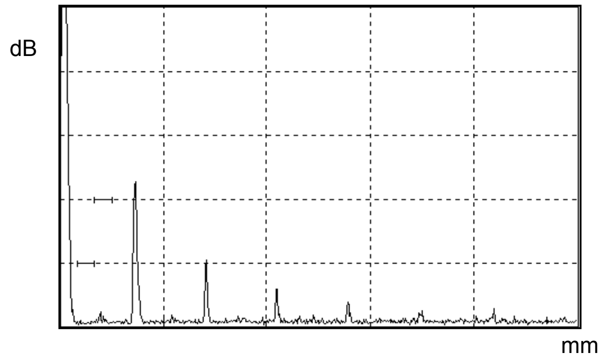
Group of spots:	SWS-3.6mm
Spot name:	SWS-66
Date:	29.05.2003
Time:	3:22:52 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.66 A-Scan of SWS-66 with 3.6 mm probe



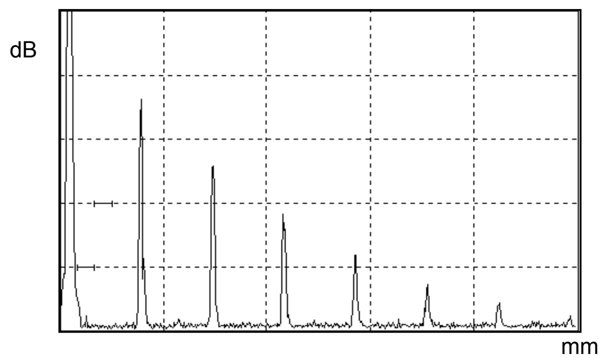
Group of spots:	SWS-3.6mm
Spot name:	SWS-67
Date:	29.05.2003
Time:	3:24:23 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.67 A-Scan of SWS-67 with 3.6 mm probe



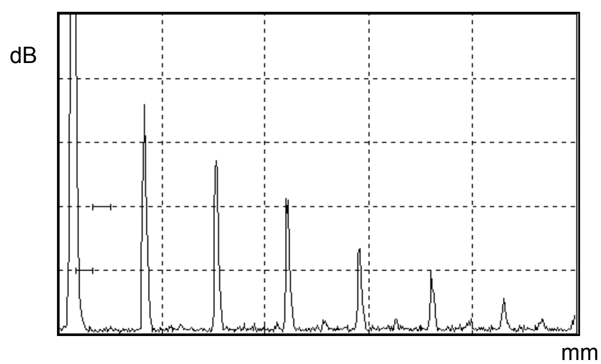
Group of spots:	SWS-3.6mm
Spot name:	SWS-68
Date:	29.05.2003
Time:	3:25:34 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.68 A-Scan of SWS-68 with 3.6 mm probe



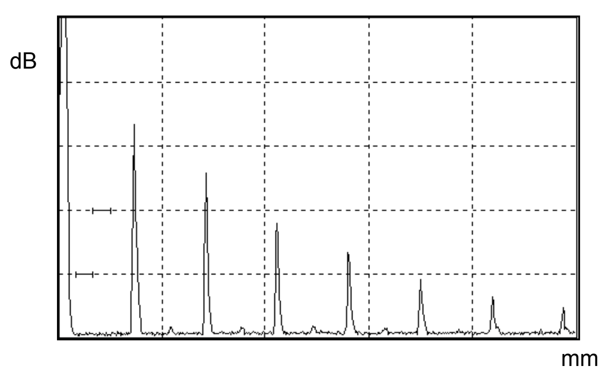
Group of spots:	SWS-3.6mm
Spot name:	SWS-69
Date:	29.05.2003
Time:	3:26:29 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.69 A-Scan of SWS-69 with 3.6 mm probe



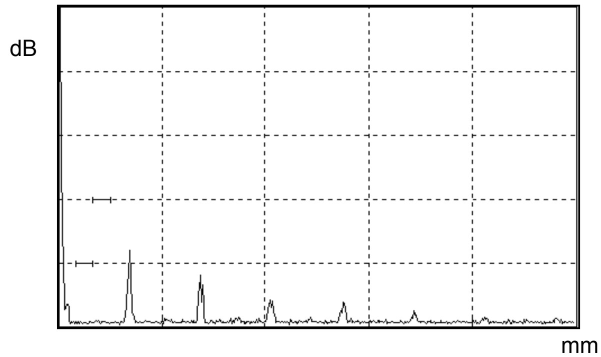
Group of spots:	SWS-3.6mm
Spot name:	SWS-70
Date:	29.05.2003
Time:	3:50:53 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.70 A-Scan of SWS-70 with 3.6 mm probe



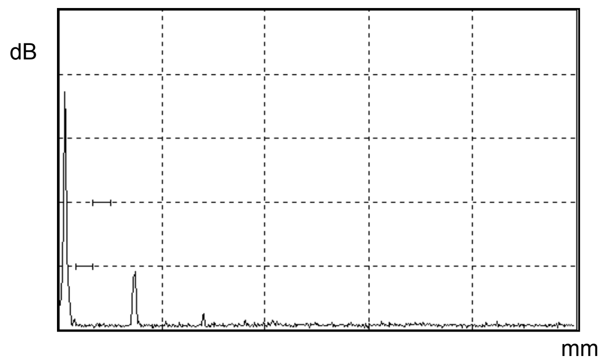
Group of spots:	SWS-3.6mm
Spot name:	SWS-71
Date:	29.05.2003
Time:	3:54:33 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.71 A-Scan of SWS-71 with 3.6 mm probe



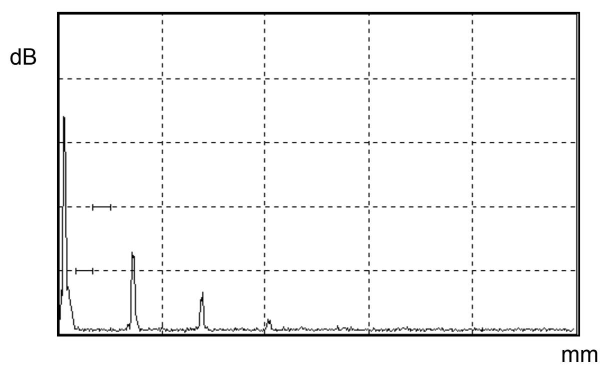
Group of spots:	SWS-3.6mm
Spot name:	SWS-72
Date:	29.05.2003
Time:	3:56:22 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.72 A-Scan of SWS-72 with 3.6 mm probe



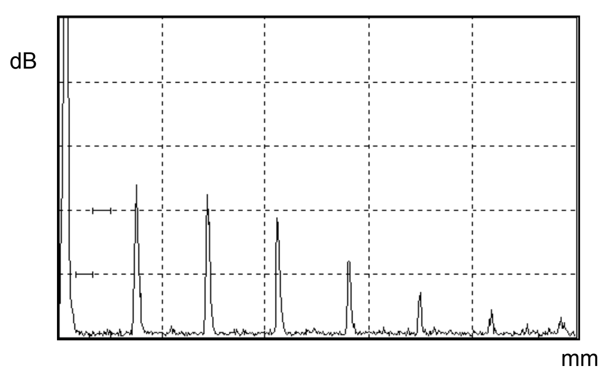
Group of spots:	SWS-3.6mm
Spot name:	SWS-73
Date:	29.05.2003
Time:	3:57:25 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.73 A-Scan of SWS-73 with 3.6 mm probe



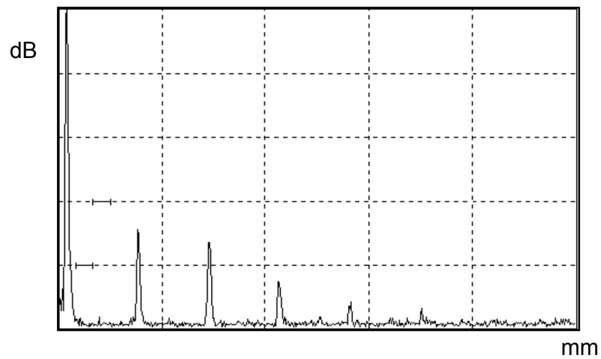
Group of spots:	SWS-3.6mm
Spot name:	SWS-74
Date:	29.05.2003
Time:	3:58:31 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	67 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.74 A-Scan of SWS-74 with 3.6 mm probe



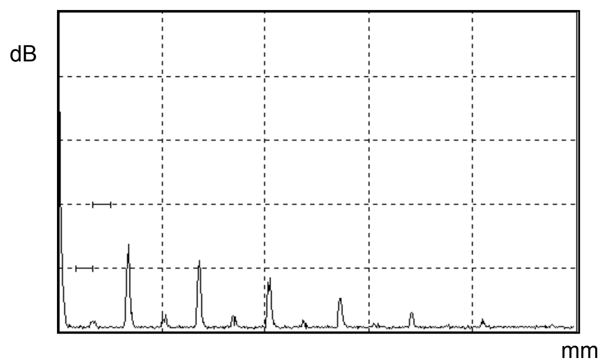
Group of spots:	SWS-3.6mm
Spot name:	SWS-75
Date:	29.05.2003
Time:	3:59:49 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.75 A-Scan of SWS-75 with 3.6 mm probe



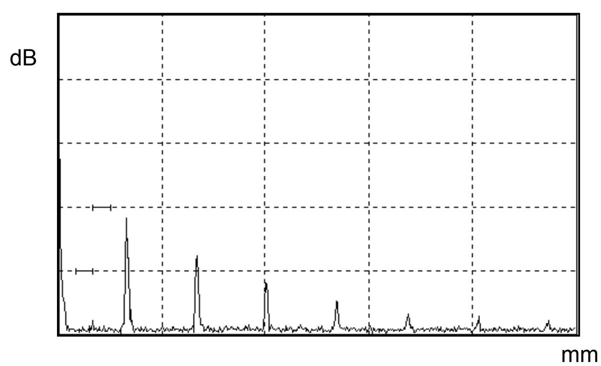
Group of spots:	SWS-3.6mm
Spot name:	SWS-76
Date:	29.05.2003
Time:	4:00:33 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.76 A-Scan of SWS-76 with 3.6 mm probe



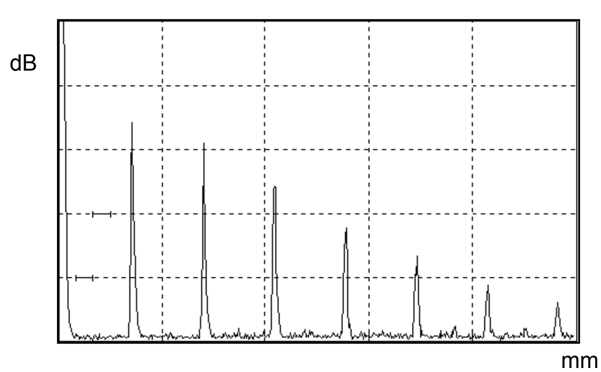
Group of spots:	SWS-3.6mm
Spot name:	SWS-77
Date:	29.05.2003
Time:	4:01:44 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.77 A-Scan of SWS-77 with 3.6 mm probe



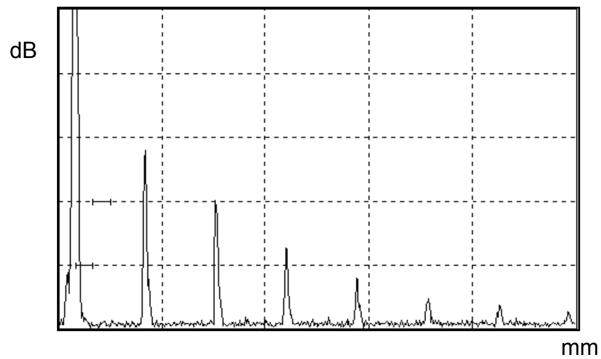
Group of spots:	SWS-3.6mm
Spot name:	SWS-78
Date:	29.05.2003
Time:	4:02:25 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.78 A-Scan of SWS-78 with 3.6 mm probe



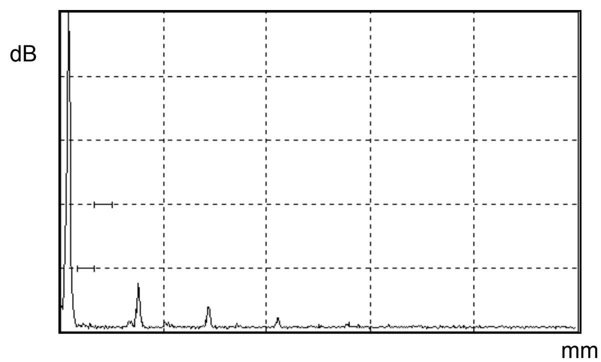
Group of spots:	SWS-3.6mm
Spot name:	SWS-79
Date:	29.05.2003
Time:	4:03:17 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.79 A-Scan of SWS-79 with 3.6 mm probe



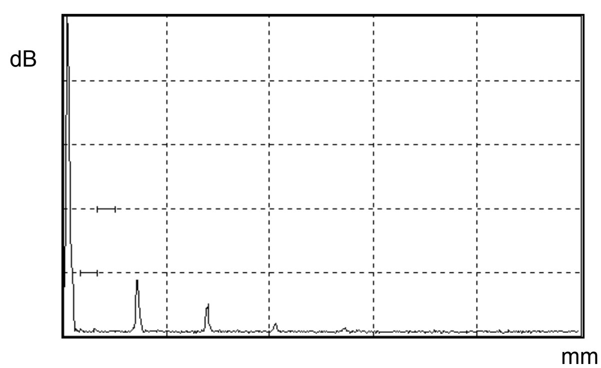
Group of spots:	SWS-3.6mm
Spot name:	SWS-80
Date:	29.05.2003
Time:	4:04:13 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.80 A-Scan of SWS-80 with 3.6 mm probe



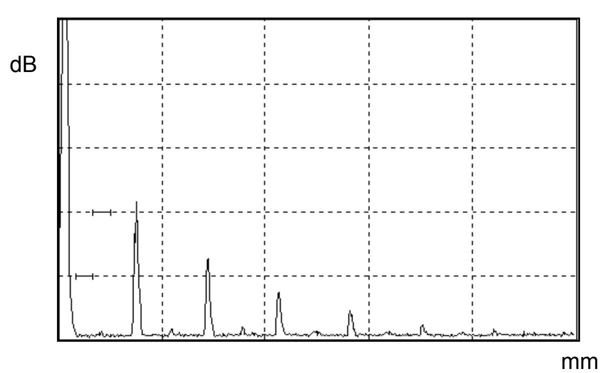
Group of spots:	SWS-3.6mm
Spot name:	SWS-81
Date:	29.05.2003
Time:	4:05:21 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.81 A-Scan of SWS-81 with 3.6 mm probe



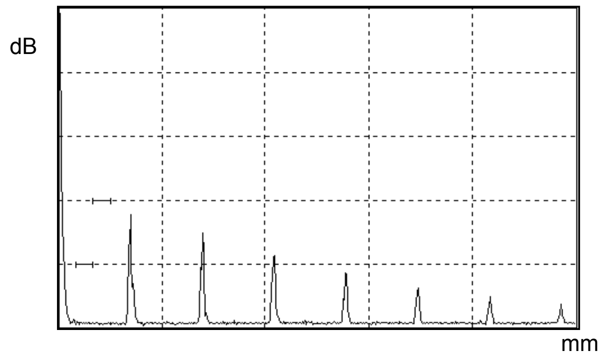
Group of spots:	SWS-3.6mm
Spot name:	SWS-82
Date:	29.05.2003
Time:	4:06:02 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.82 A-Scan of SWS-82 with 3.6 mm probe



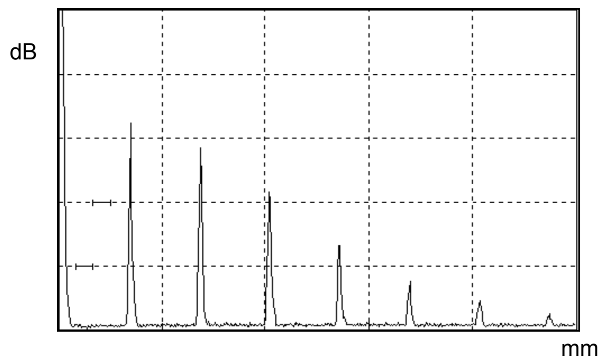
Group of spots:	SWS-3.6mm
Spot name:	SWS-83
Date:	29.05.2003
Time:	4:06:48 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.83 A-Scan of SWS-83 with 3.6 mm probe



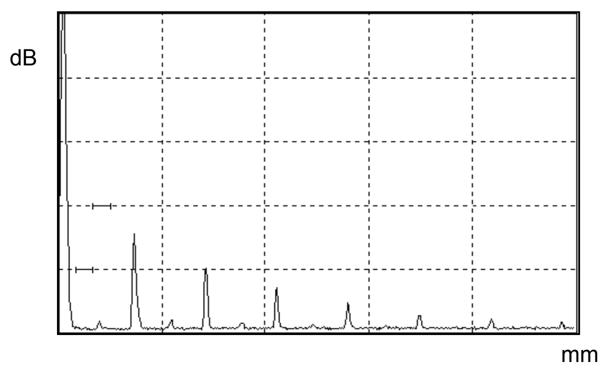
Group of spots:	SWS-3.6mm
Spot name:	SWS-84
Date:	29.05.2003
Time:	4:07:44 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	66 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.84 A-Scan of SWS-84 with 3.6 mm probe



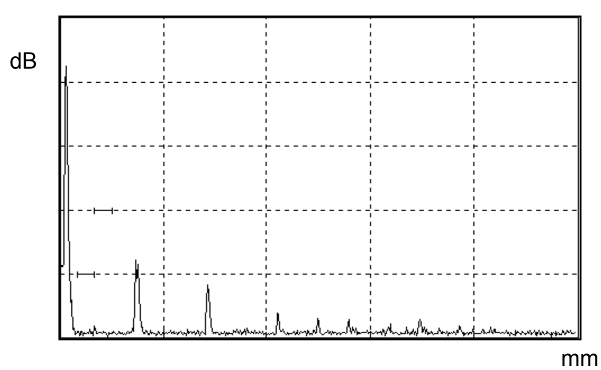
Group of spots:	SWS-3.6mm
Spot name:	SWS-85
Date:	29.05.2003
Time:	4:08:19 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.85 A-Scan of SWS-85 with 3.6 mm probe



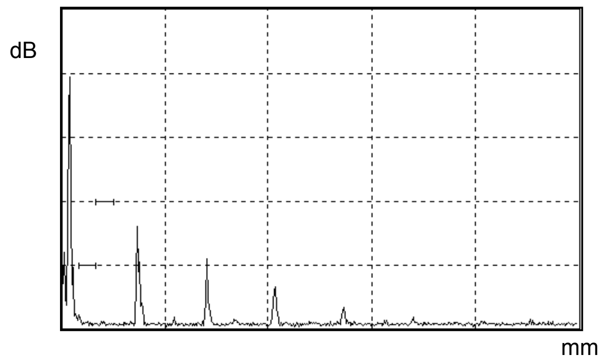
Group of spots:	SWS-3.6mm
Spot name:	SWS-86
Date:	29.05.2003
Time:	4:09:04 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.86 A-Scan of SWS-86 with 3.6 mm probe



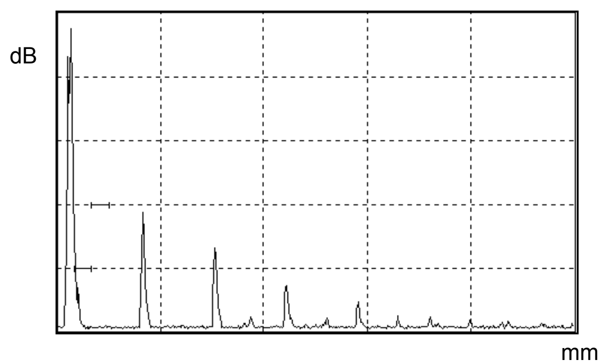
Group of spots:	SWS-3.6mm
Spot name:	SWS-87
Date:	29.05.2003
Time:	4:10:37 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.87 A-Scan of SWS-87 with 3.6 mm probe



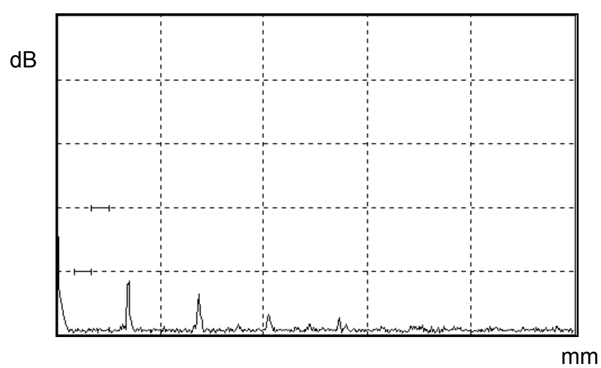
Group of spots:	SWS-3.6mm
Spot name:	SWS-88
Date:	29.05.2003
Time:	4:11:22 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.88 A-Scan of SWS-88 with 3.6 mm probe



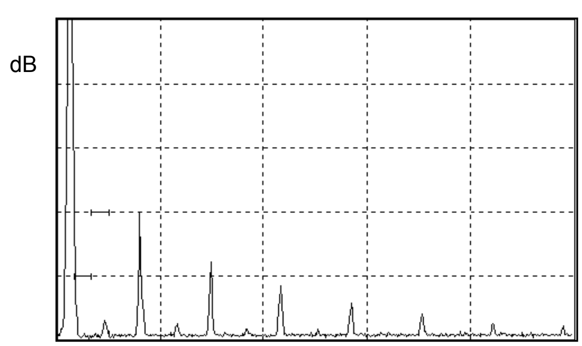
Group of spots:	SWS-3.6mm
Spot name:	SWS-89
Date:	29.05.2003
Time:	4:12:41 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.89 A-Scan of SWS-89 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-90
Date:	29.05.2003
Time:	4:13:27 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

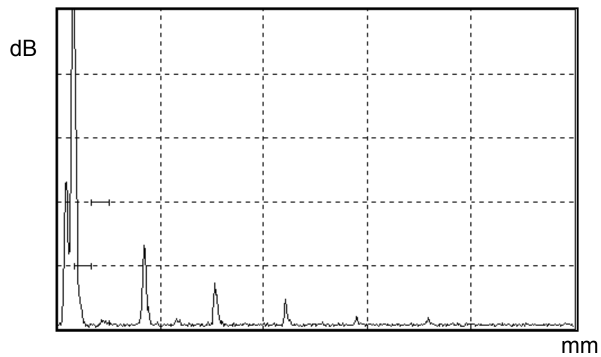
Figure D.90 A-Scan of SWS-90 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-91
Date:	29.05.2003
Time:	4:16:24 PM
Number of plates:	2
Result:	bad through-weld.
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

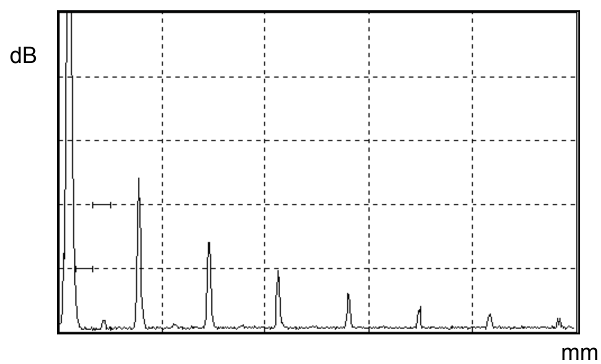
mm

Figure D.91 A-Scan of SWS-91 with 3.6 mm probe



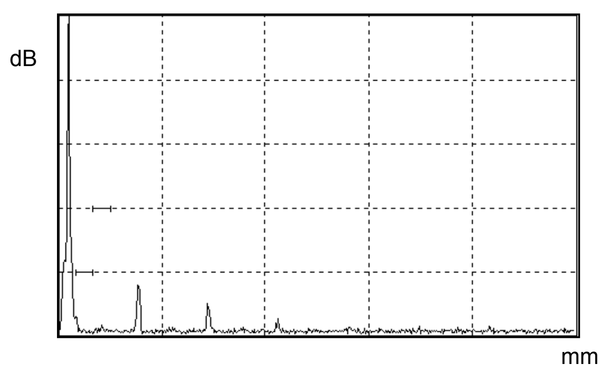
Group of spots:	SWS-3.6mm
Spot name:	SWS-92
Date:	29.05.2003
Time:	4:17:22 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.92 A-Scan of SWS-92 with 3.6 mm probe



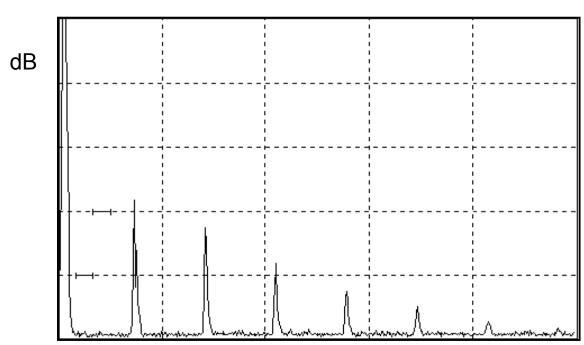
Group of spots:	SWS-3.6mm
Spot name:	SWS-93
Date:	29.05.2003
Time:	4:18:55 PM
Number of plates:	2
Result:	bad through
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.93 A-Scan of SWS-93 with 3.6 mm probe



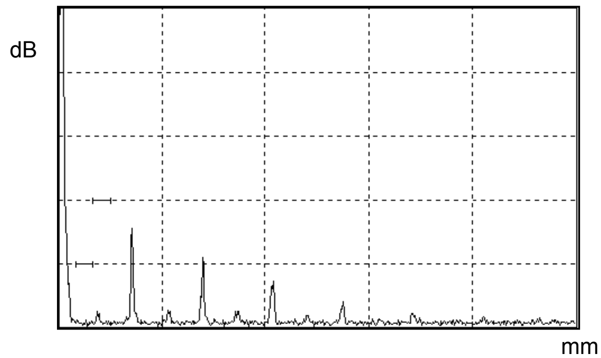
Group of spots:	SWS-3.6mm
Spot name:	SWS-94
Date:	29.05.2003
Time:	4:20:04 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.94 A-Scan of SWS-94 with 3.6 mm probe



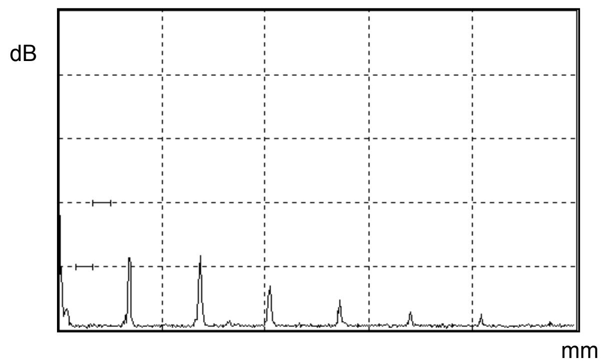
Group of spots:	SWS-3.6mm
Spot name:	SWS-95
Date:	29.05.2003
Time:	4:20:33 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	64 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.95 A-Scan of SWS-95 with 3.6 mm probe



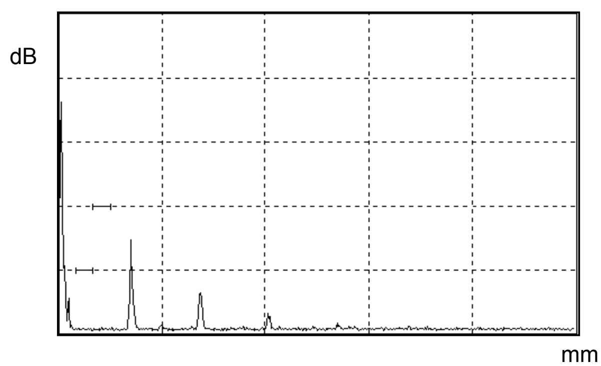
Group of spots:	SWS-3.6mm
Spot name:	SWS-96
Date:	29.05.2003
Time:	4:21:22 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.96 A-Scan of SWS-96 with 3.6 mm probe



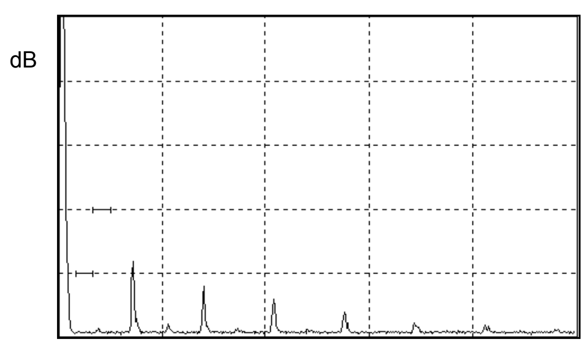
Group of spots:	SWS-3.6mm
Spot name:	SWS-97
Date:	29.05.2003
Time:	4:22:43 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.97 A-Scan of SWS-97 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-98
Date:	29.05.2003
Time:	4:23:21 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	65 dB
Probe delay:	19 µs
Range:	30 mm

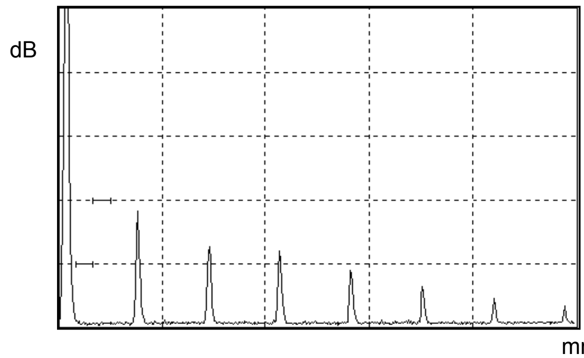
Figure D.98 A-Scan of SWS-98 with 3.6 mm probe



Group of spots:	SWS-3.6mm
Spot name:	SWS-99
Date:	29.05.2003
Time:	4:25:03 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	63 dB
Probe delay:	19 µs
Range:	30 mm

mm

Figure D.99 A-Scan of SWS-99 with 3.6 mm probe



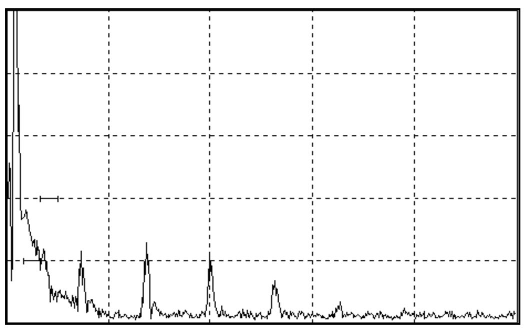
Group of spots:	SWS-3.6mm
Spot name:	SWS-100
Date:	29.05.2003
Time:	4:26:28 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	62 dB
Probe delay:	19 µs
Range:	30 mm

Figure D.100 A-Scan of SWS-100 with 3.6 mm probe

APPENDIX E

Inspection Plan :	SWS-8mm		Inspector:	Okan Okay KOÇAK	
Probe name:	SW PROBE		Probe number:	G15MN	
Probe diameter:	8.0	mm	Probe frequency:	15	MHz
Evaluation Threshold:	10	%	Tolerance of electrode mark:	10	%
Plate Thickness 1:	2		Sofware Version:	Ultralog Version 2.1	
Plate Thickness 2:	2	mm	Surface:	Without coating	

dB

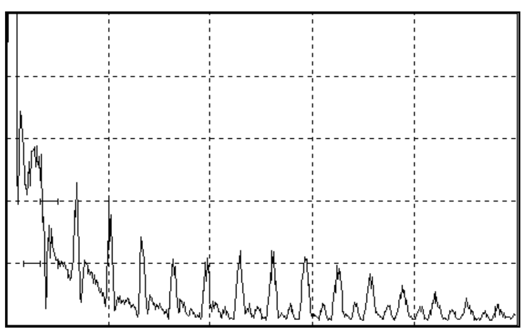


mm

Group of spots:	SWS-8mm
Spot name:	SWS-01
Date:	25.04.2003
Time:	10:32:44 AM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.1 A-Scan of SWS-01 with 8.0 mm probe

dB

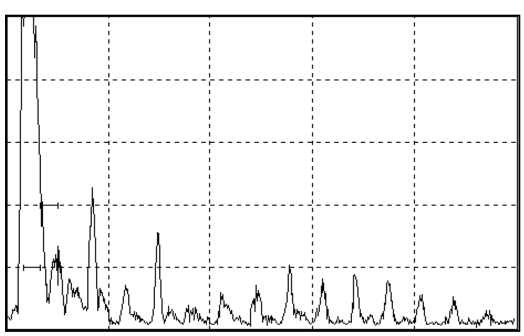


mm

Group of spots:	SWS-8mm
Spot name:	SWS-02
Date:	25.04.2003
Time:	10:34:03 AM
Number of plates:	2
Result:	loose
Plate thickness:	1,92 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.2 A-Scan of SWS-02 with 8.0 mm probe

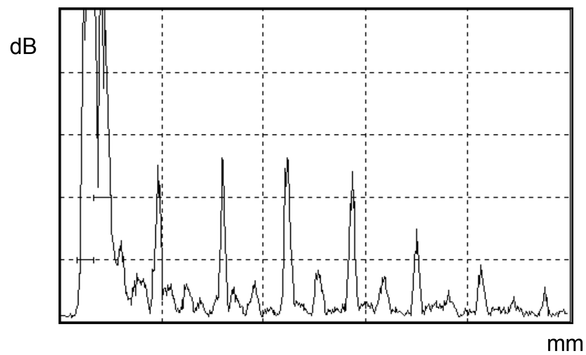
dB



Group of spots:	SWS-8mm
Spot name:	SWS-03
Date:	25.04.2003
Time:	10:39:36 AM
Number of plates:	2
Result:	stick weld
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	47 dB
Probe delay:	20 µs
Range:	30 mm

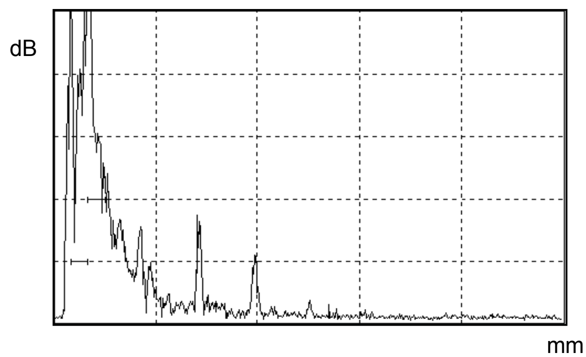
mm

Figure E.3 A-Scan of SWS-03 with 8.0 mm probe



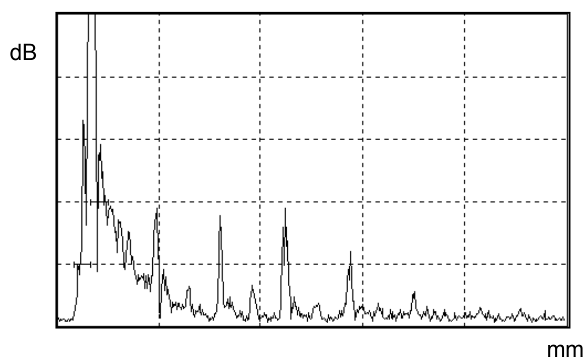
Group of spots:	SWS-8mm
Spot name:	SWS-04
Date:	25.04.2003
Time:	10:43:25 AM
Number of plates:	2
Result:	stick weld
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.4 A-Scan of SWS-04 with 8.0 mm probe



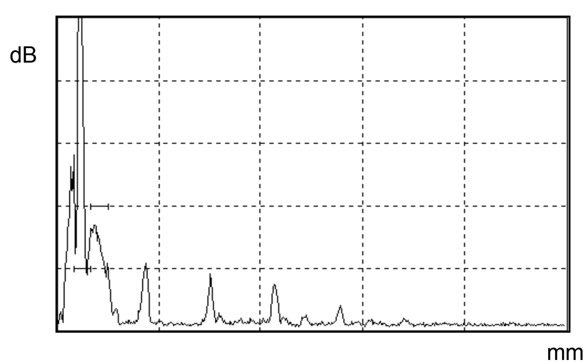
Group of spots:	SWS-8mm
Spot name:	SWS-05
Date:	25.04.2003
Time:	10:46:39 AM
Number of plates:	2
Result:	burnt
Plate thickness:	3,4 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.5 A-Scan of SWS-05 with 8.0 mm probe



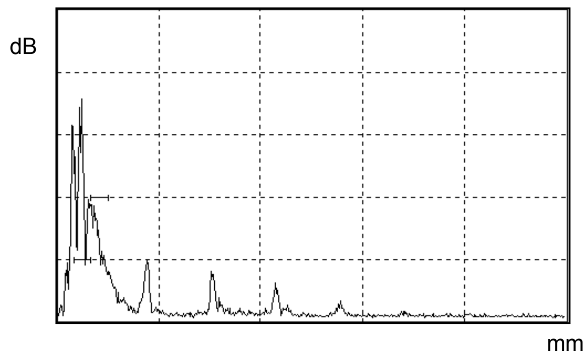
Group of spots:	SWS-8mm
Spot name:	SWS-06
Date:	25.04.2003
Time:	10:48:59 AM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.6 A-Scan of SWS-06 with 8.0 mm probe



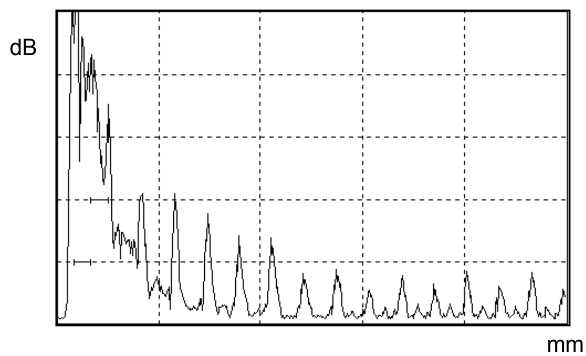
Group of spots:	SWS-8mm
Spot name:	SWS-07
Date:	25.04.2003
Time:	10:50:45 AM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.7 A-Scan of SWS-07 with 8.0 mm probe



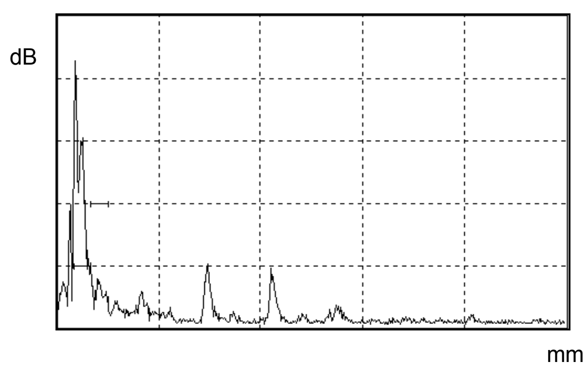
Group of spots:	SWS-8mm
Spot name:	SWS-08
Date:	25.04.2003
Time:	10:52:01 AM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.8 A-Scan of SWS-08 with 8.0 mm probe



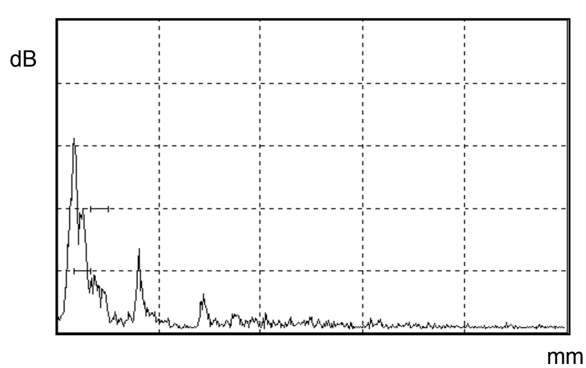
Group of spots:	SWS-8mm
Spot name:	SWS-09
Date:	25.04.2003
Time:	10:53:36 AM
Number of plates:	2
Result:	loose
Plate thickness:	1,92 mm
Sound velocity:	5920 m/s
Gain:	48 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.9 A-Scan of SWS-09 with 8.0 mm probe



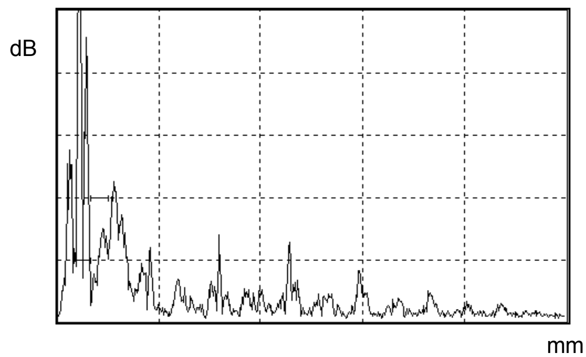
Group of spots:	SWS-8mm
Spot name:	SWS-10
Date:	25.04.2003
Time:	10:57:07 AM
Number of plates:	2
Result:	OK
Plate thickness:	3,81 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.10 A-Scan of SWS-10 with 8.0 mm probe



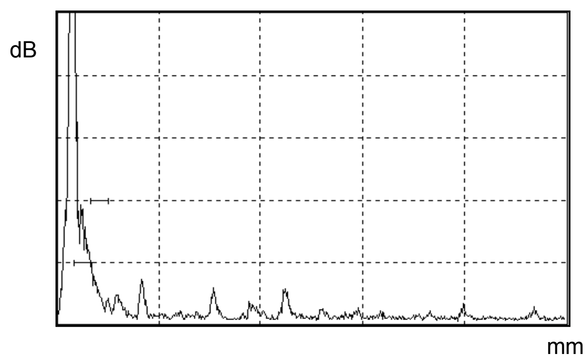
Group of spots:	SWS-8mm
Spot name:	SWS-11
Date:	25.04.2003
Time:	10:59:38 AM
Number of plates:	2
Result:	OK
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	47 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.11 A-Scan of SWS-11 with 8.0 mm probe



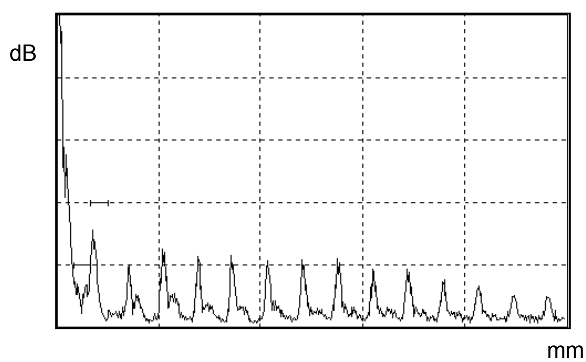
Group of spots:	SWS-8mm
Spot name:	SWS-12
Date:	25.04.2003
Time:	11:01:26 AM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.12 A-Scan of SWS-12 with 8.0 mm probe



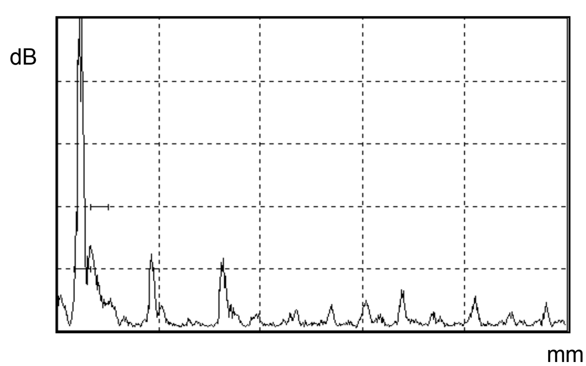
Group of spots:	SWS-8mm
Spot name:	SWS-13
Date:	25.04.2003
Time:	11:03:16 AM
Number of plates:	2
Result:	OK
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.13 A-Scan of SWS-13 with 8.0 mm probe



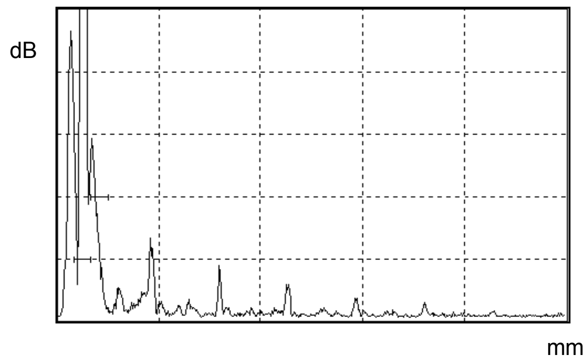
Group of spots:	SWS-8mm
Spot name:	SWS-14
Date:	25.04.2003
Time:	11:03:54 AM
Number of plates:	2
Result:	loose
Plate thickness:	2,07 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.14 A-Scan of SWS-14 with 8.0 mm probe



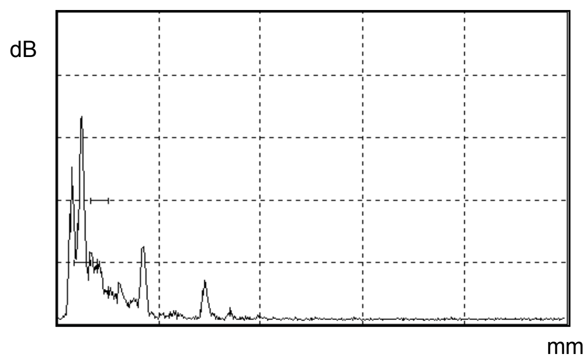
Group of spots:	SWS-8mm
Spot name:	SWS-15
Date:	25.04.2003
Time:	11:25:19 AM
Number of plates:	2
Result:	OK
Plate thickness:	4,28 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.15 A-Scan of SWS-15 with 8.0 mm probe



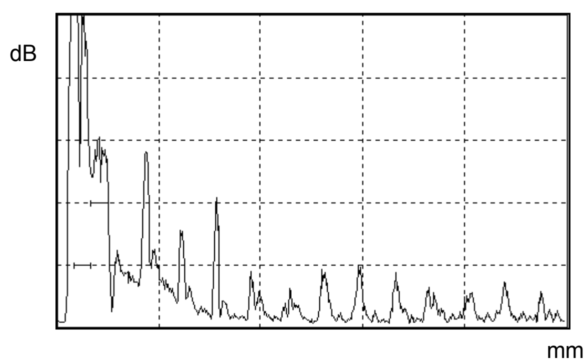
Group of spots:	SWS-8mm
Spot name:	SWS-16
Date:	25.04.2003
Time:	11:26:36 AM
Number of plates:	2
Result:	burnt
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.16 A-Scan of SWS-16 with 8.0 mm probe



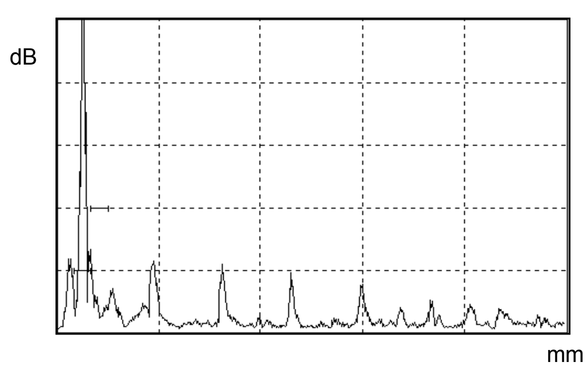
Group of spots:	SWS-8mm
Spot name:	SWS-17
Date:	25.04.2003
Time:	11:27:25 AM
Number of plates:	2
Result:	burnt
Plate thickness:	3,57 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.17 A-Scan of SWS-17 with 8.0 mm probe



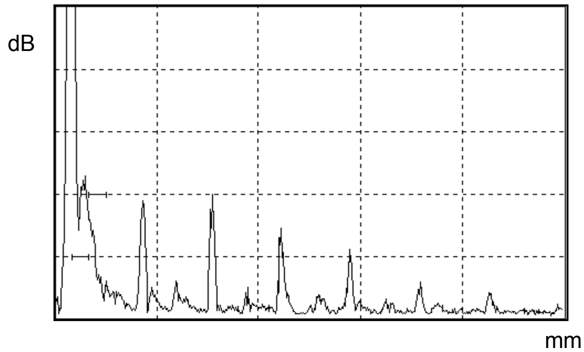
Group of spots:	SWS-8mm
Spot name:	SWS-18
Date:	25.04.2003
Time:	11:28:02 AM
Number of plates:	2
Result:	stick weld
Plate thickness:	8,38 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.18 A-Scan of SWS-18 with 8.0 mm probe



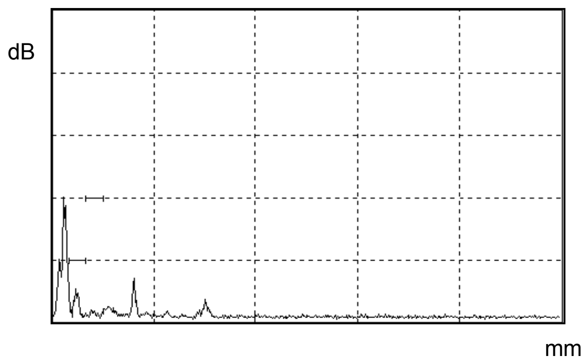
Group of spots:	SWS-8mm
Spot name:	SWS-19
Date:	25.04.2003
Time:	11:30:08 AM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.19 A-Scan of SWS-19 with 8.0 mm probe



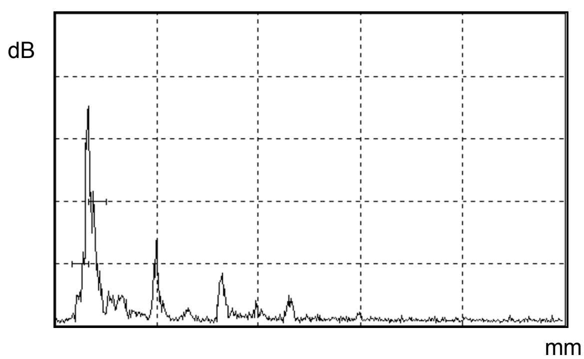
Group of spots:	SWS-8mm
Spot name:	SWS-20
Date:	25.04.2003
Time:	11:31:31 AM
Number of plates:	2
Result:	small nugget
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.20 A-Scan of SWS-20 with 8.0 mm probe



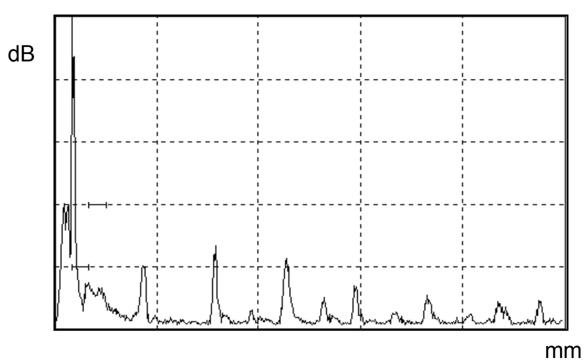
Group of spots:	SWS-8mm
Spot name:	SWS-21
Date:	25.04.2003
Time:	11:32:53 AM
Number of plates:	2
Result:	burnt
Plate thickness:	3,46 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.21 A-Scan of SWS-21 with 8.0 mm probe



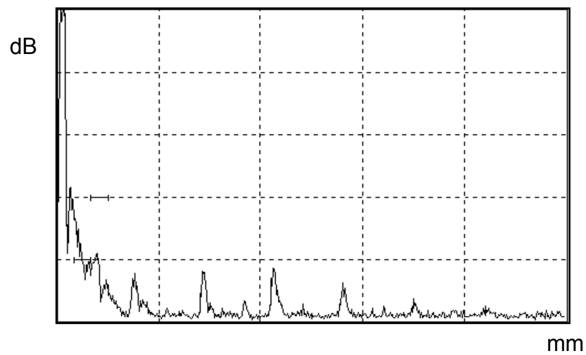
Group of spots:	SWS-8mm
Spot name:	SWS-22
Date:	25.04.2003
Time:	11:34:15 AM
Number of plates:	2
Result:	burnt
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	45 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.22 A-Scan of SWS-22 with 8.0 mm probe



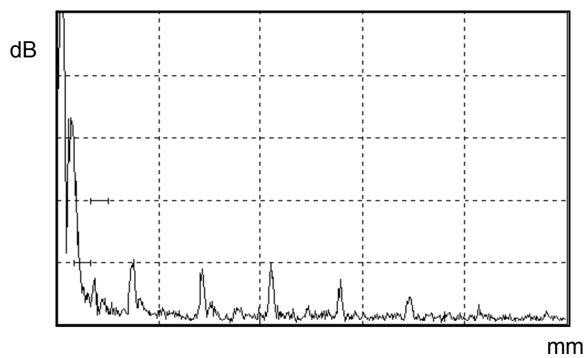
Group of spots:	SWS-8mm
Spot name:	SWS-23
Date:	25.04.2003
Time:	11:36:03 AM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	42 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.23 A-Scan of SWS-23 with 8.0 mm probe



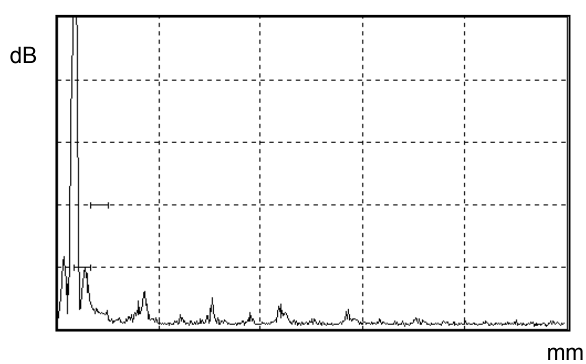
Group of spots:	SWS-8mm
Spot name:	SWS-24
Date:	25.04.2003
Time:	11:36:35 AM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	42 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.24 A-Scan of SWS-24 with 8.0 mm probe



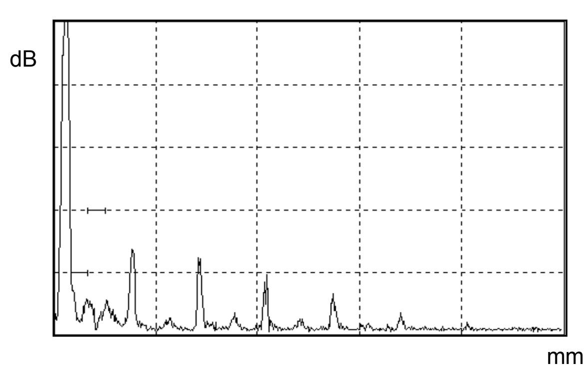
Group of spots:	SWS-8mm
Spot name:	SWS-25
Date:	25.04.2003
Time:	11:37:01 AM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	42 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.25 A-Scan of SWS-25 with 8.0 mm probe



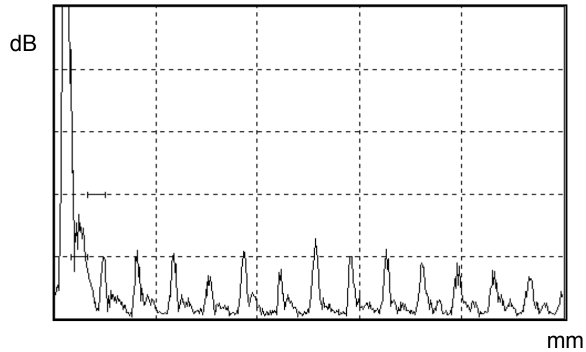
Group of spots:	SWS-8mm
Spot name:	SWS-26
Date:	25.04.2003
Time:	11:38:08 AM
Number of plates:	2
Result:	burnt
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	42 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.26 A-Scan of SWS-26 with 8.0 mm probe



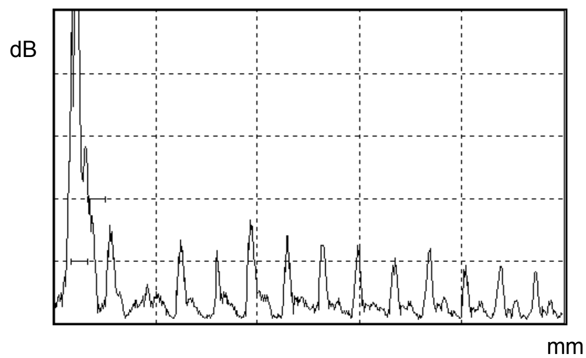
Group of spots:	SWS-8mm
Spot name:	SWS-27
Date:	25.04.2003
Time:	11:38:59 AM
Number of plates:	2
Result:	burnt
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	42 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.27 A-Scan of SWS-27 with 8.0 mm probe



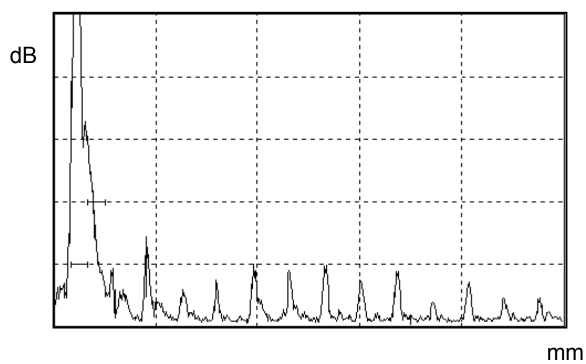
Group of spots:	SWS-8mm
Spot name:	SWS-28
Date:	25.04.2003
Time:	11:39:39 AM
Number of plates:	2
Result:	loose
Plate thickness:	2,05mm
Sound velocity:	5920m/s
Gain:	42dB
Probe delay:	20µs
Range:	30mm

Figure E.28 A-Scan of SWS-28 with 8.0 mm probe



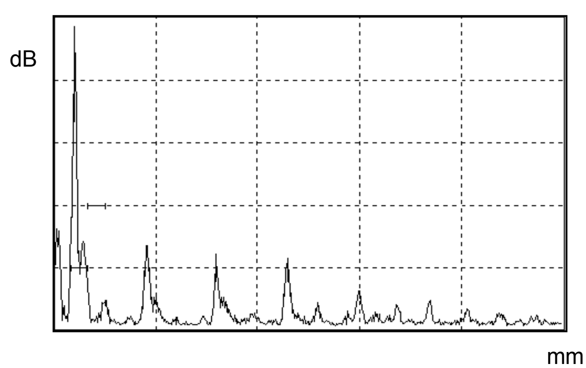
Group of spots:	SWS-8mm
Spot name:	SWS-29
Date:	25.04.2003
Time:	11:41:11 AM
Number of plates:	2
Result:	stick weld
Plate thickness:	2,23mm
Sound velocity:	5920m/s
Gain:	46dB
Probe delay:	20µs
Range:	30mm

Figure E.29 A-Scan of SWS-29 with 8.0 mm probe



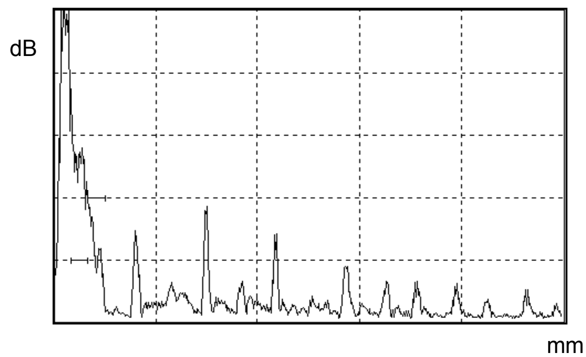
Group of spots:	SWS-8mm
Spot name:	SWS-30
Date:	25.04.2003
Time:	11:41:49 AM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16mm
Sound velocity:	5920m/s
Gain:	46dB
Probe delay:	20µs
Range:	30mm

Figure E.30 A-Scan of SWS-30 with 8.0 mm probe



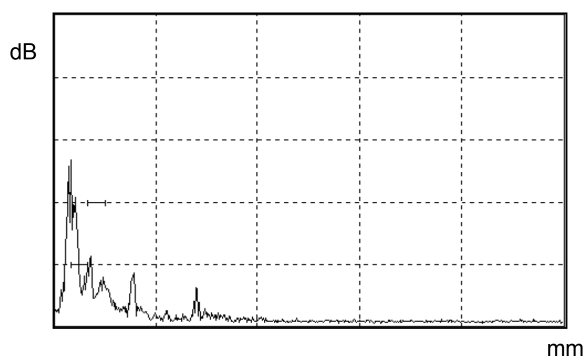
Group of spots:	SWS-8mm
Spot name:	SWS-31
Date:	25.04.2003
Time:	11:44:17 AM
Number of plates:	2
Result:	OK
Plate thickness:	4,16mm
Sound velocity:	5920m/s
Gain:	45dB
Probe delay:	20µs
Range:	30mm

Figure E.31 A-Scan of SWS-31 with 8.0 mm probe



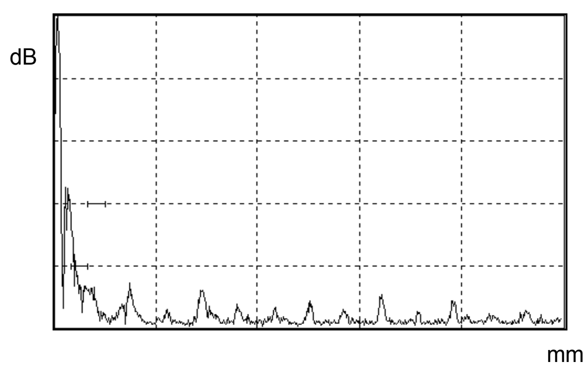
Group of spots:	SWS-8mm
Spot name:	SWS-32
Date:	25.04.2003
Time:	12:10:36 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1mm
Sound velocity:	5920m/s
Gain:	46dB
Probe delay:	20µs
Range:	30mm

Figure E.32 A-Scan of SWS-32 with 8.0 mm probe



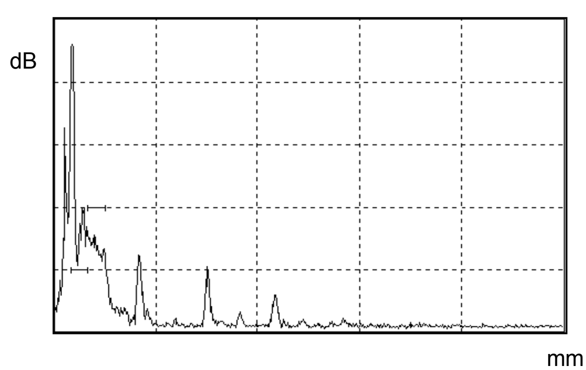
Group of spots:	SWS-8mm
Spot name:	SWS-33
Date:	25.04.2003
Time:	12:11:22 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,63mm
Sound velocity:	5920m/s
Gain:	46dB
Probe delay:	20µs
Range:	30mm

Figure E.33 A-Scan of SWS-33 with 8.0 mm probe



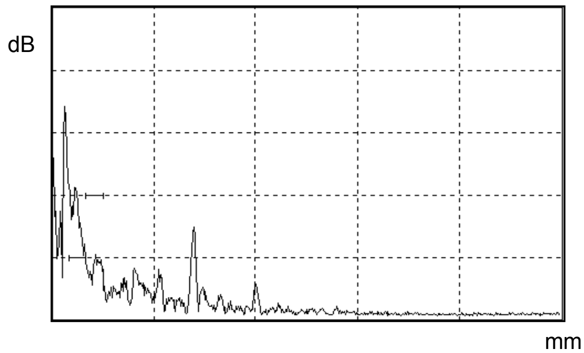
Group of spots:	SWS-8mm
Spot name:	SWS-34
Date:	25.04.2003
Time:	12:13:01 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16mm
Sound velocity:	5920m/s
Gain:	43dB
Probe delay:	20µs
Range:	30mm

Figure E.34 A-Scan of SWS-34 with 8.0 mm probe



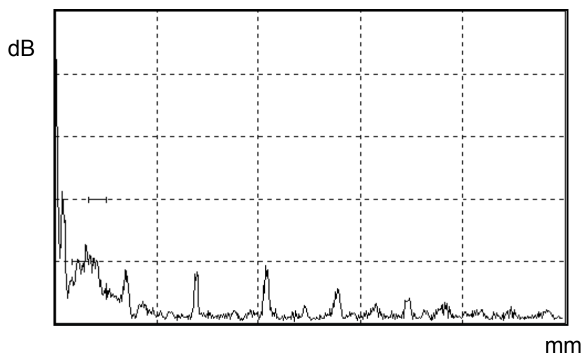
Group of spots:	SWS-8mm
Spot name:	SWS-35
Date:	25.04.2003
Time:	12:14:44 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04mm
Sound velocity:	5920m/s
Gain:	44dB
Probe delay:	20µs
Range:	30mm

Figure E.35 A-Scan of SWS-35 with 8.0 mm probe



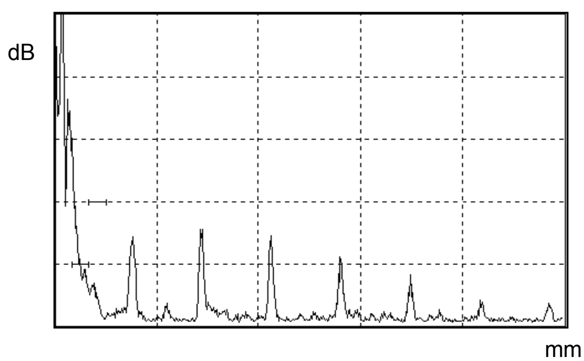
Group of spots:	SWS-8mm
Spot name:	SWS-36
Date:	25.04.2003
Time:	12:16:43 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	3,69 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.36 A-Scan of SWS-36 with 8.0 mm probe



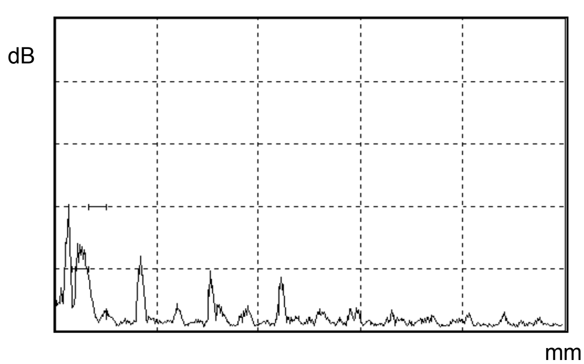
Group of spots:	SWS-8mm
Spot name:	SWS-37
Date:	25.04.2003
Time:	12:18:09 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.37 A-Scan of SWS-37 with 8.0 mm probe



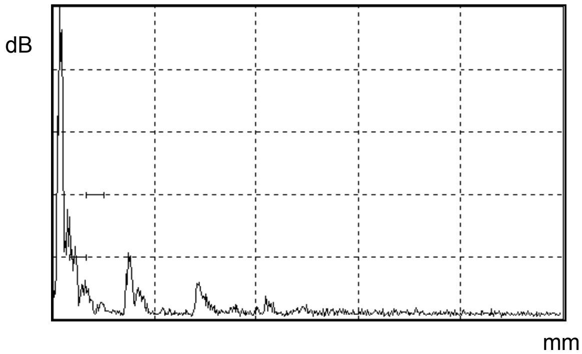
Group of spots:	SWS-8mm
Spot name:	SWS-38
Date:	25.04.2003
Time:	12:21:41 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.38 A-Scan of SWS-38 with 8.0 mm probe



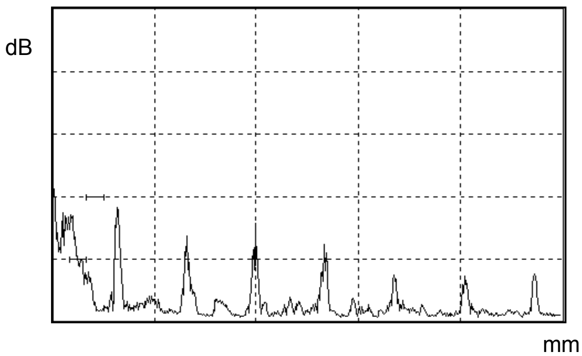
Group of spots:	SWS-8mm
Spot name:	SWS-39
Date:	25.04.2003
Time:	12:22:57 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.39 A-Scan of SWS-39 with 8.0 mm probe



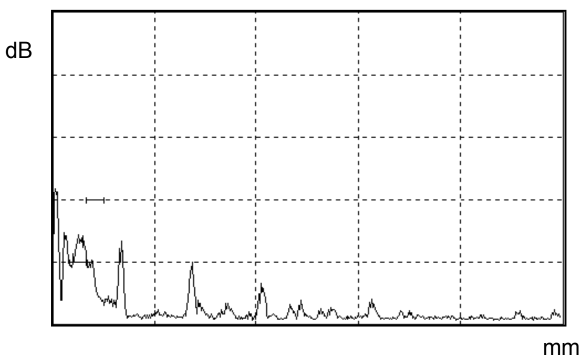
Group of spots:	SWS-8mm
Spot name:	SWS-40
Date:	25.04.2003
Time:	12:24:00 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.40 A-Scan of SWS-40 with 8.0 mm probe



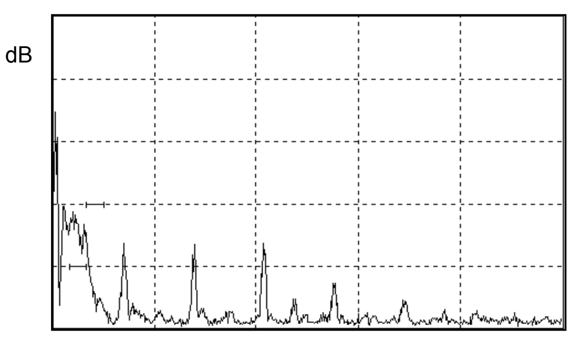
Group of spots:	SWS-8mm
Spot name:	SWS-41
Date:	25.04.2003
Time:	12:26:06 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.41 A-Scan of SWS-41 with 8.0 mm probe



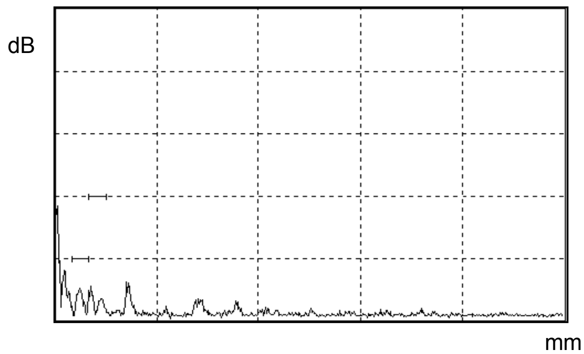
Group of spots:	SWS-8mm
Spot name:	SWS-42
Date:	25.04.2003
Time:	12:27:31 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.42 A-Scan of SWS-42 with 8.0 mm probe



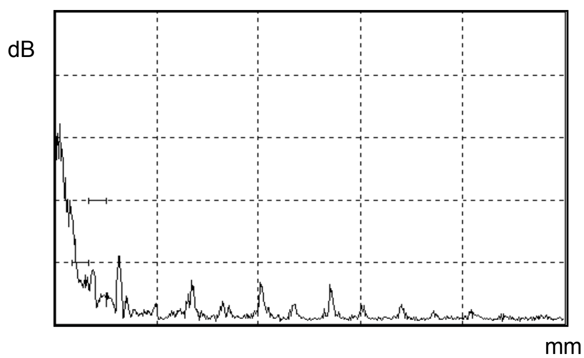
Group of spots:	SWS-8mm
Spot name:	SWS-43
Date:	25.04.2003
Time:	12:28:22 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.43 A-Scan of SWS-43 with 8.0 mm probe



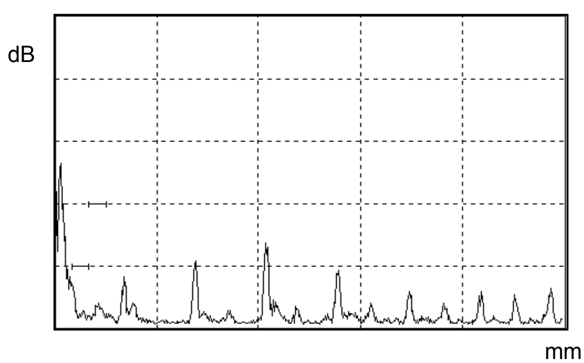
Group of spots:	SWS-8mm
Spot name:	SWS-44
Date:	25.04.2003
Time:	12:29:47 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	2,75 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.44 A-Scan of SWS-44 with 8.0 mm probe



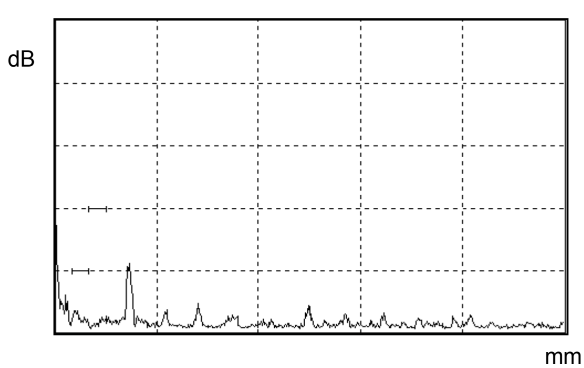
Group of spots:	SWS-8mm
Spot name:	SWS-45
Date:	25.04.2003
Time:	12:30:17 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.45 A-Scan of SWS-45 with 8.0 mm probe



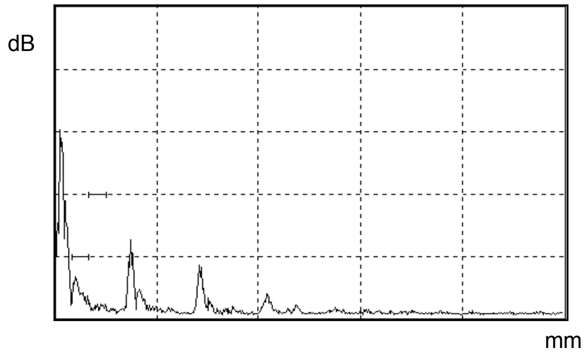
Group of spots:	SWS-8mm
Spot name:	SWS-46
Date:	25.04.2003
Time:	12:31:42 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,28 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.46 A-Scan of SWS-46 with 8.0 mm probe



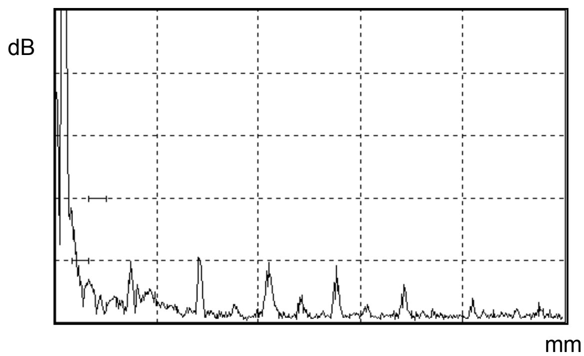
Group of spots:	SWS-8mm
Spot name:	SWS-47
Date:	25.04.2003
Time:	12:33:29 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.47 A-Scan of SWS-47 with 8.0 mm probe



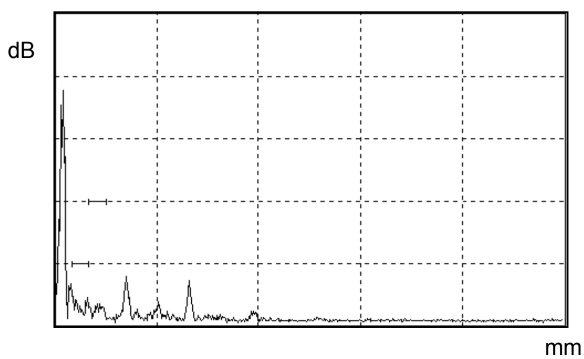
Group of spots:	SWS-8mm
Spot name:	SWS-48
Date:	25.04.2003
Time:	12:34:07 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.48 A-Scan of SWS-48 with 8.0 mm probe



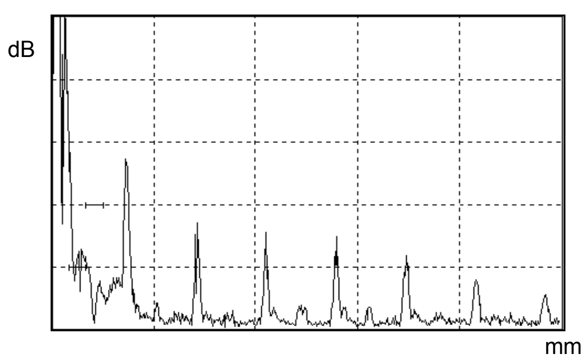
Group of spots:	SWS-8mm
Spot name:	SWS-49
Date:	25.04.2003
Time:	12:35:19 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.49 A-Scan of SWS-49 with 8.0 mm probe



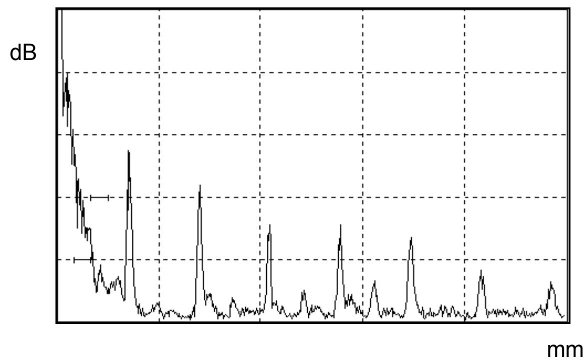
Group of spots:	SWS-8mm
Spot name:	SWS-50
Date:	25.04.2003
Time:	12:37:20 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,75 mm
Sound velocity:	5920 m/s
Gain:	44 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.50 A-Scan of SWS-50 with 8.0 mm probe



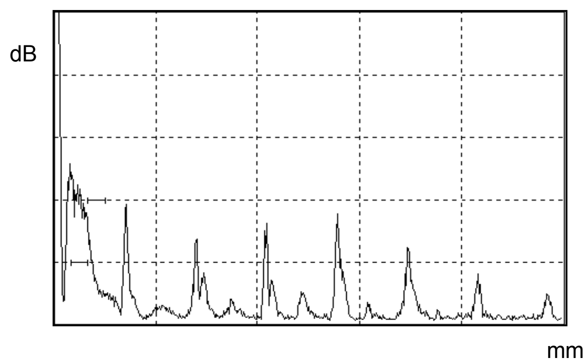
Group of spots:	SWS-8mm
Spot name:	SWS-51
Date:	06.06.2003
Time:	2:53:10 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	47 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.51 A-Scan of SWS-51 with 8.0 mm probe



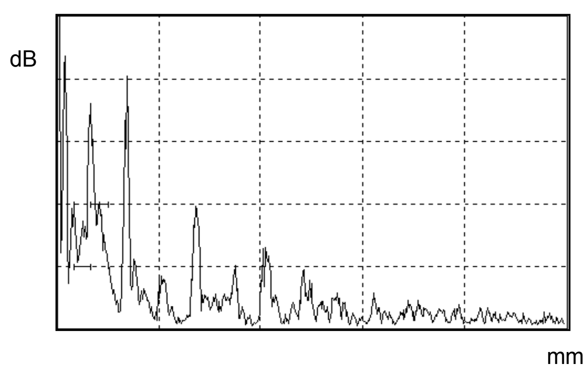
Group of spots:	SWS-8mm
Spot name:	SWS-52
Date:	06.06.2003
Time:	2:54:12 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,28 mm
Sound velocity:	5920 m/s
Gain:	47 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.52 A-Scan of SWS-52 with 8.0 mm probe



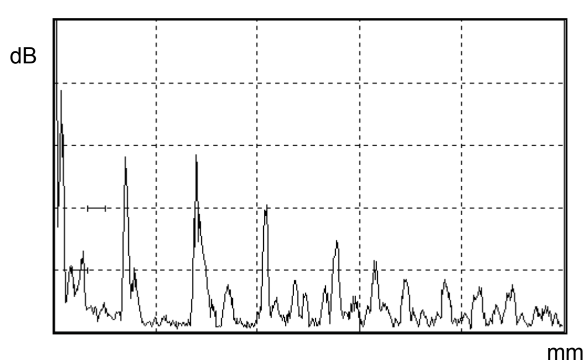
Group of spots:	SWS-8mm
Spot name:	SWS-53
Date:	06.06.2003
Time:	2:55:30 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	47 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.53 A-Scan of SWS-53 with 8.0 mm probe



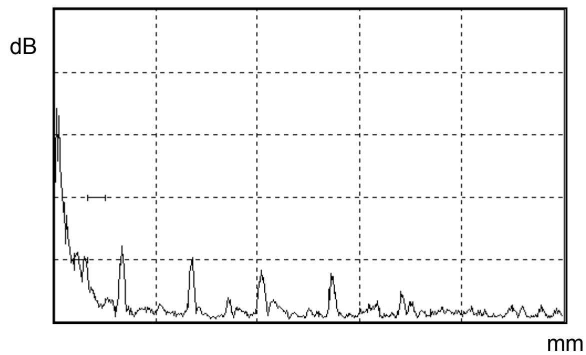
Group of spots:	SWS-8mm
Spot name:	SWS-54
Date:	06.06.2003
Time:	3:07:07 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	54 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.54 A-Scan of SWS-54 with 8.0 mm probe



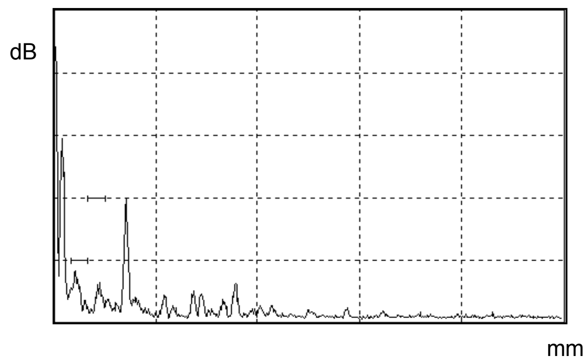
Group of spots:	SWS-8mm
Spot name:	SWS-55
Date:	06.06.2003
Time:	3:08:55 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	54 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.55 A-Scan of SWS-55 with 8.0 mm probe



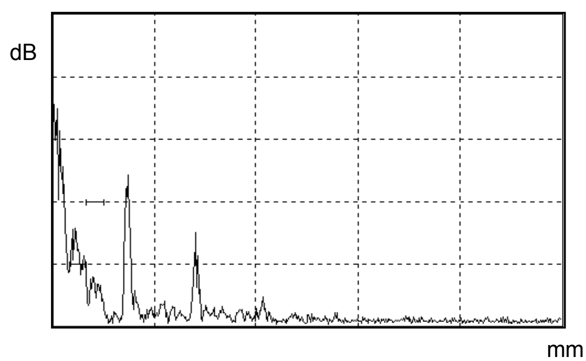
Group of spots:	SWS-8mm
Spot name:	SWS-56
Date:	06.06.2003
Time:	3:15:06 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	46 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.56 A-Scan of SWS-56 with 8.0 mm probe



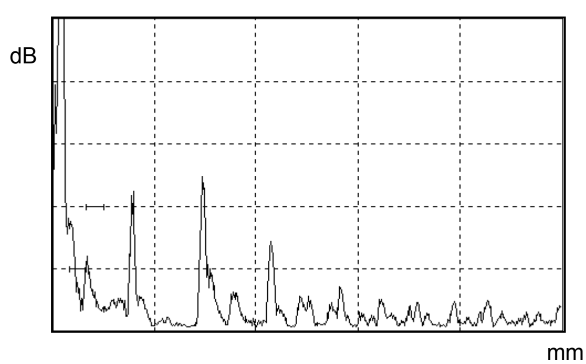
Group of spots:	SWS-8mm
Spot name:	SWS-57
Date:	06.06.2003
Time:	3:19:01 PM
Number of plates:	2
Result:	burnt
Plate thickness:	6,45 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.57 A-Scan of SWS-57 with 8.0 mm probe



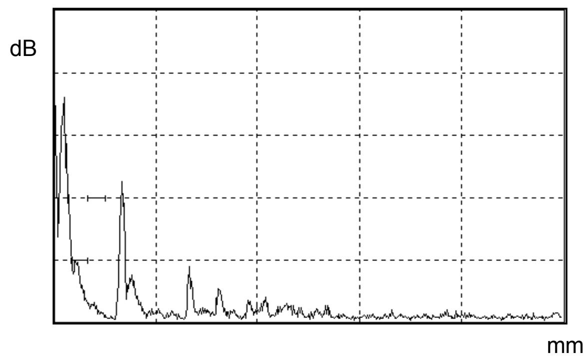
Group of spots:	SWS-8mm
Spot name:	SWS-58
Date:	06.06.2003
Time:	3:20:06 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.58 A-Scan of SWS-58 with 8.0 mm probe



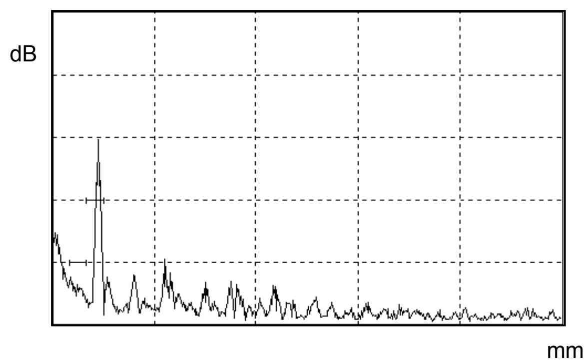
Group of spots:	SWS-8mm
Spot name:	SWS-59
Date:	06.06.2003
Time:	3:21:09 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	20 µs
Range:	30 mm

Figure E.59 A-Scan of SWS-59 with 8.0 mm probe



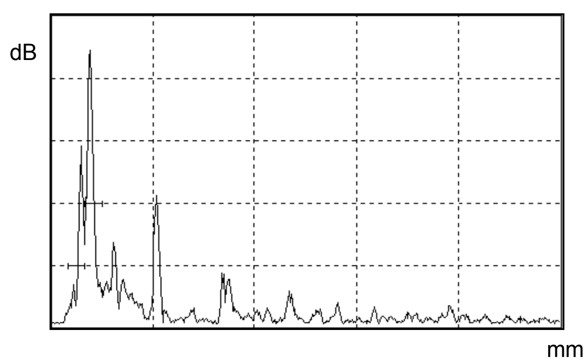
Group of spots:	SWS-8mm
Spot name:	SWS-60
Date:	06.06.2003
Time:	3:35:23 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	22 µs
Range:	30 mm

Figure E.60 A-Scan of SWS-60 with 8.0 mm probe



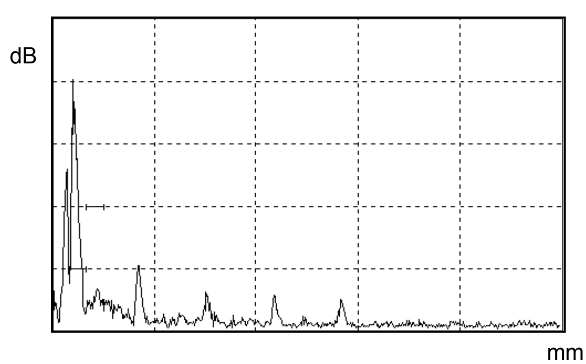
Group of spots:	SWS-8mm
Spot name:	SWS-61
Date:	06.06.2003
Time:	3:40:36 PM
Number of plates:	2
Result:	OK
Plate thickness:	2,4 mm
Sound velocity:	5920 m/s
Gain:	51 dB
Probe delay:	22 µs
Range:	30 mm

Figure E.61 A-Scan of SWS-61 with 8.0 mm probe



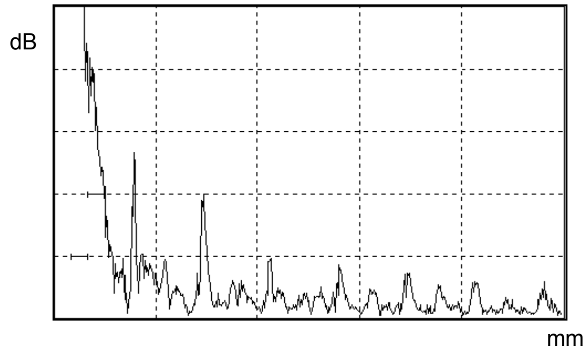
Group of spots:	SWS-8mm
Spot name:	SWS-62
Date:	06.06.2003
Time:	3:43:59 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,87 mm
Sound velocity:	5920 m/s
Gain:	51 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.62 A-Scan of SWS-62 with 8.0 mm probe



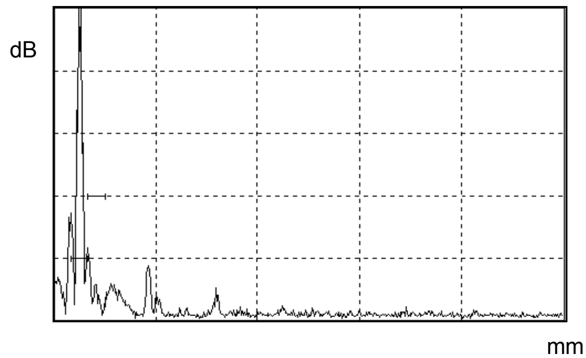
Group of spots:	SWS-8mm
Spot name:	SWS-63
Date:	06.06.2003
Time:	3:45:26 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.63 A-Scan of SWS-63 with 8.0 mm probe



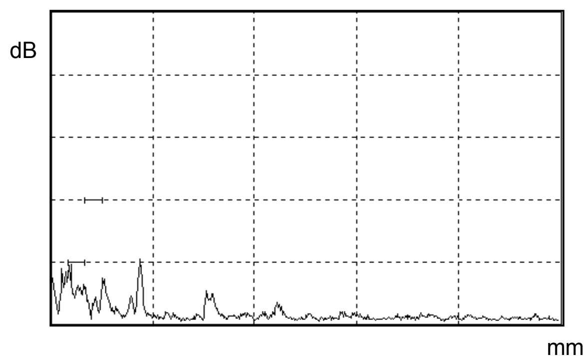
Group of spots:	SWS-8mm
Spot name:	SWS-64
Date:	06.06.2003
Time:	3:47:19 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.64 A-Scan of SWS-64 with 8.0 mm probe



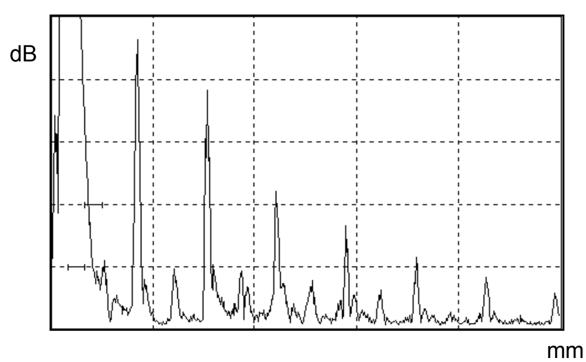
Group of spots:	SWS-8mm
Spot name:	SWS-65
Date:	06.06.2003
Time:	3:48:55 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.65 A-Scan of SWS-65 with 8.0 mm probe



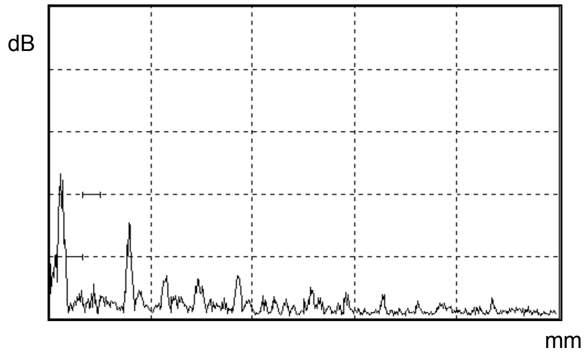
Group of spots:	SWS-8mm
Spot name:	SWS-66
Date:	06.06.2003
Time:	3:49:42 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.66 A-Scan of SWS-66 with 8.0 mm probe



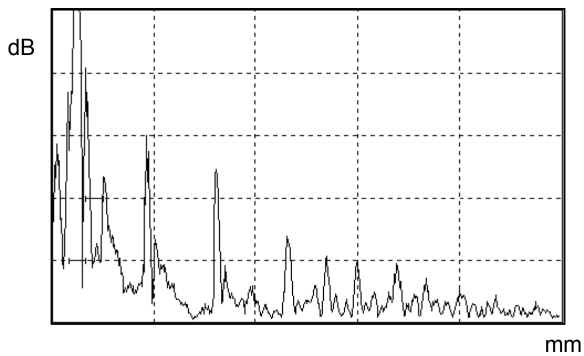
Group of spots:	SWS-8mm
Spot name:	SWS-67
Date:	06.06.2003
Time:	3:51:18 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.67 A-Scan of SWS-67 with 8.0 mm probe



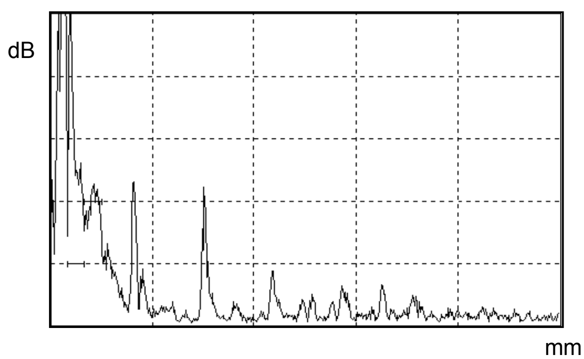
Group of spots:	SWS-8mm
Spot name:	SWS-68
Date:	06.06.2003
Time:	3:52:34 PM
Number of plates:	2
Result:	OK
Plate thickness:	2,23 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.68 A-Scan of SWS-68 with 8.0 mm probe



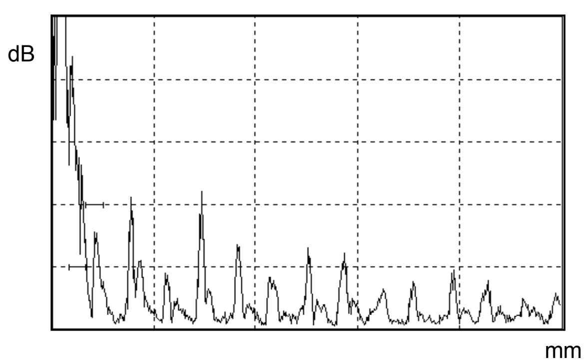
Group of spots:	SWS-8mm
Spot name:	SWS-69
Date:	06.06.2003
Time:	3:54:35 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	53 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.69 A-Scan of SWS-69 with 8.0 mm probe



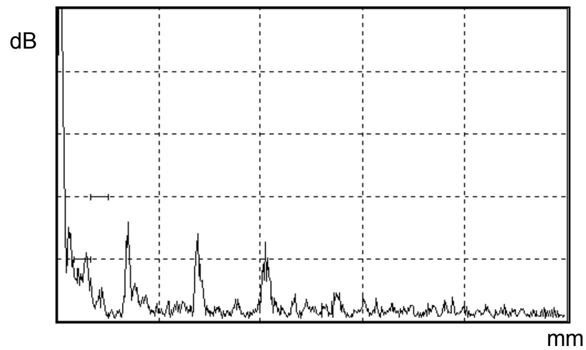
Group of spots:	SWS-8mm
Spot name:	SWS-70
Date:	06.06.2003
Time:	3:55:14 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	53 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.70 A-Scan of SWS-70 with 8.0 mm probe



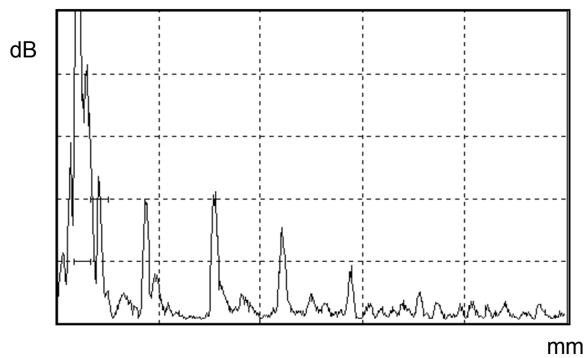
Group of spots:	SWS-8mm
Spot name:	SWS-71
Date:	06.06.2003
Time:	3:56:59 PM
Number of plates:	2
Result:	loose
Plate thickness:	2,17 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.71 A-Scan of SWS-71 with 8.0 mm probe



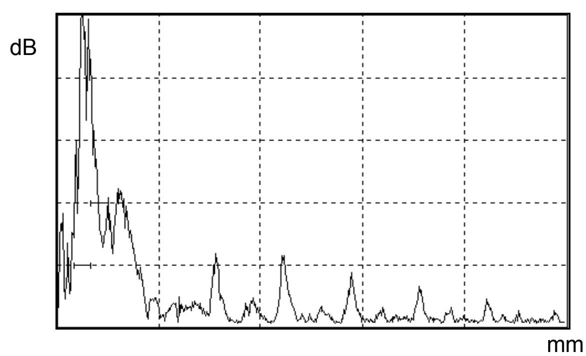
Group of spots:	SWS-8mm
Spot name:	SWS-72
Date:	06.06.2003
Time:	3:57:52 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.72 A-Scan of SWS-72 with 8.0 mm probe



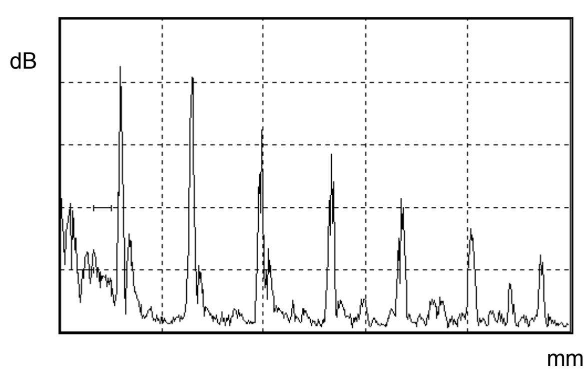
Group of spots:	SWS-8mm
Spot name:	SWS-73
Date:	06.06.2003
Time:	3:58:48 PM
Number of plates:	2
Result:	bad through
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.73 A-Scan of SWS-73 with 8.0 mm probe



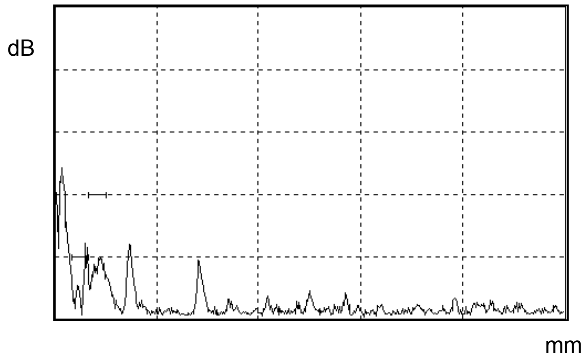
Group of spots:	SWS-8mm
Spot name:	SWS-74
Date:	06.06.2003
Time:	3:59:47 PM
Number of plates:	2
Result:	bad through
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.74 A-Scan of SWS-74 with 8.0 mm probe



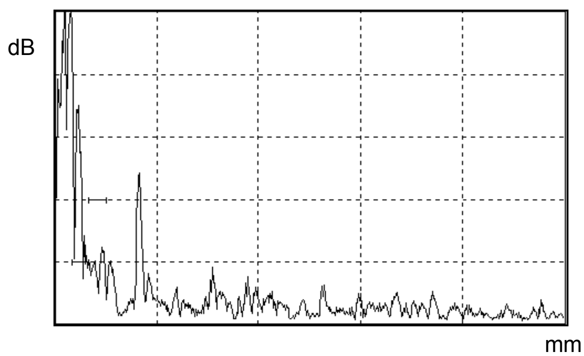
Group of spots:	SWS-8mm
Spot name:	SWS-75
Date:	06.06.2003
Time:	4:00:37 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.75 A-Scan of SWS-75 with 8.0 mm probe



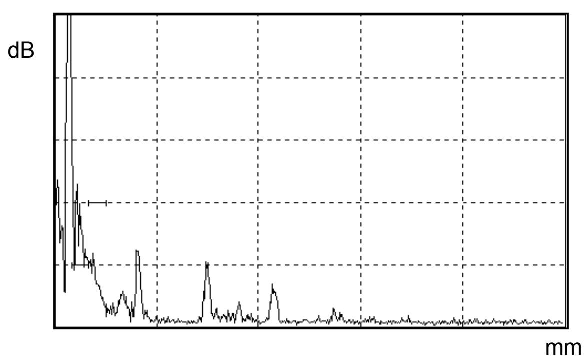
Group of spots:	SWS-8mm
Spot name:	SWS-76
Date:	06.06.2003
Time:	4:01:41 PM
Number of plates:	2
Result:	OK
Plate thickness:	2,58 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.76 A-Scan of SWS-76 with 8.0 mm probe



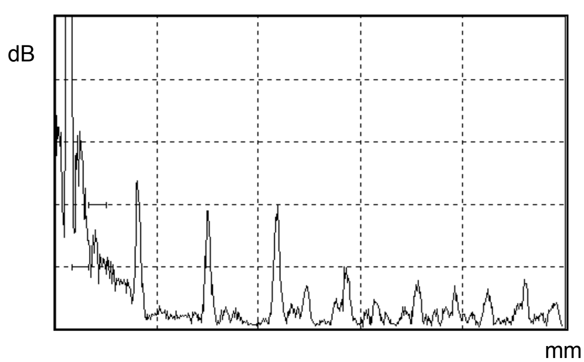
Group of spots:	SWS-8mm
Spot name:	SWS-77
Date:	06.06.2003
Time:	4:02:32 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,28 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.77 A-Scan of SWS-77 with 8.0 mm probe



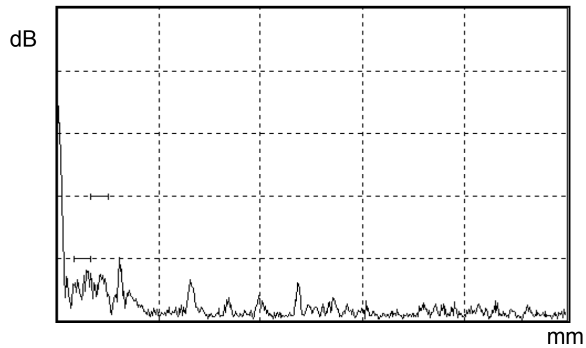
Group of spots:	SWS-8mm
Spot name:	SWS-78
Date:	06.06.2003
Time:	4:03:50 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.78 A-Scan of SWS-78 with 8.0 mm probe



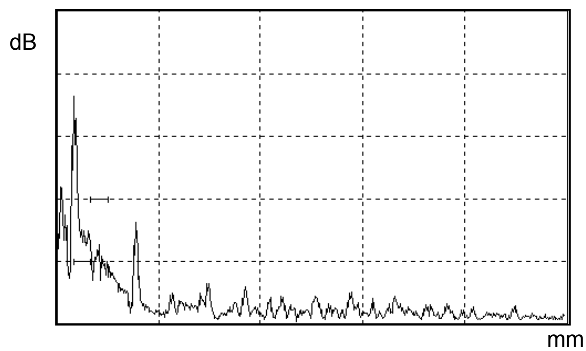
Group of spots:	SWS-8mm
Spot name:	SWS-79
Date:	06.06.2003
Time:	4:05:54 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	3,93 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.79 A-Scan of SWS-79 with 8.0 mm probe



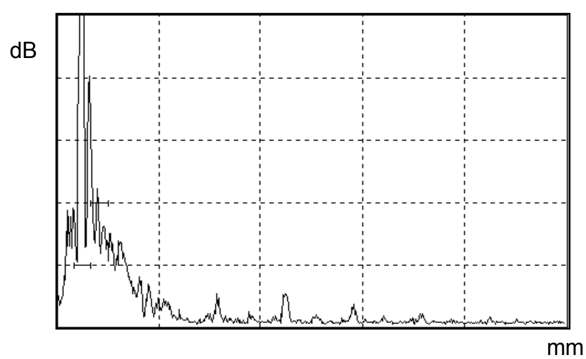
Group of spots:	SWS-8mm
Spot name:	SWS-80
Date:	06.06.2003
Time:	4:07:35 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16mm
Sound velocity:	5920m/s
Gain:	50dB
Probe delay:	21µs
Range:	30mm

Figure E.80 A-Scan of SWS-80 with 8.0 mm probe



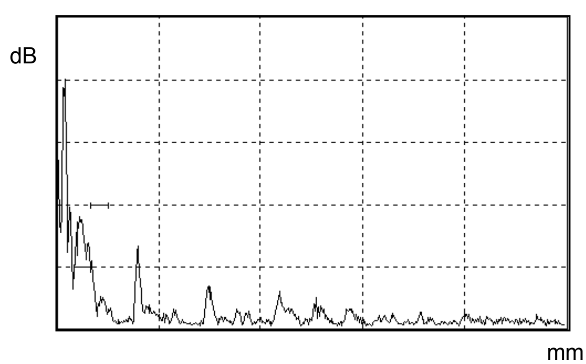
Group of spots:	SWS-8mm
Spot name:	SWS-81
Date:	06.06.2003
Time:	4:09:15 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	4,16mm
Sound velocity:	5920m/s
Gain:	50dB
Probe delay:	21µs
Range:	30mm

Figure E.81 A-Scan of SWS-81 with 8.0 mm probe



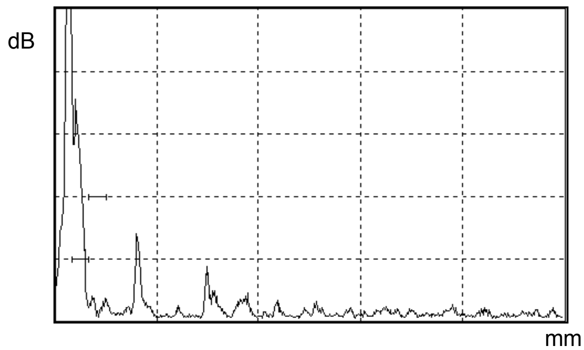
Group of spots:	SWS-8mm
Spot name:	SWS-82
Date:	06.06.2003
Time:	4:10:28 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,04mm
Sound velocity:	5920m/s
Gain:	50dB
Probe delay:	21µs
Range:	30mm

Figure E.82 A-Scan of SWS-82 with 8.0 mm probe



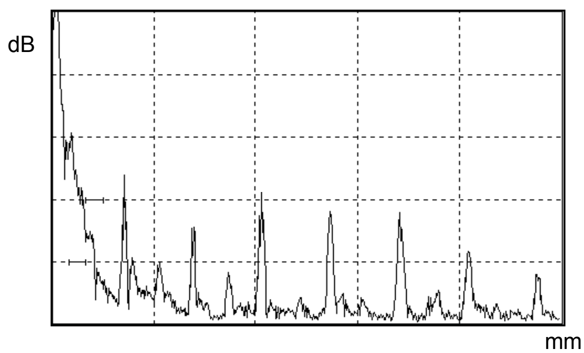
Group of spots:	SWS-8mm
Spot name:	SWS-83
Date:	06.06.2003
Time:	4:12:34 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,16mm
Sound velocity:	5920m/s
Gain:	50dB
Probe delay:	21µs
Range:	30mm

Figure E.83 A-Scan of SWS-83 with 8.0 mm probe



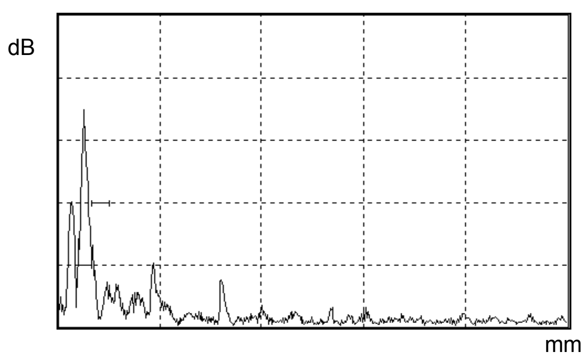
Group of spots:	SWS-8mm
Spot name:	SWS-84
Date:	06.06.2003
Time:	4:14:14 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	48 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.84 A-Scan of SWS-84 with 8.0 mm probe



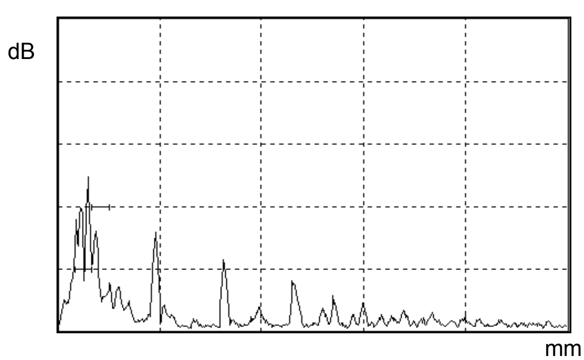
Group of spots:	SWS-8mm
Spot name:	SWS-85
Date:	06.06.2003
Time:	4:14:58 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	48 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.85 A-Scan of SWS-85 with 8.0 mm probe



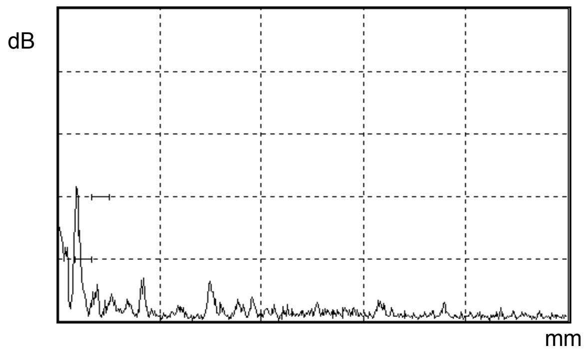
Group of spots:	SWS-8mm
Spot name:	SWS-86
Date:	06.06.2003
Time:	4:16:55 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	48 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.86 A-Scan of SWS-86 with 8.0 mm probe



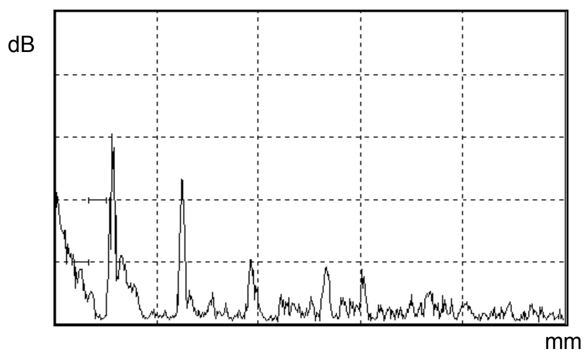
Group of spots:	SWS-8mm
Spot name:	SWS-87
Date:	06.06.2003
Time:	4:18:41 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,04 mm
Sound velocity:	5920 m/s
Gain:	48 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.87 A-Scan of SWS-87 with 8.0 mm probe



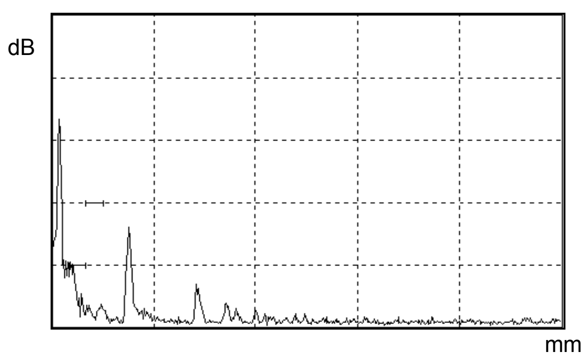
Group of spots:	SWS-8mm
Spot name:	SWS-88
Date:	06.06.2003
Time:	4:19:28 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,87 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.88 A-Scan of SWS-88 with 8.0 mm probe



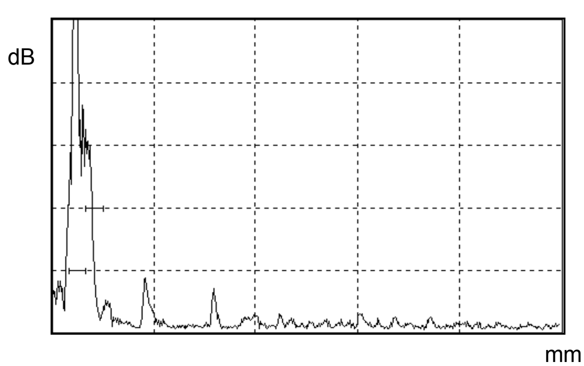
Group of spots:	SWS-8mm
Spot name:	SWS-89
Date:	06.06.2003
Time:	4:21:21 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.89 A-Scan of SWS-89 with 8.0 mm probe



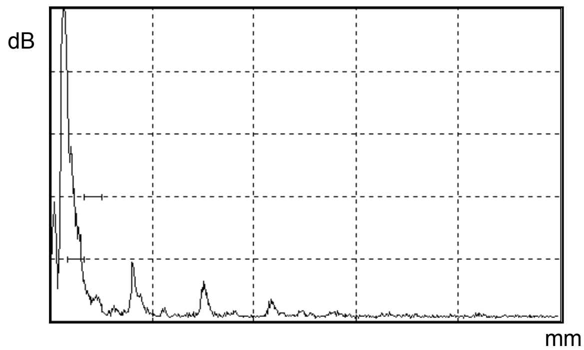
Group of spots:	SWS-8mm
Spot name:	SWS-90
Date:	06.06.2003
Time:	4:22:18 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.90 A-Scan of SWS-90 with 8.0 mm probe



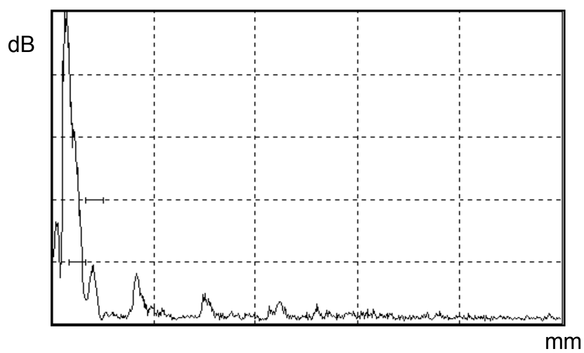
Group of spots:	SWS-8mm
Spot name:	SWS-91
Date:	06.06.2003
Time:	4:23:59 PM
Number of plates:	2
Result:	burnt
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.91 A-Scan of SWS-91 with 8.0 mm probe



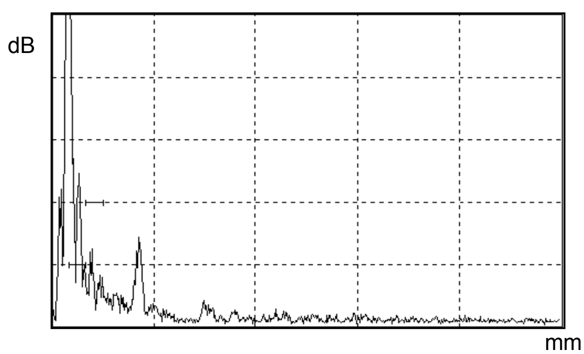
Group of spots:	SWS-8mm
Spot name:	SWS-92
Date:	06.06.2003
Time:	4:24:55 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,16 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.92 A-Scan of SWS-92 with 8.0 mm probe



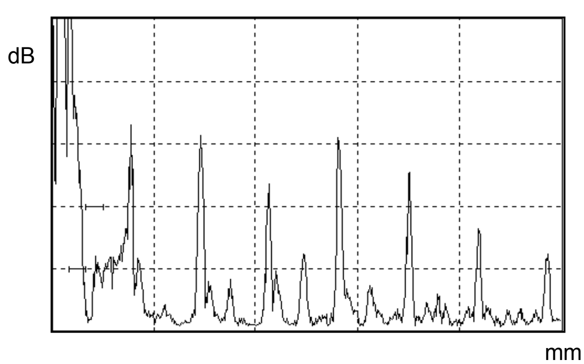
Group of spots:	SWS-8mm
Spot name:	SWS-93
Date:	06.06.2003
Time:	4:25:34 PM
Number of plates:	2
Result:	burnt
Plate thickness:	2,52 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.93 A-Scan of SWS-93 with 8.0 mm probe



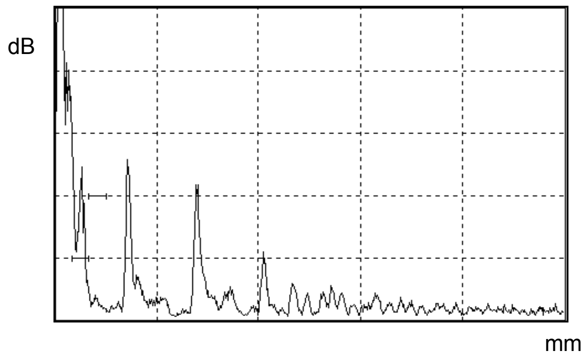
Group of spots:	SWS-8mm
Spot name:	SWS-94
Date:	06.06.2003
Time:	4:51:58 PM
Number of plates:	2
Result:	small nugget
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.94 A-Scan of SWS-94 with 8.0 mm probe



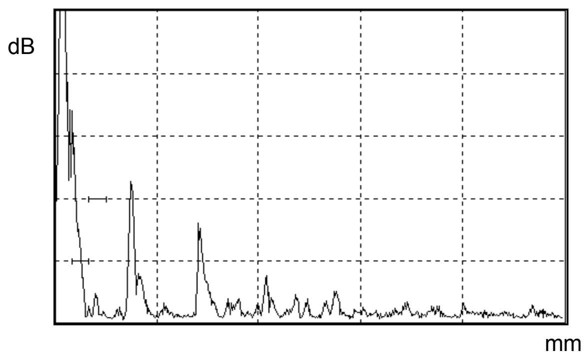
Group of spots:	SWS-8mm
Spot name:	SWS-95
Date:	06.06.2003
Time:	4:53:28 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.95 A-Scan of SWS-95 with 8.0 mm probe



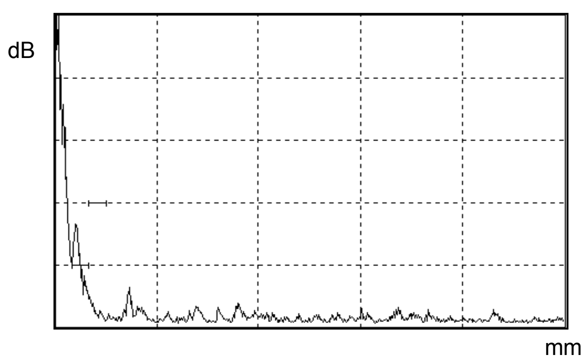
Group of spots:	SWS-8mm
Spot name:	SWS-96
Date:	06.06.2003
Time:	4:53:57 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.96 A-Scan of SWS-96 with 8.0 mm probe



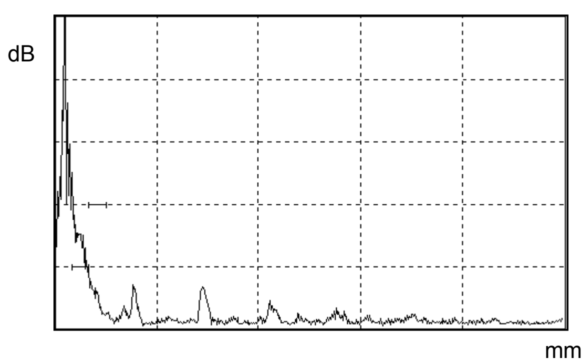
Group of spots:	SWS-8mm
Spot name:	SWS-97
Date:	06.06.2003
Time:	4:54:26 PM
Number of plates:	2
Result:	OK
Plate thickness:	3,98 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.97 A-Scan of SWS-97 with 8.0 mm probe



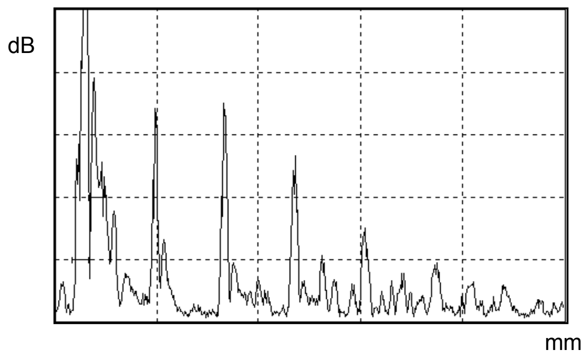
Group of spots:	SWS-8mm
Spot name:	SWS-98
Date:	06.06.2003
Time:	4:55:15 PM
Number of plates:	2
Result:	burnt
Plate thickness:	4,28 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.98 A-Scan of SWS-98 with 8.0 mm probe



Group of spots:	SWS-8mm
Spot name:	SWS-99
Date:	06.06.2003
Time:	4:56:30 PM
Number of plates:	2
Result:	OK
Plate thickness:	4,1 mm
Sound velocity:	5920 m/s
Gain:	50 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.99 A-Scan of SWS-99 with 8.0 mm probe



Group of spots:	SWS-8mm
Spot name:	SWS-100
Date:	06.06.2003
Time:	4:58:37 PM
Number of plates:	2
Result:	stick weld
Plate thickness:	4,22 mm
Sound velocity:	5920 m/s
Gain:	52 dB
Probe delay:	21 µs
Range:	30 mm

Figure E.100 A-Scan of SWS-100 with 8.0 mm probe