

EAA Aluminium Automotive Manual – Joining

8. Mechanical joining

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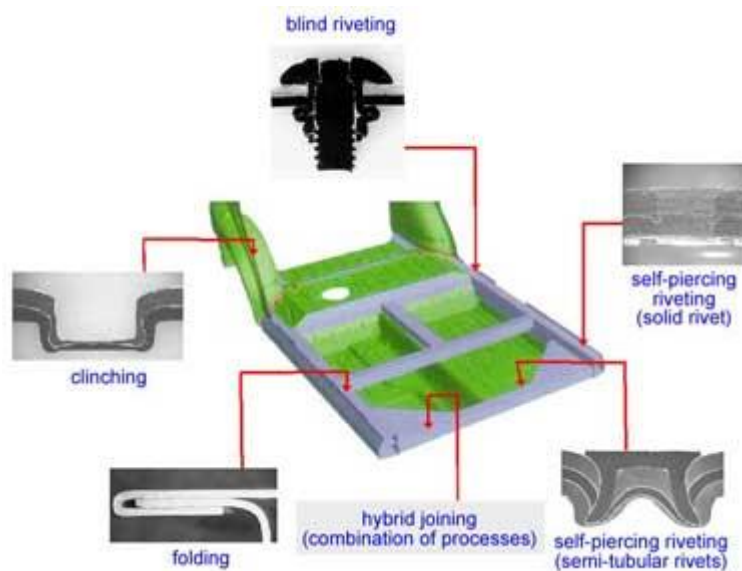
8.2.2.6 Tack high-speed joining

8.0 Introduction

Two groups of mechanical joining techniques can be differentiated:

- Mechanical joining methods without additional fastener
- Mechanical joining methods with an additional fastener.

In the first group, the joint is realised without the need of additional joining elements, only using the work pieces to be joined. In the second group, an additional fastener is applied which, in general, remains within the joint.



Compared to fusion welding techniques, the advantages of mechanical joining methods include:

- Applicable for materials difficult to weld and dissimilar material combinations
- Little or no damage to pre-coated materials
- No fume or heat generation, low noise emission, low energy consumption
- Minimum geometrical distortion (no heat input).

Because of the sensitivity of work-hardened and age-hardened aluminium alloys for the heat input from fusion and resistance spot welding and due to the effects of oxide films on electrode life in resistance spot welding, the use of "non-thermal" joining techniques has gained particular importance in automotive applications. Mechanical joining techniques like bolting, self-piercing riveting, blind riveting, clinching and the combination of these techniques with adhesive bonding have, therefore, been developed to substitute the traditional resistance spot welding.

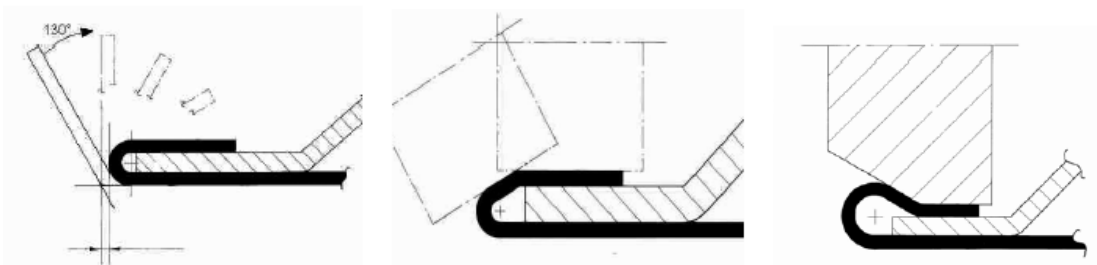
8.1 Mechanical joining without additional fastener

8.1.1 Hemming

In automobile assembly, hemming is used as a secondary operation after the deep drawing, trimming and flanging operation to join two sheet metal parts (generally outer and inner closure panels) together. Typical parts for this type of assembly are hoods, doors, trunk lids and fenders. This technique is also used for the reliable joining of sunroofs.

8.1.1.1 Hemming process

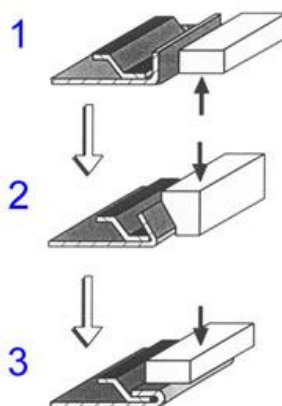
Hemming is a metalworking process in which a sheet metal is folded over onto itself. Normally hemming operations are used to connect parts together, to improve the appearance of a part and to reinforce part edges.



Various hem designs: Flat hem (left), wedge-shaped hem (centre) and droplet-shaped hem (right)

The accuracy of the hemming operation is very important since it affects the appearance of the surface and surface quality. Compared to the standard flat hem, a wedge-shaped hem (which can be further developed to a 180° bend of the outer panel) allows the creation of a sharper edge, improving the visual appearance of the gap between two adjoining panels. A droplet-shaped hem (“rope hem”) is only used when insufficient ductility of the outer panel prevents the realization of a flat hem. A “rope hem” can also alleviate the potential for the formation of unfavourable “streamers” across the visible surfaces of the outer panel.

Hemming belongs to the cold forming processes. Basically, it consists of three steps:



Step 1: bending 90°, Step 2: hemming 45°, Step 3: folding 180°

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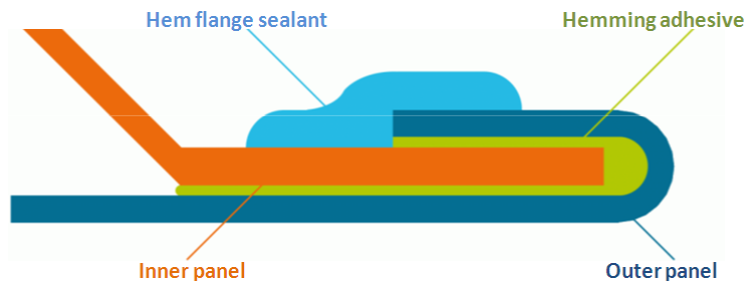
The quality of the hem strongly depends on the formability of the applied sheet material characterized by its minimum bend radius. Important influencing factors are:

- the applied aluminium alloy (composition and heat treatment),
- the thickness of the aluminium sheet,
- the forming history of the sheet / part, and
- the hemming process parameters.

Today, the droplet-shaped hem – formerly common for aluminium alloy sheets – is applied only in exceptional cases where formability is strongly reduced, for example by preceding age hardening effects or strong cold deformation. Normally the flat hem can be realised without any difficulty. High requirements on the visual appearance of the gap may lead to special demands with regard to gap clearance. Specifically developed aluminium alloys for outer body applications fulfill the requirements for flat folds (bending factor < 0.5) and enable the realisation of flanges with inner bending radii of almost 0 mm.

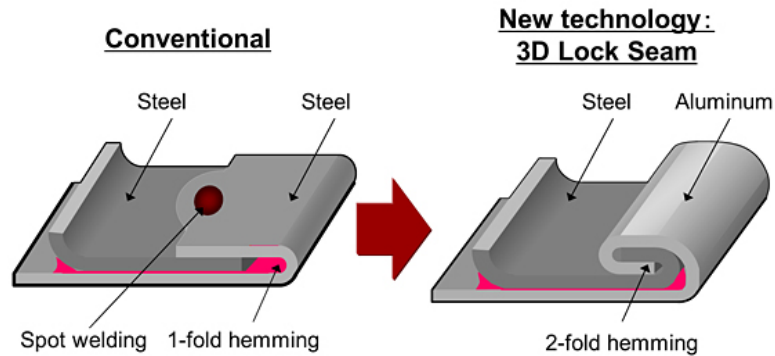
The material deformation during the hemming process, can lead to dimensional variations and other defects. Typical hemming defects are splits or wrinkles in the flange, material overlaps in the corner areas or material roll-in. In practice, numerical simulation tools are used in order to better understand the hemming process and to reduce the number of loops during try-out and production. The standard software packages used for the simulation of stamping processes also properly represent the hemming process.

Closure panels are usually made by hemming the outer panel over the inner panel which also conceals the sharp metal edges. Generally, the hem flanges are protected by a sealant to prevent crevice corrosion of the sandwiched metal. In principle, the hemming technique produces sufficiently strong mechanical joints around the periphery of closure panels. Nevertheless, hemming adhesives are widely used in these flanges to give improved strength, part stiffness, crash performance and corrosion protection (see also 10.1.1). Applied adhesives used include epoxies, PVC or acrylic plastisols, rubber based materials and PVC-epoxy hybrids.



Set-up of the hem flange of a typical closure panel

A more sophisticated hem seam design has been introduced by Honda to join dissimilar metals (steel and aluminium). In the patented "3D Lock Seam" structure, the steel and aluminium panel are layered and hemmed together twice.



3D Lock Seam structure

(Source: Honda)

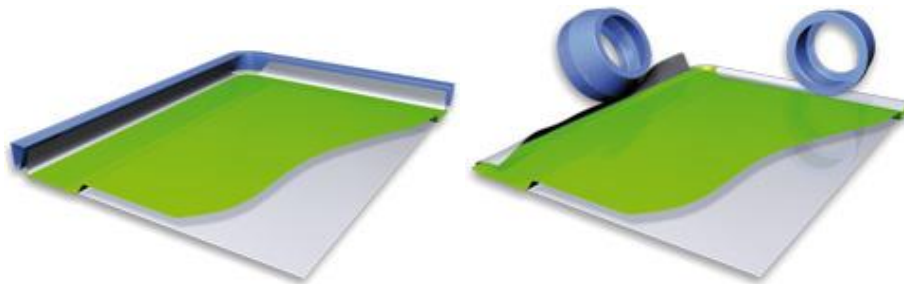
8.1.1.2 Hemming systems

Different hemming systems are available. In addition to optimised solutions for volume production with extremely short cycle times, there is also equipment for niche vehicle production. Special emphasis is always placed on the requirements for increasing fitting accuracy and minimum gap dimensions at reduced costs and with maximum process reliability.

The hemming process involves bending an outer metal sheet around an inner metal sheet. In automotive applications, two methods are used:

- Conventional die hemming
- Roll hemming.

In conventional die hemming, the flange is folded over the entire length with a hemming tool. In roll hemming, the hemming roller is guided by an industrial robot to form the flange.



Conventional die hemming (left) and roll hemming (right)

Conventional die hemming is suitable for mass production. The flange is folded over the entire length with a hemming tool. Normally, the actual hemming operation is the result of a forming step where the flange is formed with a hemming tool after completion of the drawing and trimming operations. The formed flange is then hemmed in several steps. These steps include, for example, the pre-hemming and final hemming depending on the respective opening angle of the flange. Production plants for conventional die hemming are very expensive, but the cycle times are very short.

Roll hemming is carried out incrementally. A robot guides the hemming roller and forms the flange. Roll hemming operation can also be divided into several pre-hemming and final hemming steps. It is a very flexible process and tool costs are significantly lower compared to those of conventional die hemming. However, the cycle times are much longer since the hemming is the hemming roller follows a defined path.

a) Press hemming

Hemming presses are widely used in automotive manufacturing. The process uses traditional hydraulically operated stamping presses to hem closure parts as the last forming step in the stamping line. Press hemming is a fully automated, high cost process suitable for large parts, but due to the complex force geometries restricted to relatively flat, uncomplicated panels.

b) Tabletop hemming

Today, table top hemming is the dominate die hemming technology. Instead of a large hydraulic press, tabletop hemming uses a series of electrically actuated cycle heads. Tabletop hemming devices are used for medium to high production volumes, achieving cycle times down to 15 seconds.



Tabletop hemming equipment

(Source: DV Automation)

Tabletop hemming is a highly adaptable process. It can be used in a variety of cases where conventional die hemming equipment is less suitable, such as for high-mix, low-volume production and most complex panel geometries. Optimum panel surface quality is guaranteed through the hemming principle of the closed ring (corresponds to hemming in the stamping tool).

c) Roll hemming

A particularly flexible solution in closure manufacture, primarily developed for low to medium volumes, is robotic or roller hemming. With roller hemming, the plates are clamped in a tool bed. The roller hemming head is attached to an industrial robot. Rollers which are necessary for various hemming work steps are attached to the roller hemming head. As a result of reduced process forces, the surface quality of complex sheet metal geometries is improved. Dimensional accuracy and tolerances are controlled by selectively influencing the robot program.



Robotic roll hemming

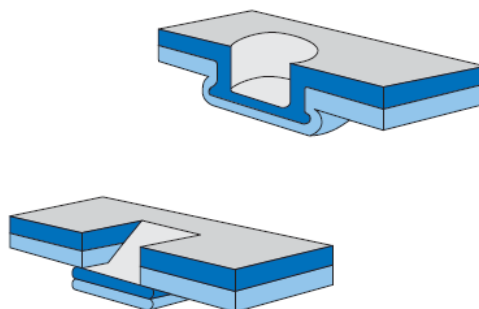
(Source: Kuka)

Automation of the hemming operation can be implemented flexibly. For example, changeable roller hemming tools for different work pieces and manufacturing processes can be provided in an automated cell. Minor changes and modifications to panel hemming conditions can also be accommodated allowing a quick and cost-effective reaction.

8.1.2 Clinching

Clinching is a high speed, mechanical fastening method to join two or more sheet metals by local plastic deformation without an additional fastener or heat impact. It is an inexpensive and easily automated process which only requires a punch and a die. The punch pushes the sheet metal into the die, forming an interlocking friction joint with good static and dynamic strength.

In technical terms, clinching is defined as a single or multi-step fabricating process with a common displacement of the materials to be joined combined with local incision or plastic deformation and followed by cold compression, so that a quasi-form locking joint is produced by flattening or flow pressing (impact extrusion)



Clinch point geometries with and without local incision

The most significant feature of the clinching technique, which is established in the DIN 8593 standard, is that the joint is formed from the material of the metal parts to be joined. The parts to be clinched can be of the same or differing sheet thickness. In industrial applications, clinching is applied from a single

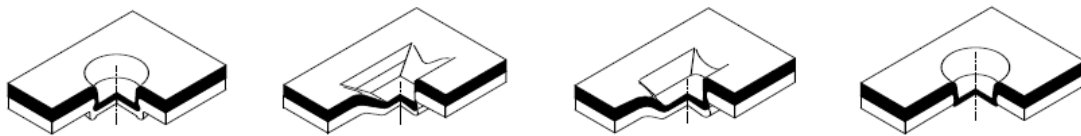
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sheet thickness of 0.1 mm up to a total layer thickness of 12 mm and materials up to a tensile strength of 800 N/mm². In laboratory tests, materials with significantly higher strength values have been successfully clinched.

The clinching process is applicable for aluminium alloy combinations as well for multi-material combinations (e.g. aluminium and steel) and also with pre-coated, painted or galvanized materials. Furthermore, clinching can be combined with an adhesive, a sealant or an intermediate layer (e.g. a sound dampener).

Special tools are used to plastically form the mechanical interlock between the sheets. Tool systems with and without moving die parts have been designed. During clinching with movable die parts, the flow of the displaced metal is determined by the yielding characteristic of the dies. On the other hand, during clinching without movable die parts, the displaced metal flow into a grooved ring in the die. A further differentiation can be made according to the process kinetics. The two main principles are single stroke and double stroke. Single-stroke clinching requires special tool sets for each set of parameters, especially different sheet thicknesses. While double-stroke clinching can adapt to a range of thicknesses, it requires a larger capital investment and is difficult to integrate into the stamping press line.

The wide range of clinching geometries and tool concepts allows the selection of the appropriate type of joint for the each application.



Different types of clinched joints

(Source: Eckold)

Most widely used in automotive applications is the round clinching element where neither sheet is cut ("closed joint"). Clinching joints where either both sheets or only one sheet are cut have generally a rectangular shape. In the latter case, the element is closed on the punch side. In special cases, also a sheet with a pre-punched hole can be placed on the die side.

Clinching often replaces spot welding. The static and dynamic strength of clinched joints are higher than with common spot welded connections. Clinched joints are lower strength than comparable self-piercing rivet connections. The reason is the absence of the auxiliary joining fastener that affects the cross tension strengths in particular. Clinching is thus used primarily in non-crash-relevant areas.

It is a cold forming process, offering up to 60% cost savings over spot welding. Life expectancy for clinching tools is in the hundreds of thousands of cycles. There is no need for pre-cleaning or a process-specific surface pre-treatment and subsequent finishing. Also clinching provides a quieter and cleaner working environment (no sparks and fumes, little noise). An additional benefit of clinching is the avoidance of damage to the integrity of the coatings eliminating such problems as corrosion and degradation.

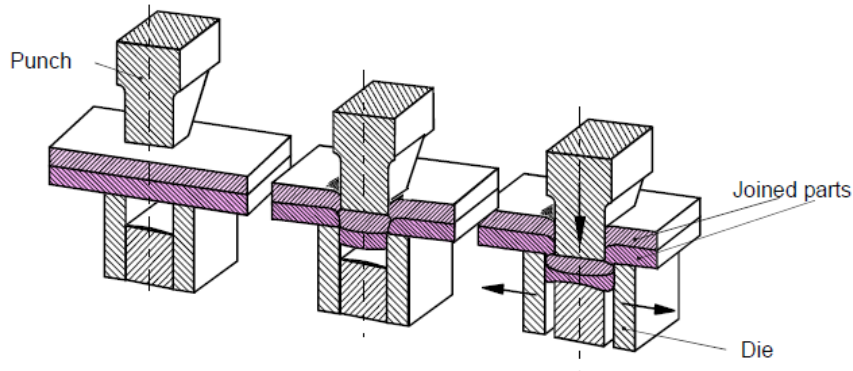


Joining of an aluminium heat shield with a hand held clinching tool

(Source: Attexor)

Clinching systems come in all sizes and types of operations and speeds. Options range from handheld units to multi-head systems with double-acting punch and dies, and self-centring heads. Clinch machines can be used to simultaneously set one or several points and can be easily integrated within robotic cells or other manufacturing systems.

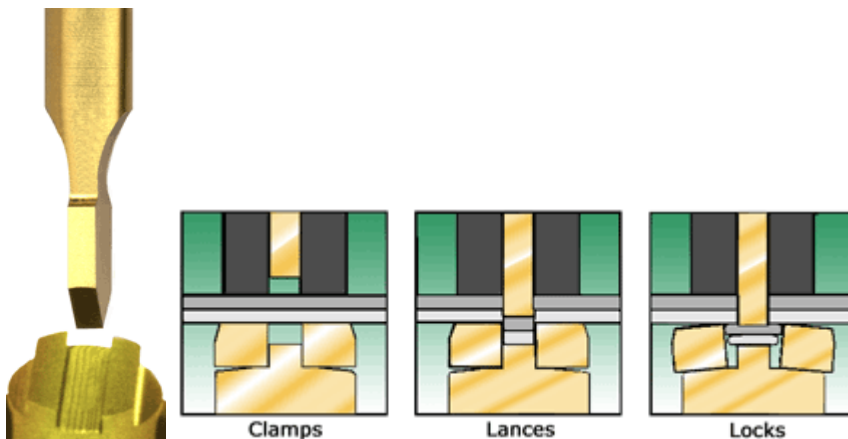
8.1.2.1 Clinching with local incision



Process steps in single-step clinching with local incision

Clinching with local incision creates a permanent joint under the combined action of shear and penetration processes, in which the penetration and incision limit the joint region, and a cold compression process, in which the sheet material pushed out of the sheet plane is compressed and flattened. In the single-step clinching process, the joint is created during an uninterrupted stroke of a single tool component. In the multi-step process, the clinch joint is created under the action of successive motions of the tool components.

Based on this principle, joints with different geometries have been developed over the years. The joint strength increases with an increase of the sheared area as well as with a reduction of the locally incised part (which is replaced by a corresponding increase in the plastically formed part). For this reason, clinching joints without local incision are generally preferred.

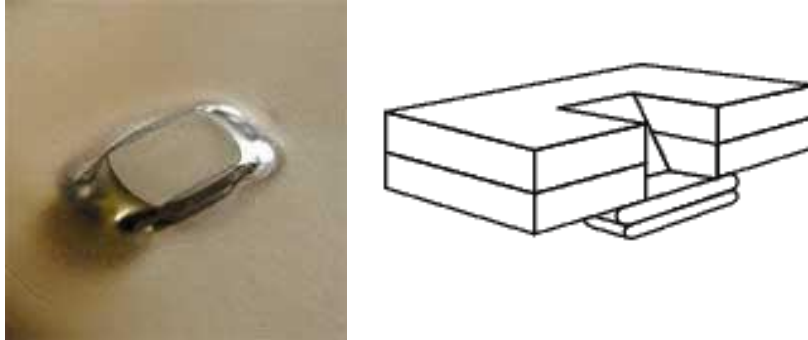


Lance-N-Loc® joining system

(Source: BTM)

In automotive application, clinching with local incision has found limited application. Clinching systems with local incision are primarily suited for multi-layer joints (up to 5 layers or more), certain dissimilar material combinations and high strength, low ductility materials (ultra high strength steels, stainless steels, etc.). Two or more layers of metal typically ranging in thickness from 0.2 mm to 4.0 mm per sheet can be reliably joined in most cases.

As an example, in the Lance-N-Loc® system, a joint is formed by lancing the two long sides of the joint and gradually drawing the ends. The material on the sides of the joint is compressed, expanding the width to form a lock on two sides, all in a single press stroke. The resulting joints are characterized by a “button” formed on the die side layer of metal and a recess formed in the punch side layer. The button is a good indicator of joint quality and simplifies quality control.



Lance-N-Loc™ button side (left) and cross section (right)

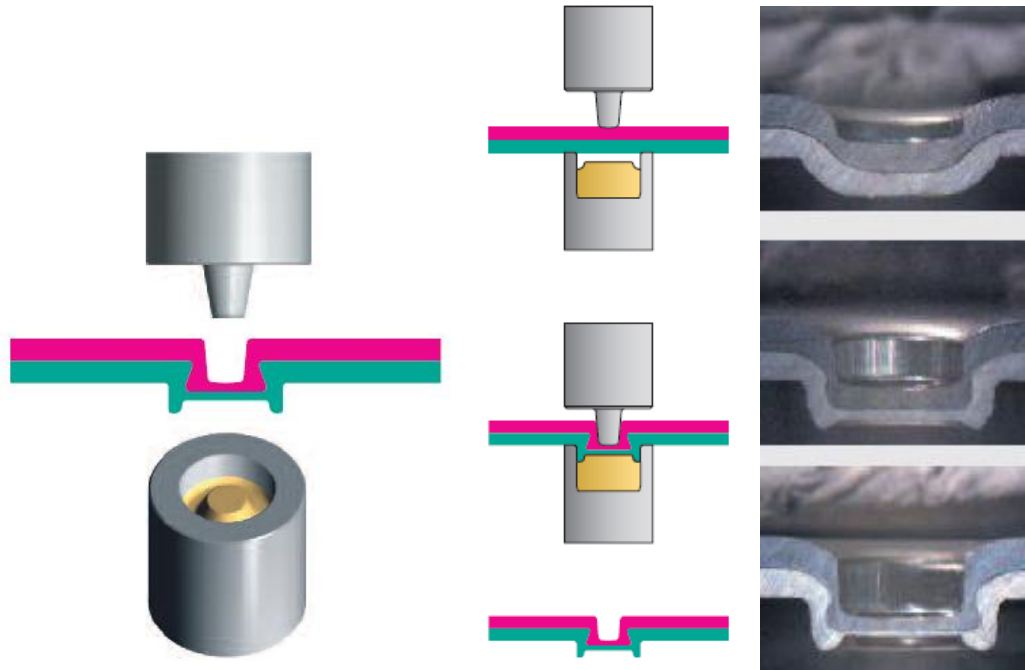
(Source: BTM)

8.1.2.2 Clinching without local incision

The clinching process without incision is a method of joining two or more material layers by localized cold forming using a special punch and die. The punch forces the material layers into the die cavity (“local penetration”) where the pressure exerted by the punch forces the metal to flow laterally (“cold compression”). The result of the process is a button shaped extrusion on the die side of the assembly (which acts as an interlocking joint) and a small, cylindrical cavity on the punch side. No finishing is required. The produced clinch joints are visually appealing, gas tight, protect existing surface coatings better and offer high corrosion and fatigue resistance. In general, round points are utilised. However, with special die designs, also rectangular joints can be created.

a) Solid dies (without moving parts)

The clinch joint is carried out by plastic deformation of the materials to be joined inside a rigid die. In the simplest form (“single-stroke process”), a round punch presses the overlapping materials into the die cavity. As the force continues to increase, the punch side material is forced to spread outwards, but is contained by the solid die walls. Consequently, the die side material is squeezed into a ring-shaped channel in the mechanically locked anvil until a preset clinching force is reached. The result is an aesthetically pleasing round button, which joins clearly without any burrs or sharp edges. The material strain hardening in the neck area and the lack of any notch effect result in a high retaining forces.

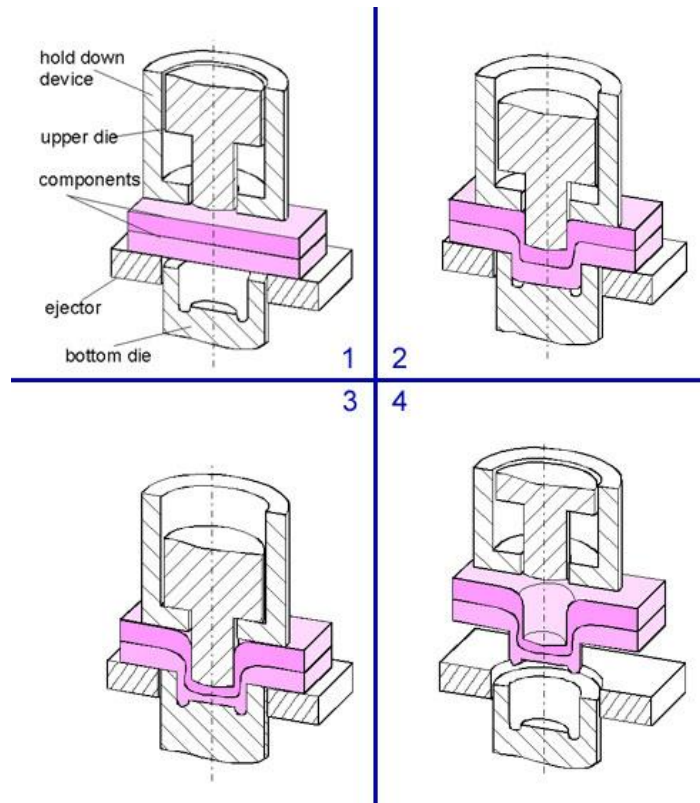


TOX® round clinch joint, a one-step process with a solid die

(Source: TOX Pressotechnik)

The advantage of the die without moving parts lies in the absence of wear of the components. The disadvantage is that oiled aluminium sheets can lead to the formation of a "hydrostatic cushion" in the closed die, leading eventually to the destruction of the die. Similar problems arise in hybrid joining "adhesive bonding plus clinching" or in connection with other intermediate layers.

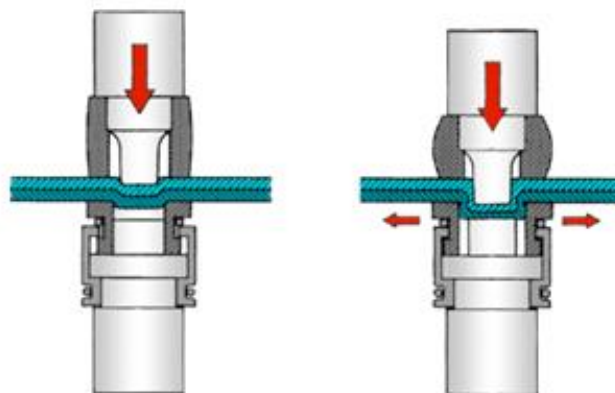
More sophisticated methods include a blank holder and a moving die ("multi-stroke process"). In a first step, the punch and blank holder move downward, the work pieces are clamped and fixed by spring force of the blank holder. By action of the punch, the material flows into the bottom die cavity forming a cup (step 2). The process parameters and dimensions of the punch and die are tuned to the sheet thicknesses of the work pieces to ensure that no material is laterally drawn into the joint from surrounding area. Finally, the thickness of the cup's bottom is reduced by upsetting and the material forced into the die groove and in lateral direction, forming the necessary undercut (step 3). After reaching a pre-set maximum force (force controlled) or a pre-set displacement (stroke controlled), the punch is retracted and the clamping force relieved (step 4).



Single-step clinching without cutting using solid dies

b) Dies with moveable parts

In clinching systems using dies with moveable parts, the materials to be joined are generally clamped by a punch side stripper. Then the punch draws a material section into the die. The die wall, which is split in two or more segments, remains closed. As soon as the material touches the die anvil (i.e. the bottom of the die cavity), the material starts to flow laterally under the pressure exerted by the punch. The movable die sections are pushed outwards, sliding on a base, until the punch-to-anvil distance reaches a pre-set value. Thus, the material forms the button-like mechanical interlock. Finally, the punch is returned to its starting position by the operator or by a pneumatic timer which removes the force. The joined component can now be removed and the die walls close again.



Single-step clinching using a die with moveable segments

(Source: Attexor)

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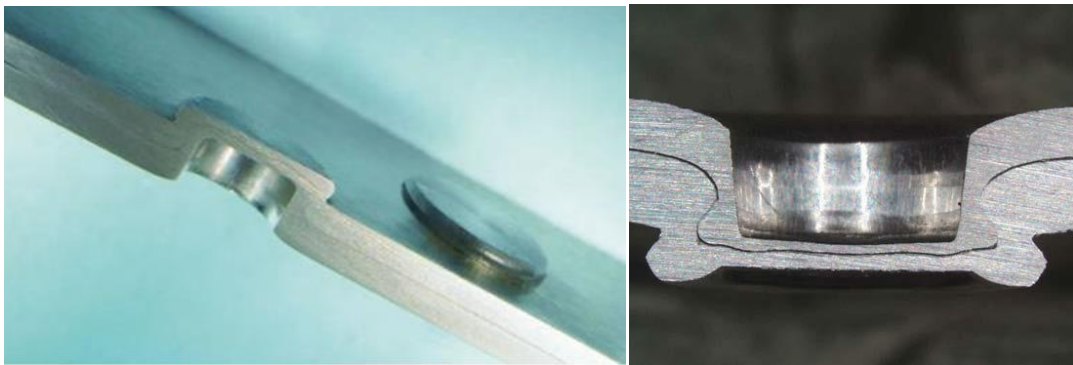
Various die designs are used by the different system suppliers. Dies may include two or more moveable segments which are pulled back together by a spring or a similar mechanism. More versatile die designs include fixed as well as flexible segments. The materials and the punch are centred by the solid segments, thereby guaranteeing that the joint formation is perfectly concentric. The mobile parts allow an interlocking of the material in the joint.



Examples of clinching dies with moveable segments: Eckold R-DF (left), Böllhoff RIVCLINCH® (centre) and TOX® SKB (right) system

(Sources: Eckold / Böllhoff / TOX Pressotechnik)

The advantages of clinching with moveable dies over methods with non-segmented dies are seen in a more flat protrusion of the joint and a higher flexibility when sheet metals of different thickness have to be joined. Very high pull-out tension values can be achieved due to improved flow behind the material because the die opens during clinching and the material can flow to the side. Moveable die systems are also beneficial when joining oily sheets and for applications where an adhesive is applied between the metal layers.



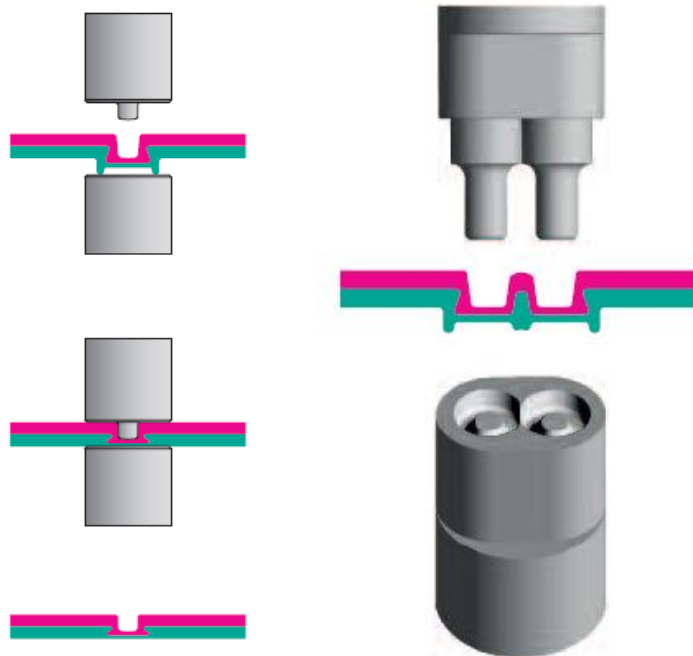
Clinch joints produced with moveable dies, at right, a cross section of an adhesively bonded material combination

(Source: Böllhoff/Eckold)

c) Clinching methods for special applications

The applications for clinching are so diverse that special methods have been developed to take into account the individual requirements.

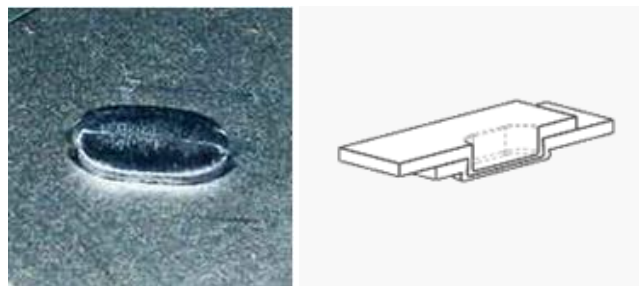
Clinching creates a protrusion on the die side, which might be considered as an obstruction. In this case, the standard clinch joint created in a first step can be flattened (± 0.1 mm) in a secondary operation using a flat die. The high shear and pull strengths of the clinch point are left virtually intact.



Special clinching methods: Flat joint (left) and twin joint (right)

(Source: TOX Pressotechnik)

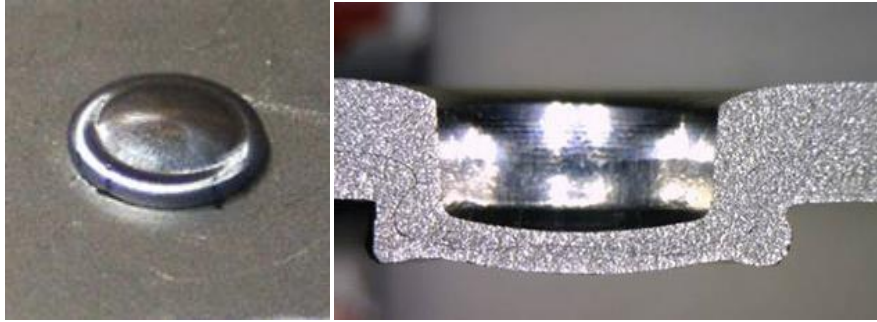
The twin clinch point shown above provides protection against rotation. Also it almost doubles the joint strength in comparison to the single joint. Whereas this solution was developed for a solid die clinching technique, anti-rotation benefits can also be achieved when using moveable dies.



Oval-shaped clinch joint: Button side view and cross section

(Source: BTM)

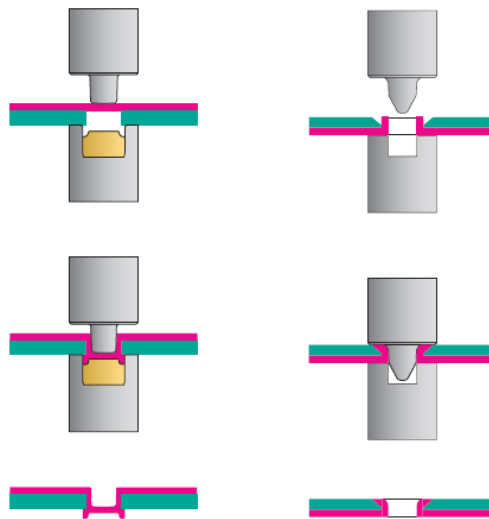
Originally developed to respond to a request for a visually improved clinch joint button, the V-Loc™ joint also results in an improved material flow within the clinch joint. A thicker side wall and improved interlock increase shear and peel strength by approximately 25% over the standard Tog-L-Loc® joint when joining some aluminium alloys. The V-Loc™ joint features a raised spherical inner diameter with a concentric outer ring, intended to give the appearance of a more traditional fastener.



V-Loc™ button side view and cross section

(Source: BTM)

Special clinching methods are also available for difficult cases, e.g. joining of sheet metal with large differences in thickness, joining of high strength or non-ductile materials with ductile materials or joining of non-metallic materials. One layer is pre-punched; the ductile material is then pushed through the hole. The resulting connection has radial and axial strength. Multiple joints can be applied in a single press stroke. However, this process requires precise alignment of the parts.



Two process variants for clinching difficult material combinations

(Source: TOX Pressotechnik)

8.1.2.3 Design criteria for clinched joints

Clinching requires open flanges with good access to both sides for punch and die tooling. Proper accessibility is needed for clamping and pressing the material between the punch and the anvil. The flange width must be sufficient to accommodate the interlocking button produced during clinching spot as well as the surrounding deformed material. Otherwise, the button may burst out of the edge of the flange or cause a local distortion of the part. As a general rule, the clearance between the centre of the joint and the flange outer edge should be 1.5 times the punch diameter. Also, the clearance between the joint and the flange inner edge must be large enough to allow tooling access to make the joint.

Clinch spots should be spaced to avoid previously formed joints or the strained area immediately around them. Clinching in or near prior joints may result in unsatisfactory joint appearance, excessive thinning of the bottom sheet and accelerated tool wear. Placing several clinch spots too near to each other may also cause distortion or bending of the joint. However, there must be enough joints to guarantee the overall design strength of the assembled component. A minimum joint spacing of two to three times the button diameter is recommended.

Proper planning of the clinching sequence and suitable clamping of the work pieces will avoid such problems. Good process control ensures that the material layers to be joined are properly drawn

together as the clinch spots are driven and set. In addition, no joining process forces will be diverted into component. Accurate overlap of the layers to be joined and a correct flange width facilitate proper alignment between the work pieces, punch and die. A pre-clamping step may be helpful if joining a flange width close to the minimum width is to be undertaken. Joints should be fully closed after the clamping stage. Poor fit-up and alignment are major contributors to inconsistent clinch quality.

The strength of a clinched joint depends basically on four main factors:

- The type of aluminium alloy of the work pieces,
- The sheet thicknesses,
- The clinch button size (the diameter should be as large as possible),
- The surface condition of the material.

A completely dry, grease-free surface will give a stronger joint than if the surface is oily or wet. On the other hand, a minimum lubrication avoids adhesion of the aluminium to the tool and significantly improves the tool life. Thus a suitable compromise must be found.

Cinching is a cold forming process. Therefore, the formability of the involved materials must be sufficiently high. As a rough estimate, good clinch joints can be achieved if:

Elongation to fracture $A_{80} \geq 12 \%$
Yield ratio $R_{p0.2}/R_m \leq 0.7$.

A limited ability to apply clinch joints is given when:

Elongation to fracture $12 \% \geq A_{80} \geq 8 \%$
Yield ratio $R_{p0.2}/R_m \geq 0.7$.

In this case, it is important to qualify the clinching performance in laboratory tests before practical application.

When dissimilar materials are being joined, best results are achieved if the following rules regarding the joining direction are observed:

"Thick sheet into thin sheet" and
"High strength into low strength".

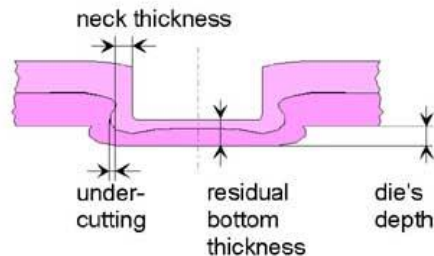
The localisation of the thicker material on the top ensures that enough material can flow into the die cavity. Otherwise, the neck area will be very fragile. The thicker material should not be more than twice the thickness of the thinner material. The combined thickness of the two plies should not exceed the combined maximum thickness recommended for the die. Also, if one material is considerably harder than the other, the harder material should be on the punch side. If the softer material is on the punch side, the punch may go right through the softer material, instead of deforming. However, for special applications, various suppliers also offer tool designs which can be optimised to adapt different combinations.

8.1.2.4 Quality criteria for clinched joints

The quality of a clinched joint is determined by many different factors. It depends on the joining method/equipment, the applied tools and specific joining parameters and in particular on the parts to be joined (number of parts, material quality and thickness, surface conditions, joint geometry and accessibility, joining direction, etc.). Therefore, prior laboratory tests of the specific joint arrangement are recommended to determine the relevant design parameter like static and dynamic strength, crash resistance, etc.

For clinching, there is a causal relationship between joint quality and the geometry of the clinch joint. It is therefore possible to estimate the quality of the joint from a visual evaluation of the clinch joint and

by measuring geometric parameters. As an example, for non-cutting, round button clinching techniques, the strength of the connection is determined by the magnitude of the undercut and the neck thickness. These values are influenced by the tool dimensions, such as the punch diameter and the depth and diameter of the die cavity, as well as by the setting of the displacement limits for the upper-die. A larger undercut can be achieved by reducing the residual bottom thickness. However, to avoid overloading the tools and work piece due to excessive joining forces, a compromise between maximum joint strength and tool life is required.

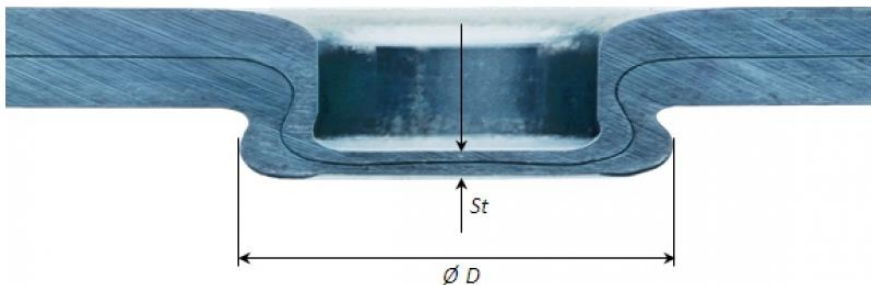


Quality criteria for a clinched connection

a) Quality control

Clinched joints result from the interaction between clinching equipment, material, and punch and die. As a consequence, the material has been geometrically changed in comparison to the original flat sheet metal. Therefore, the joint quality can be monitored by measuring the bottom thickness of the joint and/or the button width.

The residual bottom thickness correlates well with the joint strength and is generally used as a non-destructive quality control measurement.



Practical quality control normally includes measuring the residual base thickness (S_t) and the joint diameter (D) on the die side of the joint. The optimum values are predetermined in laboratory tests for each application. Comparison of these reference data with the parameters measured during production guarantees a reliable quality control of the clinch joints.

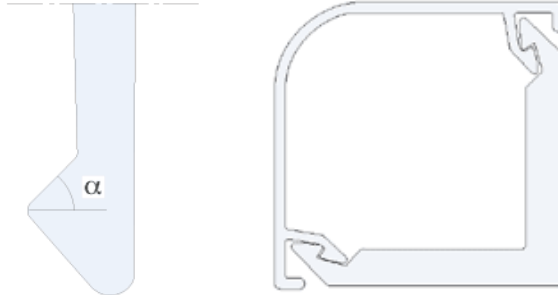
b) Process monitoring

An electronic, process controller can be used to check the joining process for automated or mass production. Process monitoring consists of measuring force and displacement of the punch, as joints are being made, and checking that the values of these parameters are being correctly maintained by the clinching equipment.

A force sensor is installed on a C-frame. Another sensor measures the tooling position. Thus, a force-displacement curve is generated in real time for every clinch joint. The software allows checking process "windows" which must be previously programmed along the curve. The last one is the final value of the completed joint. The width of this acceptance range can be altered to suit the requirements of specific applications. Results outside the acceptance range normally indicate faults or variations in process operation or materials, which could lead to unacceptable joint quality.

8.1.3 Mechanical interlocking

Due to its elasticity, aluminium is highly suited to realise snap-fit joints, allowing far quicker assembly than, for example, screw or welded joints. Snap-fit joints are a most interesting joining technique for extruded aluminium profiles and widely used in a range of industries. In automotive design, relevant application areas can be found primarily in the floor structure and in the interior, in particular when joining extruded aluminium and plastic sections.

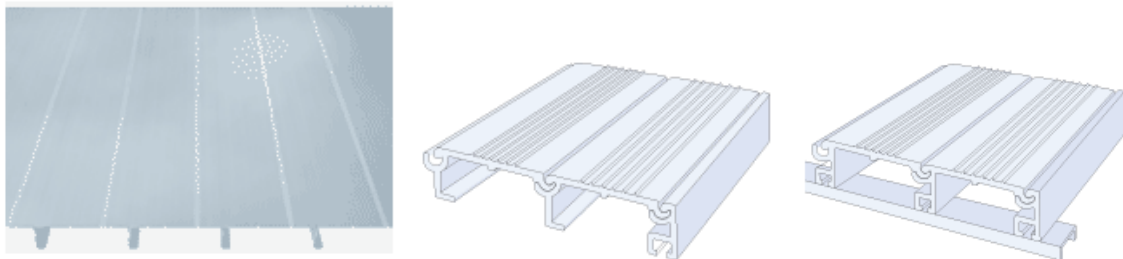


Design of snap-fit joints

(Source: Sapa)

In detachable snap-fit joints, the hook angle is $\alpha = 45^\circ$. In permanent snap-fit joints, the hook angle is $\alpha = 0^\circ$ (or negative). The length of the snap-fit joint has an effect on design; it should not be below 15 mm. If a design cannot accommodate hooking arms of sufficient length, however, the sprung part of the profile should be replaced by plastic clips. The same applies if the joint is to be repeatedly opened as the fatigue properties of aluminium do not permit frequent changes in loading.

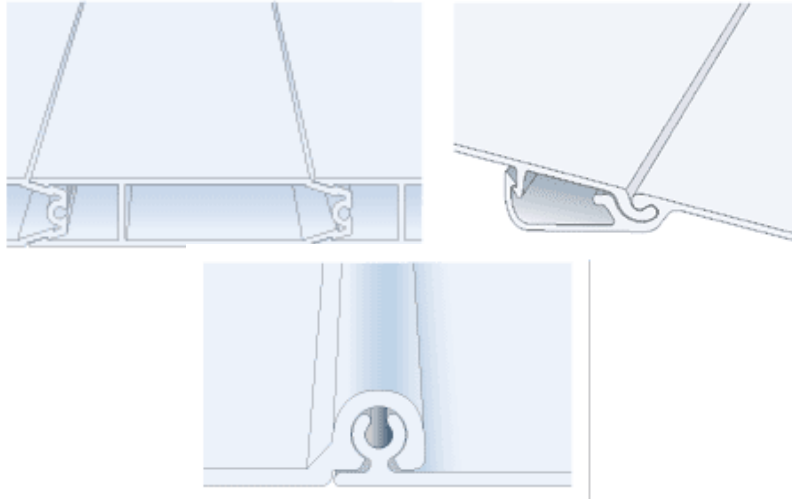
As an example, larger cross-sectional areas can be economically created by joining together a number of extruded aluminium profiles together. This solution is often chosen because it is easier to machine smaller profiles individually rather than a single construction as a whole.



Large cross-sectional areas realised with snap-fit joints

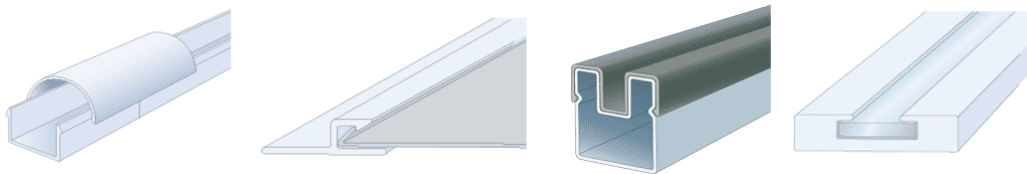
(Source: Sapa)

For latitudinal joining, mechanical (snap-fit) connections can be used as a cost-efficient alternative to other joining methods like adhesive bonding, fusion welding or friction stir welding. The use of a flat bar or a similar measure ensures proper flatness. The assembled structure can be additionally fixed with screws, the introduction of a tubular spring or properly designed clamps.



Latitudinal joining using with a snap-fit (left or centre) or screw ports (right)

(Source: Sapa)



Snap-fit joints allow various design solutions (from left to right):

- Longitudinal joint using spring and friction mechanisms
- Snap-fit joint with a formed sheet panel
- Snap-fit joint between aluminium and plastic profiles
- To deal with high local surface loads and reduce wear (e.g. from a rolling steel wheel), a steel strip can be inserted into the aluminium profile.

(Source: Sapa)

8.2 Mechanical joining with an additional fastener

Mechanical assembly methods using an additional fastener can be classified according to the necessary preparation of the parts to be joined and the accessibility.

In this section, functional components are also covered. In particular when joining thin sheets, it is often difficult to introduce a load-bearing screw thread. Therefore, functional components which fulfil the function of either a nut or a bolt or screw are often attached, depending on the specific joining task. The functional component which is later used in the actual joining process stays within the assembled structure.

8.2.1 Screws and bolts

With the help of screw-and-nut fasteners, it is possible to create large clamping forces. Bolted or threaded connections for the attachment of equipment to aluminium components and structures may be produced by simply bolting through the aluminium part. In some cases, it may be necessary to provide internal support if bolting through a closed section, e.g. when attaching the engine or

suspension to the body front rails. This support can be with tubes or extrusions fixed inside the hollow section to prevent the section from collapse under high installation loads.

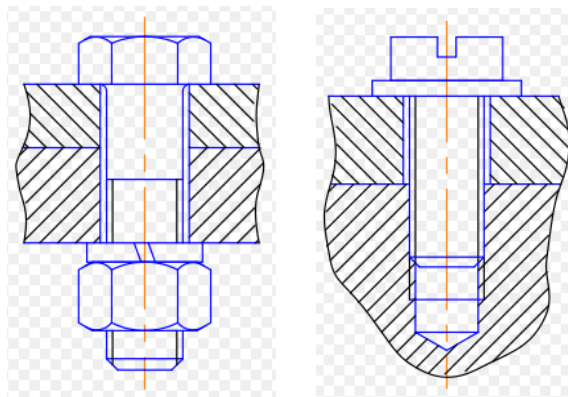
Bolted connections can also be achieved with threaded studs and nuts which are fixed to the aluminium part. The selection of insert type depends upon the strength (torque) required and whether access is only possible from one side (blind) or both sides of the aluminium part. Aluminium welded studs and nuts are available that may be welded directly to the aluminium parts, e.g. by an electric arc welding process (see 3.3). Aluminium threads are, however, not recommended for situations where frequent removal for service is required. Steel threaded studs and nuts are preferred for applications where higher strength or frequent dismantling may be necessary.

Care must be taken if bolting material combinations are used, which are critical with respect to galvanic corrosion. Except for stainless steel, all steel inserts assembled into aluminium parts must be coated to prevent galvanic corrosion. Insert manufacturers can supply a range of suitable coatings. Sealants, gaskets or protective coatings may be required in severe corrosive environments, whereas simple surface treatment of the steel and/or the aluminium may be adequate in a dry internal environment.

8.2.1.1 Threaded fasteners

Threaded fasteners are one of the most universal and widely used types of fasteners and are manufactured in a wide variety of shapes and sizes. Threaded (or screw) joints belong to the group of detachable joints. They can be designed as pierced, pierced and protruding or blind-hole joints. Threaded fasteners require either a mating thread (which must be manufactured separately) or the use of an extra, internally threaded component (nut).

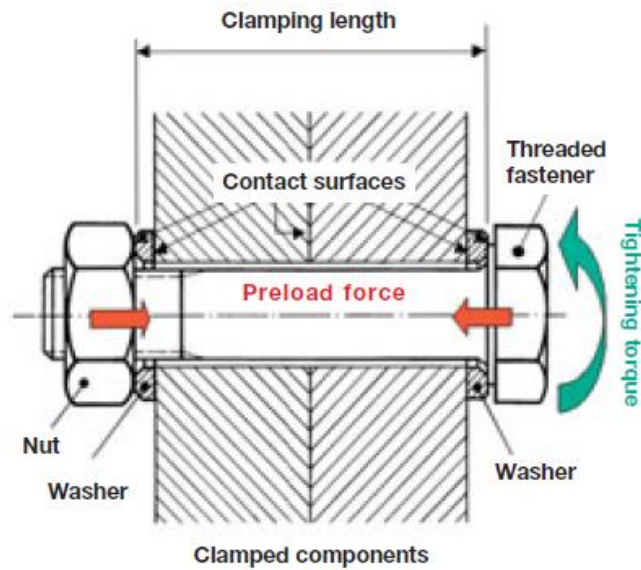
A distinction can be made between connections formed using a clearance hole (bolts) and internally threaded holes (screws). If appropriate measures are taken against corrosion, screw joints are suitable for formed aluminium sheet components, profiles and castings with other aluminium alloys or dissimilar materials.



Bolted (left) and screwed joint (right)

Threaded fasteners for aluminium are usually made of stainless steel or properly surface-coated steel, but also other materials (including high strength aluminium alloys) can be used. Since aluminium alloys have a relatively low compressive strength, the contact surfaces must be generally protected by the use of washers under the screw and the nut.

The classic threaded connection is formed by joining two or more components by means of form-fit or friction-fit fasteners. Threaded connections should be designed in such a way that the permissible stresses in the mating components are never exceeded by the forces acting on the connection as a whole. The tightening torque should be selected such that the preload force produced creates a purely frictional connection between the components and thus prevents them from sliding against each other or having to be supported by the shaft of the fastener (as compared to a rivet connection).



Joining with threaded fasteners

(Source: Böllhoff)

The selection of the required fastener relies upon a precise knowledge of all loads that might occur, and is thus dependent on the specific application. The most important factor is that sufficient load-bearing turns of the thread are engaged to be able to withstand the prevailing forces.

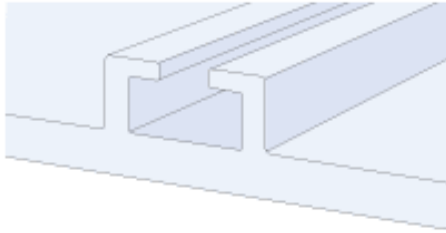


Threaded screws with driving features particularly suited to automatic assembly

(Source: Böllhoff)

In order to meet the increasing demands for automation in manufacture, special fasteners have been developed to satisfy the dual requirements of suitability for automatic feeding and optimisation of force transmission geometry. Angle controlled tightening methods are generally used for fully automated assembly processes.

A special benefit of the aluminium extrusion technology is the integration of continuous tracks for nuts or bolt heads into the cross section of the extruded profile. Continuous tracks enable step-less fastening with no need to machine the profile. Using special nuts/bolts, fastening can even take place without having to slide the nut/bolt in from the end of the track. Various solutions are available from screw and fastener manufacturers.

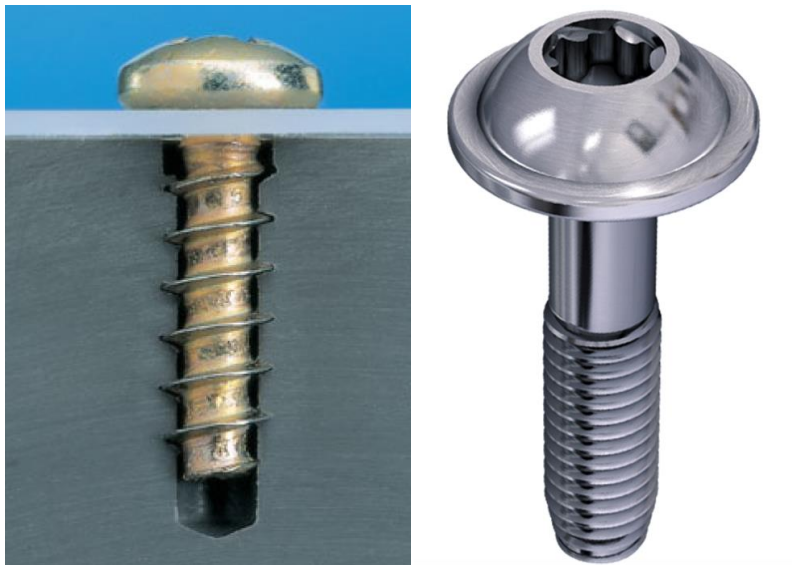


Continuous tracks for step-less fastening in extruded profiles

(Source: Sapa)

8.2.1.2 Self-tapping screws

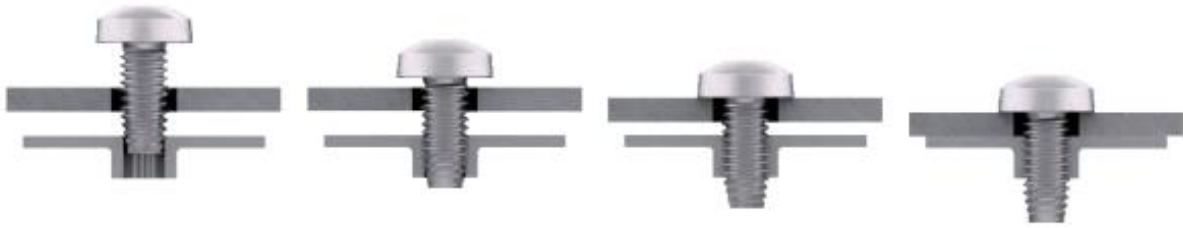
Self-tapping screws are thread forming fasteners, which form their own threads when screwed into core holes. Self-tapping (thread rolling) screws are designed to be driven into pre-drilled core holes in solid metal parts. They roll their mating thread without any cutting action. The thread end is tapered to make it easier to start the thread forming process. The rolled thread is compatible with metric external threads, i.e. a standard metric screw can be used in case a repair is required.



Self-tapping screw

(Source: Böllhoff / EJOT)

The component should be prepared either as a blind hole in full material or as a stamped (or laser cut) hole in sheet metal. For thin sheet applications, prior formation of a rim may be considered. After positioning the screw, the thread is formed and the screw is tightened. The required tapping torque is relatively low whereas the tightening torque is high. The positive fit in the self-formed thread prevents spontaneous loosening of the joint.



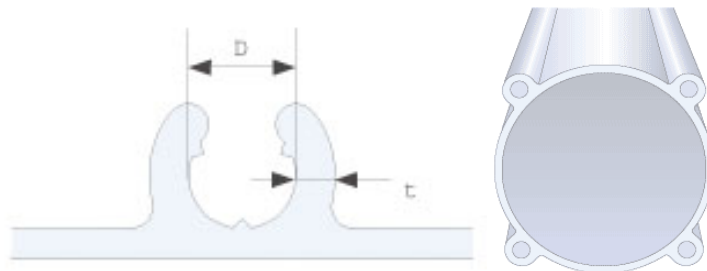
Joining with thread forming screws

(Source: Betzer)

The female thread is formed by the screw thread. The prerequisite is that the screw thread is harder than the work piece and that the mating material is sufficiently ductile to allow the thread to be formed. The basic rule is: “Coarse pitch threads for soft materials – fine pitch threads for hard materials”.

Self-tapping fasteners are highly suited for joining aluminium alloys, in particular when larger aluminium parts like extrusions and castings are involved. Using self-tapping fasteners increases productivity during assembly and reduces the joining cost. The production sequence is economised, there is no need for prior thread cutting and the number of assembly components is reduced. Furthermore, the overall component weight is lowered.

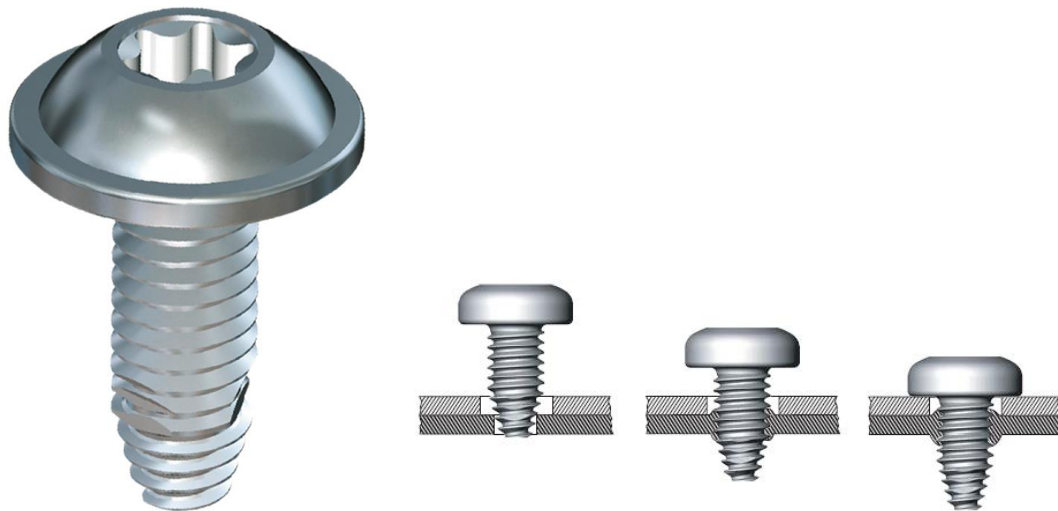
Extruded aluminium profiles offer most interesting solutions in this respect. Screw ports for transverse connections can be directly integrated into the cross section. As shown below, the screw ports will generally have projections to centre the self-tapping screws. Where the design requires a more robust screw, also closed screw port can be used. Similar approaches can be used for longitudinal connections.



Integration of screw ports into extruded aluminium profiles

(Source: Sapa)

The reliable assembly of thin sheets with pre-punched holes with self-tapping screws presents more problems. New developments, however, offer a secure solution for the reliable assembly of pre-punched metal sheets with less 1.5 mm thickness.



Joining thin sheets with pre-punched holes (EJOT SHEETtracs® system)

(Source: EJOT)

The EJOT SHEETtracs® screw features a 45° (30° / 15°) asymmetric flank angle and creates a stronger female thread in the sheet with less material displacement. This increases the stripping torque level of the joint and enables multiple repeat assemblies. In the lower, tapered area of the screw, the flank angle is reversed, and the resulting through draught is formed mainly into fastening direction. The non-circular thread forming zone ensures easy, centred application and the raised thread areas ensure a secure penetration of the sheet material. The circular cross section in the upper, load bearing thread results in higher thread engagement in the sheet metal compared to non-circular thread geometries.

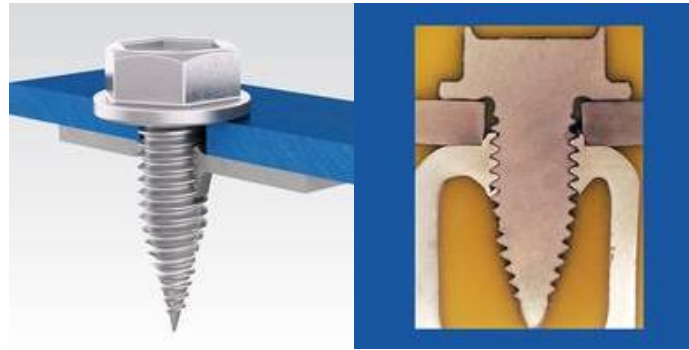
8.2.1.3 Hole and thread forming screws

The use of hole and thread forming screws for direct mounting of thin sheet metal parts allows substantial cost savings and significant quality improvements. Hole and thread forming screws eliminate the drilling operation in the assembly of thin sheets and enable the realisation of high strength screw joints due to increased thread engagement in the formed draught. The economical and qualitative advantages are essentially the same as for self-tapping screws. However, special measures must be taken as the rim necessary for the female thread is formed directly in the joining process without producing chips. Thin materials can be also joined without pilot hole; for specific material combination, a pilot hole may be recommendable. Joining of steel sheets with thicknesses up to 2 mm and of aluminium sheets with up to 5 mm thickness is generally possible.

Since there is no need for preparations like pre-punching or pre-drilling, the usual tolerance problems for screw joints such as overlapping of draught and insertion hole do not apply. The one-sided accessibility of the part provides for an assembly into hollow profiles (e.g. hydroformed or extruded aluminium profiles) without any counter support. Joining with hole and thread forming screws is highly suited for automated assembly; the screws can be also removed and the female thread can be used in case of future maintenance and repair. There are essentially two different methods.

a) Cold hole and thread forming screws

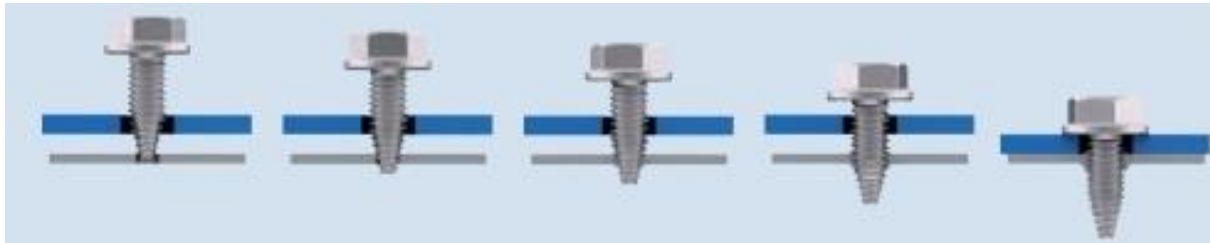
The basis for joining with cold hole and thread screws is a more sophisticated screw design. The special geometry of the screw point produces a high contact pressure per unit area which then leads to the necessary plastic deformation of the material.



Hole and thread forming screws for thin sheet metal

(Source: Betzer)

The hard point of the screw ensures that only little manual contact pressure is required. The hole begins to form after just a few turns of the screw. The specially designed cone shape and thread flanks enable proper forming of hole and rim. Then the thread is formed, the screw is fully screwed in and tightened. The resulting short cycle times allow cost-efficient assembly. Apart from the conical point, also screws with a truncated cone point are available. The conical shank end facilitates finding and positioning in particular in case of stamped thin sheets.

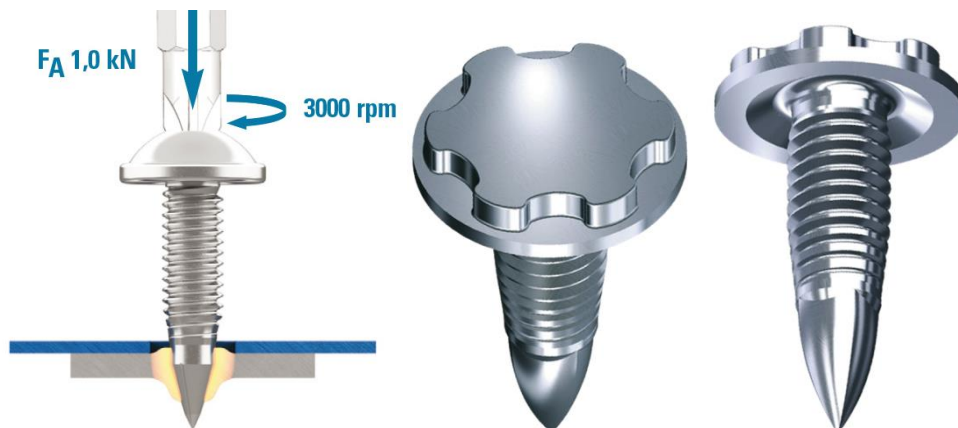


Process sequence for hole and thread forming screws

(Source: Betzer)

b) Flow forming screws

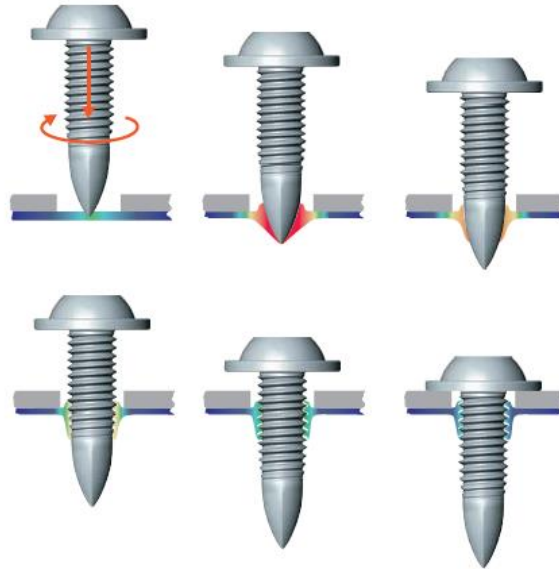
In the flow forming (drilling) process, a tapered, but unthreaded punch rotating at high speed is forced down to pierce through the metal. The sheet metal heats up and is momentarily softened. Thus, a collared hole is formed by plastic deformation. A thread can then be tapped into the cylindrical hole. Stainless steel sheet metal screws are most often used for joining aluminium alloys.



Joining with flow drilling screws

(Source: Betzer / EJOT)

After a short warming up period, the material is penetrated. Then, the draught and the thread are formed. After full thread engagement, the screw joint is tightened.



Process steps of flow drilling screws

(Source: EJOT)

Due to the increased thread engagement in the formed draught, a high-strength screw joint is created – without any undesired metal chipping. The screw joint is able to transfer high pull-out as well as shearing forces. The positive fit of the screw in the self-formed thread prevents spontaneous loosening, i.e. ideally suited for the safe assembly of dynamically loaded screw joints.

Since a small amount of the material flows against the fastening direction, the geometry below the screw head was optimised. While in the past the clearance hole was used for taking up the displaced material, it is now absorbed by the increased space below the screw head.

8.2.1.4 Functional components for screw joints

Another possibility to form a solid direct connection when the part to be screwed is thinner than the thread pitch of the tapping screw is the use of functional joining components. The applied functional components are generally threaded elements which take on the role of either the nut or the bolt and enable the attachment of additional parts by screws in a second step. Threaded studs and nuts fixed to the aluminium part may, however, also be used for other purposes. Steel threaded studs and nuts are usually installed for applications where higher strength or frequent dismantling is necessary. Aluminium studs and nuts are applied for lightly loaded connections for internal trim, electrical harnesses, equipment attachment, etc.

Different types of steel inserts for studs and nuts are available that can be installed in pre-pierced holes in the aluminium part. Other type of studs and nuts are self-piercing and do not require prepared holes. Sometimes, installation of the inserts can be incorporated into the part forming operation, e.g. in the press line after the forming, trimming and piercing or into a hydroforming tool. They can be also installed separately at any stage in the assembly sequence including in-process and in-service repair.

After installing, some types of stud and nut inserts leave a raised element on the opposite side that must be allowed for in the design of subsequent assembly of the part. For specific applications, there are also nut inserts that are sealed to prevent any leakage through the fixed joint. Due to the large variety of possible solutions, only a limited selection can be presented here.

Three types of functional components can be differentiated:

- Press-in elements using pre-punched holes
- Elements using pre-punched holes, attached by riveting
- Self-piercing elements.

Characteristic for the application of these types of functional components is, however, the necessity of double-sided access. On the other hand, a big advantage is the possibility to insert functional fasteners directly in a stamping operation. With each stroke of the press, any number or combination of fasteners may be positioned together for multiple installation. Compared to welded nuts and studs, significant cost savings can thus be achieved.

a) Press-in nuts and bolts

Press-in (or self-clinching) fasteners are threaded inserts that are pressed into a pre-punched hole in a sheet metal by applying a steady squeezing force. Self-clinching nuts and studs are available in various shapes and different materials (e.g. steel, stainless steel and aluminium).

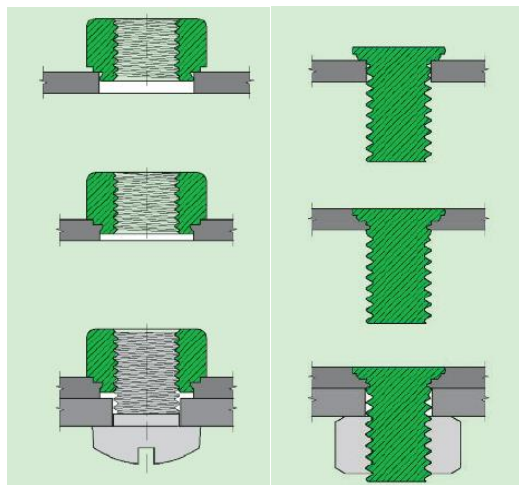


Different types of self-clinching fasteners

(Source: Emhart Teknologies)

Depending on the material combination, suitable measures have to be taken to avoid galvanic corrosion.

Characteristic for press-in fasteners is that the functional component is not deformed during installation. The deformation of the work piece leads to a displacement of the material out of the area of the wall of the hole into the gear ring / annular grooves of the insert. The clinch ring then locks the fastener into place. Once fully embedded (i.e. when the shoulder of the fastener is seated flush with the sheet surface), the knurled area underneath the shoulder of the fastener prevents torque out during the tightening of the mating part; a permanent connection is formed.



Screw joints realised with press-in nuts (left) and studs (right)

(Source: Kerb-Konus)

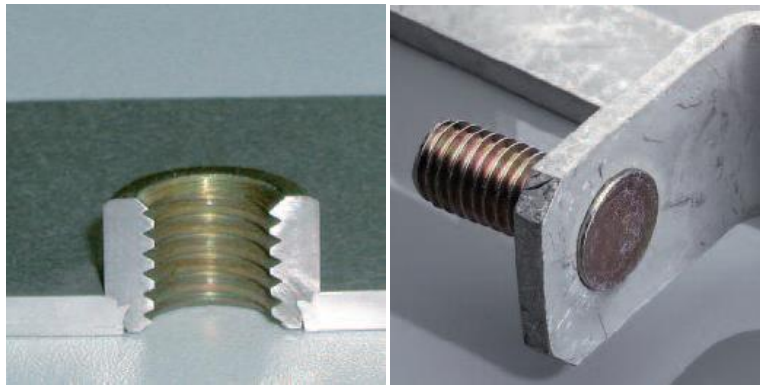
THE ALUMINIUM AUTOMOTIVE MANUAL

The receiving hole is punched, laser cut or drilled, but not deburred or countersunk. With punched holes, the insert is preferably pressed in from the punching burr side. The press-in process takes place on a plane parallel basis using a customary press with adjustable pressure level. Self-clinching or press-in fasteners are used to create wear-free screw connections capable of withstanding high loads in thin walled components from metallic materials.



Press-in nuts and studs (Clifa® system)

(Source: Kerb-Konus)

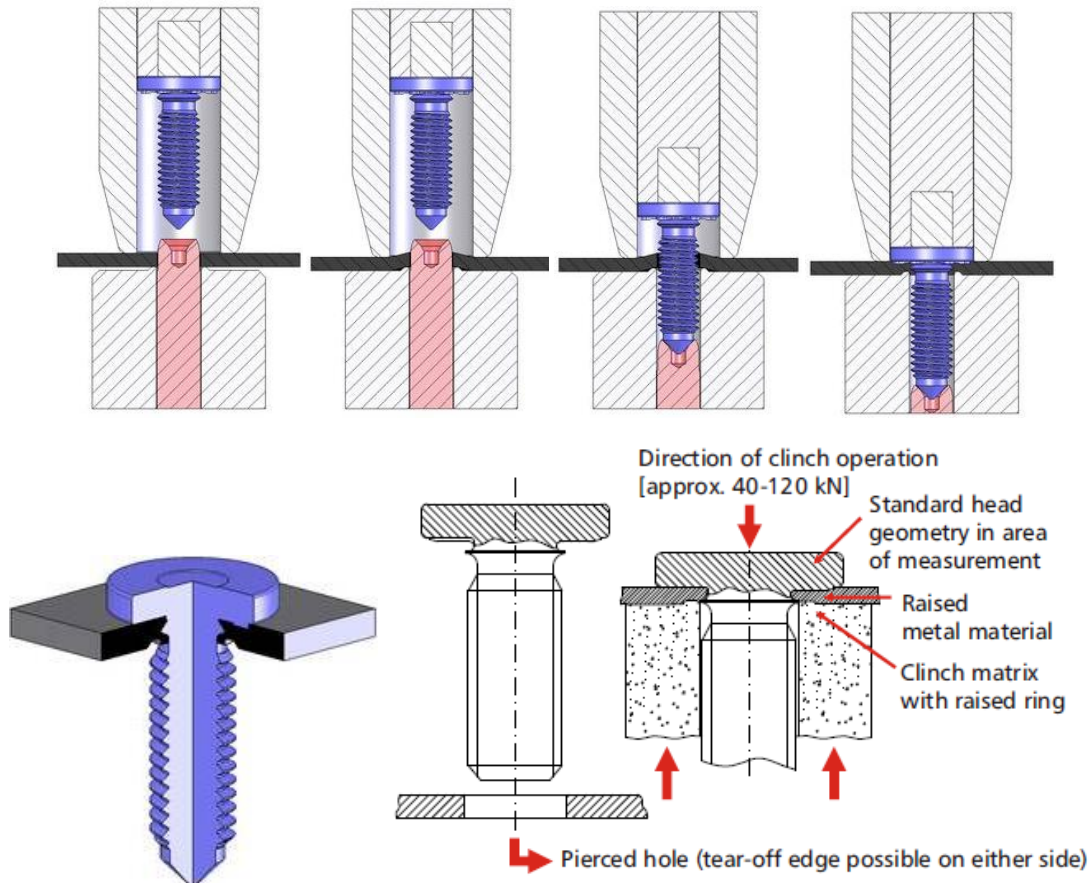


Installed press-in nuts and studs (Clifa® system)

(Source: Kerb-Konus)

Press-in nuts and studs are torque-proof, wear-resistant and capable of withstanding high loads. Press-in nuts are typically used in thin-walled work pieces with thicknesses above 0.8 mm up to 6 - 8 mm. The use of press-in studs is generally limited to metal thicknesses of 0.7 to 2.5 mm.

When installing a clinch stud, the stud is fed threaded side forward into the pre-punched hole. Initially the hole in the panel is widened by the calibrating collar, which also centres the stud. The material is deformed and pressed into the ribs under the head. Proper clinching is achieved by the displacement lobes underneath the stud head which squeeze the metal into the locking groove. An optimized tool design and the special displacement lobes guarantee a high torsion resistance and ensure that the bolt has a high load capacity. The force is applied until the shoulder of the fastener is seated flush with the sheet.



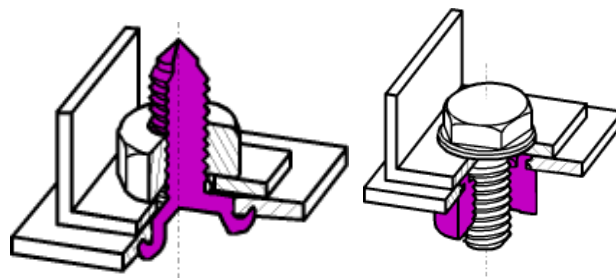
Installation of a press-in bolt (RIVTEX® system)

(Source: Arnold & Shinjo)

The installation of a clinch nut occurs in a similar way. The most important factor ensuring proper service performance is that the surface of the shoulder in the nut comes to rest flat against the surface of the sheet metal.

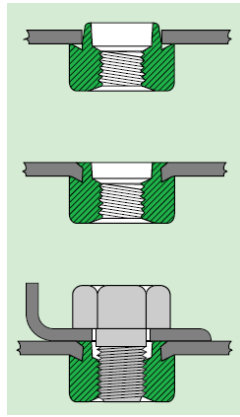
b) Elements using pre-punched holes, attached by riveting

In comparison to the self-clinching functional components, positive locking is ensured in this case by cold deformation of the functional component alone or together with the work piece.



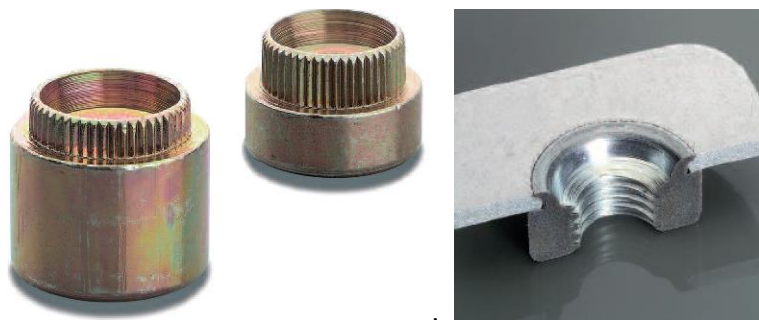
Bolt and nut, attached by riveting

In practice, this approach is mainly chosen for the insertion of nuts. The introduction of bolts (or studs) into pre-pierced holes by riveting is only used for thicker materials.

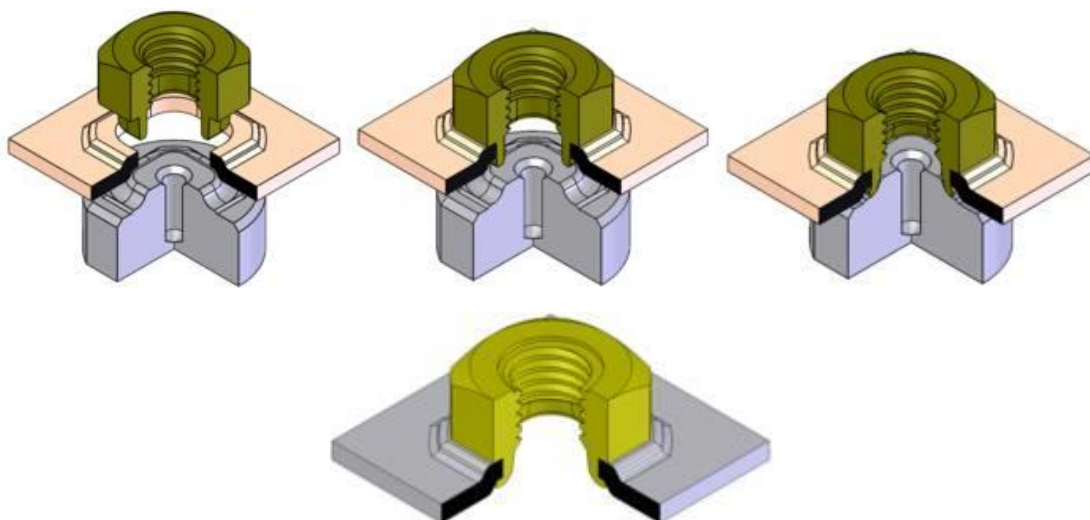


Screw connection with a rivet bushing
(Source: Kern-Konus)

The result is a rivet bushing for captive, torque-resistant screw connections capable of withstanding loads from both sides in thin-walled work pieces (0.5 to 5 mm thickness).

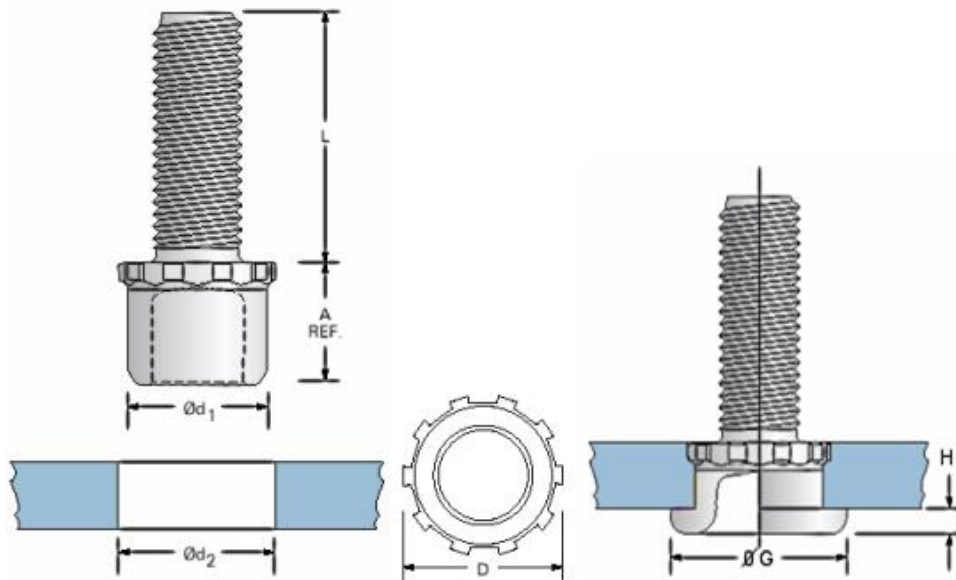


Rivet bushing (Anchor® system)
(Source: Kern-Konus)



Installation of a rivet nut (HR rivet nut)
(Source: Arnold & Shinjo)

At the start of the installation, the rivet nut is mounted in the clamps on the ram. The pre-punched sheet lies on the die. During the down stroke of the press, the rivet collar is introduced into the prepared hole. The nut shoulder comes up against the sheet. The nut is moved together with the sheet to the die and riveting begins. In the final stage, the rivet collar has been completely reshaped and an optimal connection has been achieved. Depending on the design type of the nut elements, the sheet blank is to be prepared with or without a bead.



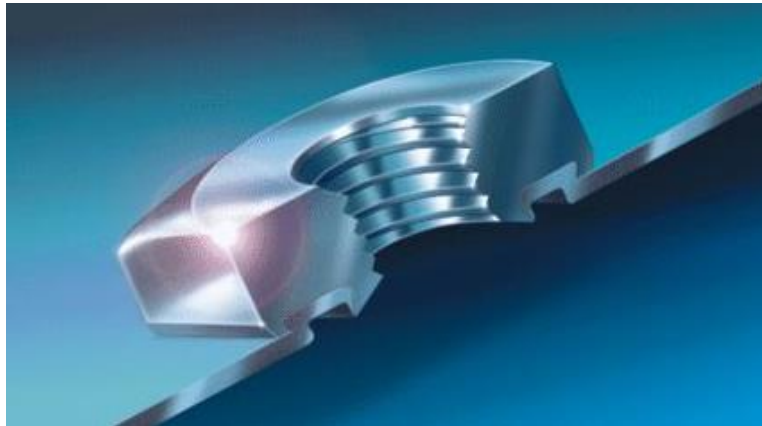
Installation of a stud by riveting

(Source: FabriSteel)

The rivet bushing is a threaded insert with a counter bored and serrated shank. It is riveted into thin-walled work pieces with pre-punched or pre-drilled receiving holes using a simple riveting tool. During this process, the riveted serrations of the shank cut into the side wall, creating an absolutely secure fastening. The special shape of the shank and the countersinking at the bottom protect the thread from damage during installation. In order to avoid deformation of thin sheet metal components, the use of a double-acting riveting tool is recommended.

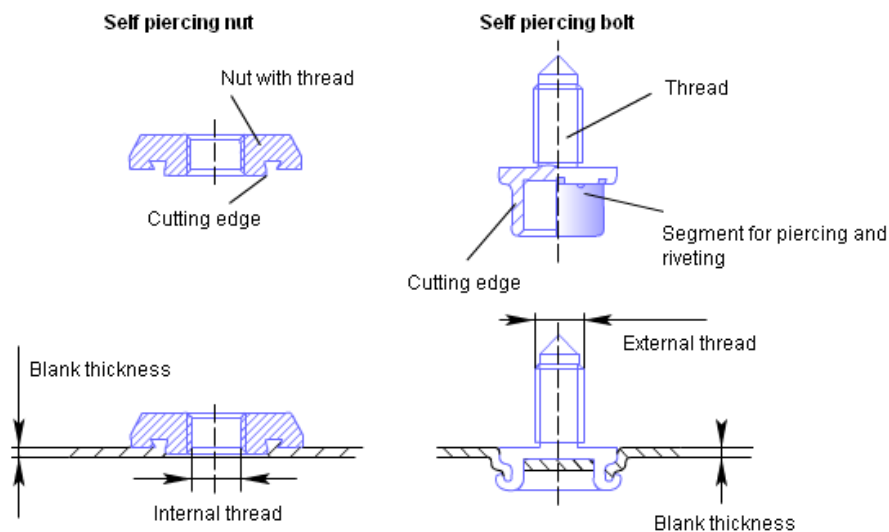
c) Self-piercing functional elements

Self-piercing nuts and bolts pierce their own hole through the part. The hole is punched and the fastener is permanently fixed to the plate in one operation. Self-piercing fasteners can be installed in pre-embossed areas, but also in flat areas. Compared to the systems using pre-punched holes, additional cost savings are possible.



Self-piercing nut after installation

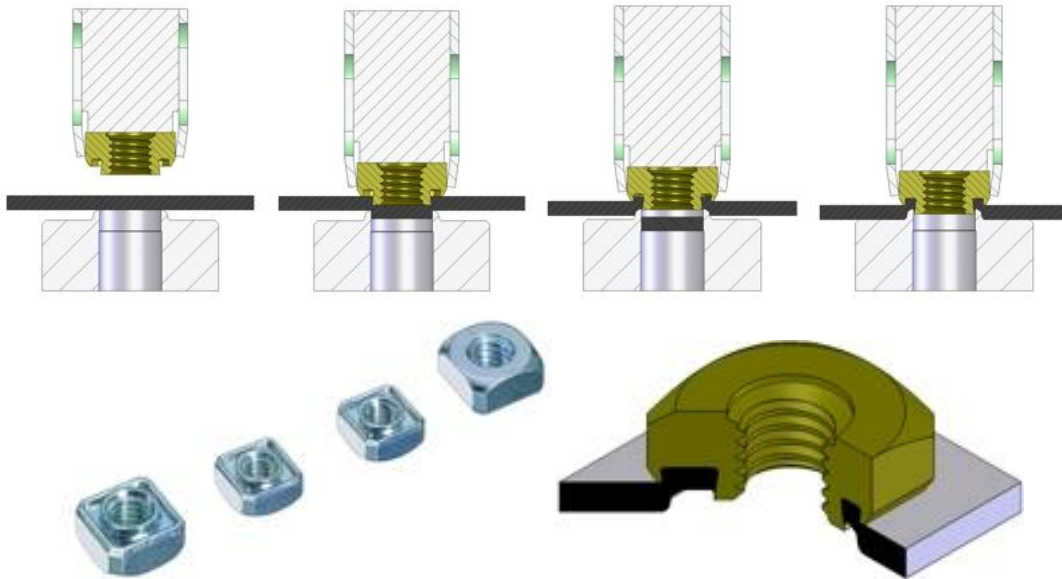
(Source: Arnold & Shinjo)



Self-piercing nuts and bolts

(Source: aluMATTER)

Installation of the self-piercing nut starts with the nut clamped in the punch; the sheet metal is placed on the die. When the punch moves down, the spigot of the nut punches a hole into the sheet component. The stamping waste drops through the die (or is pressed out by an ejector) and the sheet is pressed into the nut. When the punch is in its lower position and the sheet metal is completely forced into the undercut of the nut, the connection is completed. A positive locking connection is achieved as the metal is squeezed through the special shape of the die into the circumferential locking groove of the nut. The sectional view shows how the sheet metal has flown into the special clinching feature. As a rule, the geometry of the nut does not undergo any alteration. The joint is flush on one side.



Installation of a piercing nut (PIAS® KP piercing nut)

(Source: Arnold & Shinjo)

Various designs of self-piercing nuts are used in practice. The standard form of the self-piercing nut has a rectangular geometry, which ensures higher torque performance via a positive connection. Depending on the sheet thickness and the design of the nut, the sheet blank is to be prepared with or without a bead. Positive and non-positive connections, which can be loaded from both directions, are achieved via beading.

Rotational symmetrical self-piercing nuts require a special knurl on the punch collar to offer a torsionally strong seat in the sheet blank. Round shoulder nuts are used to attach dynamically highly-loaded components. Self-piercing nuts are typically applied for sheets with 0.6 to 2.5 mm thickness; special nut designs are applicable for sheet thicknesses up to 5 mm.

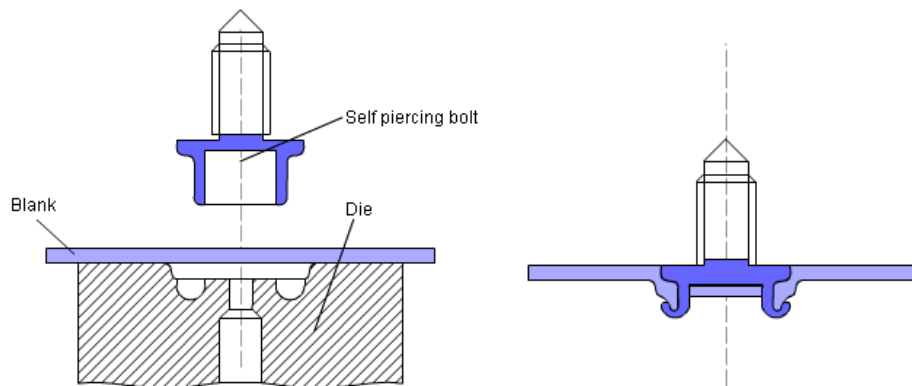


Self-piercing nuts for different applications:

- PIAS[®]HN piercing nuts for thicker sheets offering high mechanical strength and vibration resistance (upper left)
- Round RIVTEX[®] RX piercing nuts for automatic installation providing high resistance against push out and torque (upper right)
- PNC piercing nuts, a cost-effective solution for medium-strength applications (bottom)

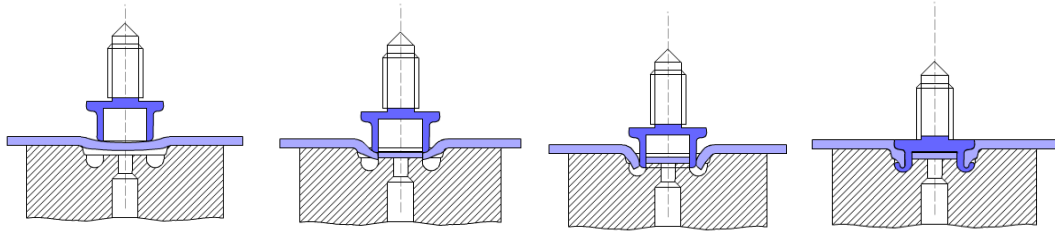
(Source: Arnold & Shinjo)

Self-piercing bolts are installed in a single step in a manner such that a plane bolting surface results. Acting forces from operating loads can be equally well accepted in both traction and compression directions. After positioning the self-piercing bolt, the sheet is pre-formed, partially cut and subsequently completely cut. As the self-piercing/riquet segment of the bolt is pressed against the cutting/curling surface of the die, it is partially rolled while being widened. The joint is completed when the partially rolled end of the self-piercing and rivet section surrounds the rim of the hole completely and generates a closed, continuous, u-shaped interlock. The slug produced during the punching process is pushed against the bottom surface of the self-piercing bolt and permanently fixed to it by the locally acting high pressure.



Self-piercing bolt

(Source: aluMATTER)



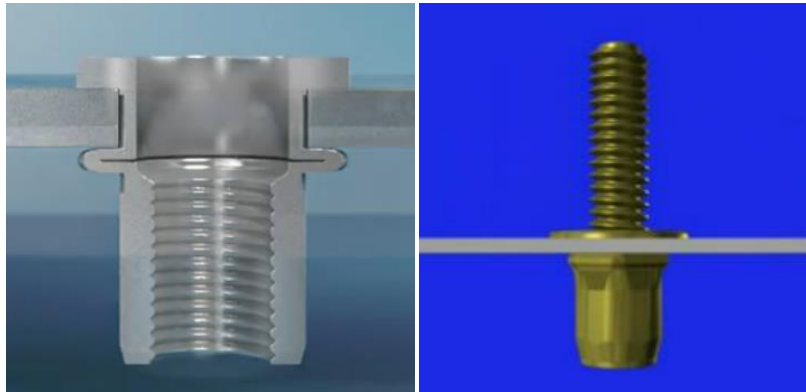
Installation of a self-piercing bolt

(Source: aluMATTER)

In contrast to self-piercing nuts, self-piercing bolts (or studs) are, however, seldom used in practice.

8.2.1.5 Blind rivet nuts and bolts

Blind rivet nuts and bolts are thread-bearing insert fasteners. They are a most versatile solution for fastening high-strength nut or bolt threads to components when tapped threads are not possible due to small wall thicknesses. They are also used when the material is too soft to support tapped threads or where disassembly is required.

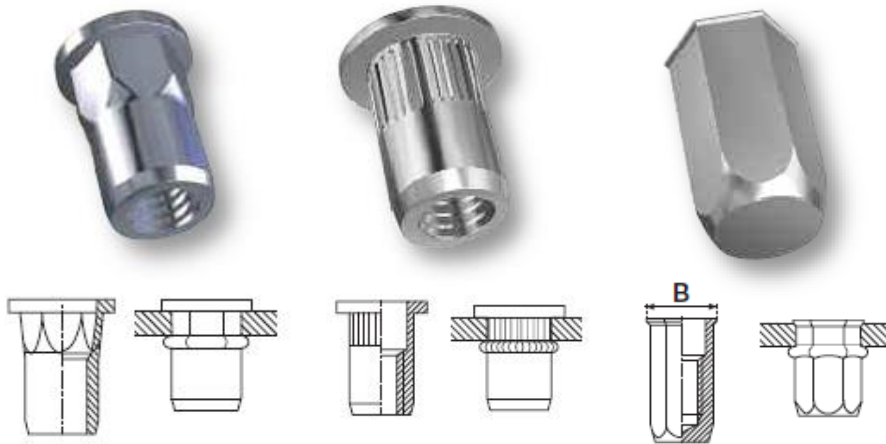


Blind riveting nut and bolt, installed by upsetting

(Source: Böllhoff)

Blind riveting elements are inserted into a pre-punched, pre-lasered or pre-drilled hole from one side and efficiently and rapidly set with a processing tool. They are mounted without counter pressure (“blindly”) and can therefore be set also at hollow sections. No additional finishing is required.

Blind riveting nuts and bolts are available in many variations and sizes offering numerous fastening solutions with additional functions. Most important are blind rivet inserts which are installed by upsetting. These types of fasteners generally protrude through the backside of the application material. During the installation process, the insert collapses into a buckled fold on the backside of the application material, trapping the material between its flange and the backside fold. The result is a high resistance to pull-out loads. The folded part also serves as a load bearing surface, which absorbs the force of setting the insert. Otherwise the setting force could spread into the application material and might damage the material.

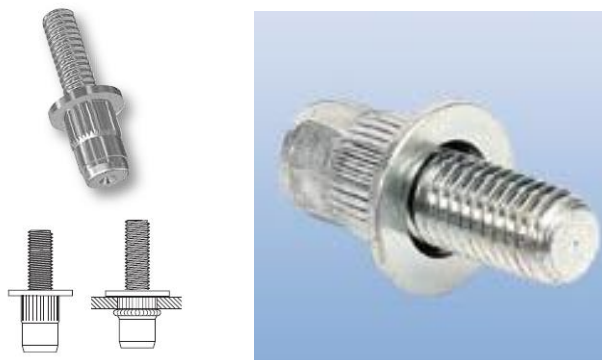


Different types of blind rivet nuts (RIVKLE® system):

- **Blind rivet nut with hexagonal body (left)**
- **Blind rivet nut with splined round body (centre)**
- **Closed blind rivet nut (right)**

(Source: Böllhoff)

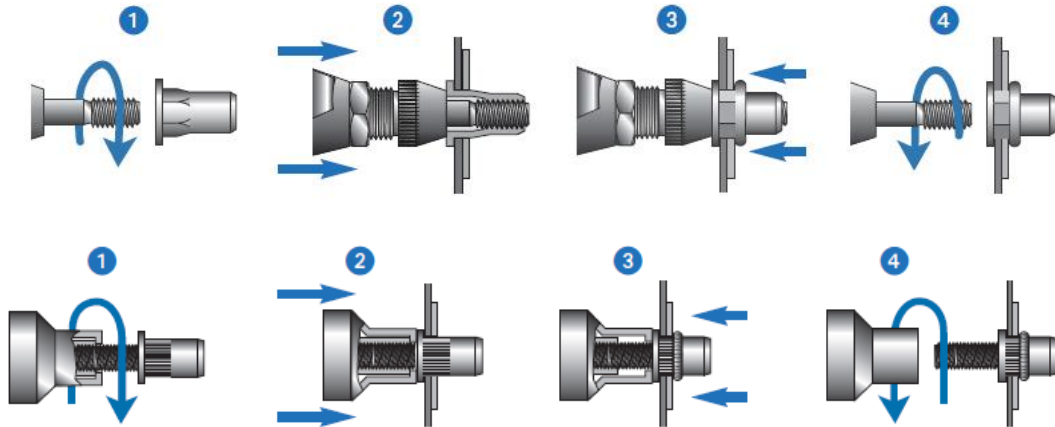
Blind rivet nuts with a hexagonal or even square body (or shank) improve the torque-to-turn in metallic materials up to 200 % or more compared to plain round body inserts. They are primarily used when high resistance to turning under vibrating loads is required (e.g. in chassis components). An improved torsionally stiff joint can be also achieved by the selection of a round insert with a splined body (up to 50 % compared to a plain body insert). The closed end prevents the ingress of dirt and fluids into the thread. Blind rivets fasteners are generally supplied in steel, aluminium and stainless steel. The choice of material depends on the required strength of the blind rivet nut or stud and corrosion resistance of the final product.



Blind rivet bolt (RIVKLE® system)

(Source: Böllhoff)

Setting of blind riveting bolts and nuts requires a rotary action to release the inserted fastener from the chuck (in case of a blind rivet bolt) or mandrel (for a blind rivet nut). Special tools for manual and automated installation are available. The spin-pull-spin setting technique is usually used. With this technique, the blind nut or stud is threaded (spun) onto the mandrel, inserted into the hole and then pulled back (without rotation) to upset the rivet nut body. Finally the mandrel is spun out.



Installation of a blind riveting nut (top) and bolt (bottom)

(Source: Böllhoff)

For special applications, further blind rivet nut designs have been developed. Specifically for applications in thin-walled sheet metal, hollow sections or plastic parts, a nut with a slit shaft is offered. Thus, the shaft is splayed out on the blind side of the carrier material and forms four "petals". With the resulting large bearing surface, it is possible to achieve maximum pull-out forces.



Blind rivet nut offering maximum pull-out resistance (RIVKLE® PN system)

(Source: Böllhoff)

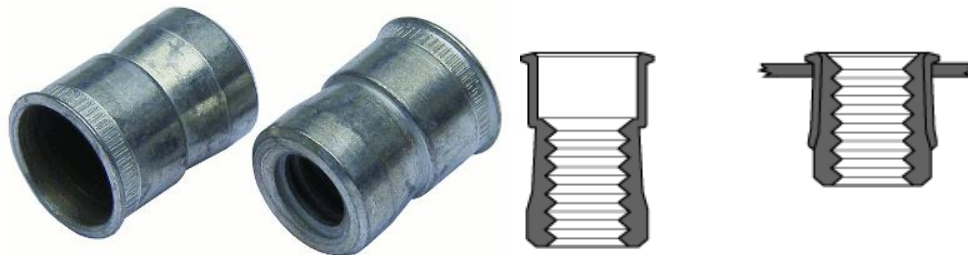
Also available are blind rivet fastener with noise and vibration damping characteristics. The elastic blind rivet nut consists of a threaded metal insert captured in an elastomer or thermoplastic elastomer body. It is used for load-bearing threaded inserts in thin-walled components where noise and vibration dampening is also required.

Another type of blind rivet design relies on four flared legs expanding outwards, with a threaded inner ring for threading a bolt into, to attach the other work piece. The "tri-fold" rivet is used where a distributed load is required – spreading it across the wide area formed by the compressed legs.



“Trifold” blind rivet nut
(Source: Emhart)

A different mounting method is used for the expanding inserts. An expanding insert is a single piece which breaks into two pieces during installation. The lower, threaded section of the insert is drawn up inside the upper sleeve section, causing the sleeve to expand over its entire circumference, thus swaging the insert into the hole. Expanding inserts show a reduced rear-sheet protrusion. However, because the insert does not form a buckled fold on the backside, an expanding insert has less resistance to push out forces (i.e. mainly suited for low load bearing applications).



Expanding blind rivet nut (Nutsert® system)
(Source: Avdel)

8.2.2 Riveting

Rivets are permanent (non-detachable) mechanical fasteners. For a long time, riveting was considered to be outdated and uneconomical. Recently, however, riveting has been rediscovered as a cost-efficient high quality joining technology for automotive applications.

In the riveting process, the parts to be joined are clamped together using an auxiliary joining element. In principle, one of the components to be joined could be designed that part of it could act as the auxiliary joining component so that no separate riveting element is necessary (e.g. a protruding flange of an aluminium casting could serve as a solid rivet). However, such connections are mainly applicable as secondary, low performance joints, suitable only in specific situations and will not be covered in more detail.

Rivet technologies can be subdivided into two groups:

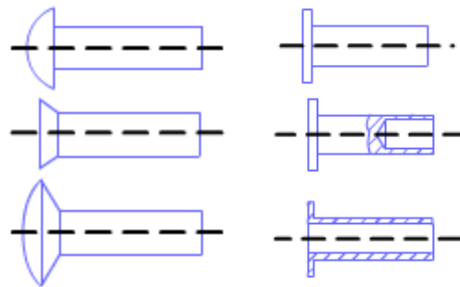
- Rivet systems requiring pre-punched holes
- Self-piercing systems which do not require pre-punched holes.

The first category includes standard (upsetting) riveting systems (solid riveting and blind riveting). In particular, the blind riveting process – which can be applied from one side only – is of great importance in automotive applications.

Assembly systems used for riveting range from hand tools and simple work stations to fully automated systems. Pneumatic, hydraulic, manual or electromagnetic processes are all highly effective in driving the rivets.

8.2.2.1 Solid rivets

Solid rivets are the oldest and most reliable type of mechanical fasteners. Solid riveting requires pre-punched or pre-drilled holes as well as two-sided access. Before being installed, a solid rivet consists of a cylindrical shaft (or shank) with a head on one end. Once the rivet has been inserted, the closing head is formed from the rivet shank by plastic deformation. Because there is effectively a head on each end of an installed rivet, it can support tension loads (loads parallel to the axis of the shaft); however, it is much more capable of supporting shear loads (loads perpendicular to the axis of the shaft). Bolts and screws are better suited for tension applications.

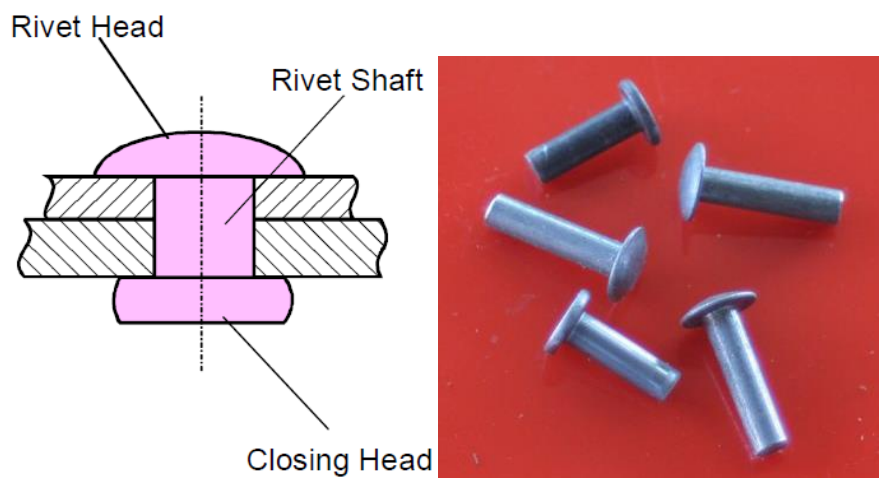


Different head shapes and shank forms of solid rivets

Rivets are classified according to the shape of the rivet head and the form of the shank. The most common types of solid rivets show a round or flat, sometimes also countersunk heads. Apart from solid shanks, also semi-tubular or tubular shanks are used in order to reduce the closing forces. Joint characteristics can vary greatly depending on the rivet type, material and geometry.

The rivet forming process and the resulting joint characteristics depend on the type of rivet shank. The shank on a solid rivet expands in the hole during the riveting process, typically forming an interference fit. On a semi-tubular rivet, where the part of the shank which protrudes beyond the back of the second work piece is hollowed out, the hollow tenon curls over on impact, drawing the parts together with minimal shank swell. Semi-tubular or tubular rivets are thus ideal to use as pivot points since the rivet only swells at the tail.

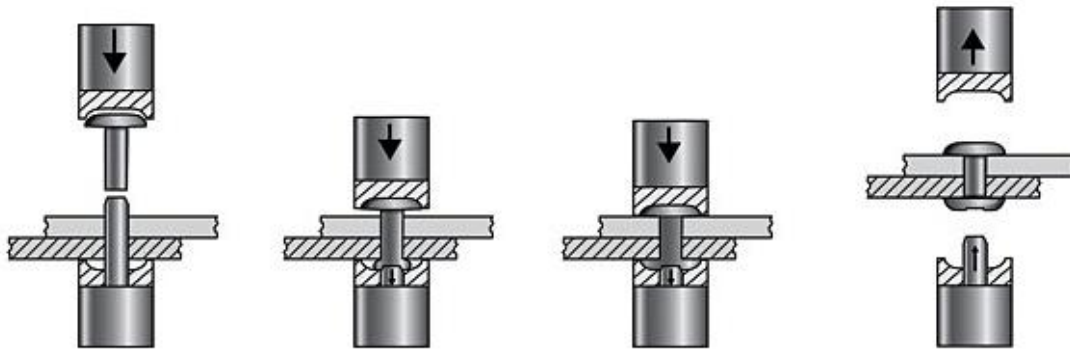
With all-aluminium constructions, cold-formed aluminium rivets are used almost exclusively. Hot-formed steel rivets are only used for joining aluminium and steel, however, care must be taken to avoid negative effects of the rivet heat on the properties of the aluminium component.



Joining by solid riveting

Solid rivets are pressed through the two materials and into a solid die. When they hit the die, the penetrating end deforms and spreads out. This creates a permanent hold since the head and the

deformed tail of the rivet are both larger than the hole in the material. Once in place, the only way to remove a rivet is to cut it from the work piece.



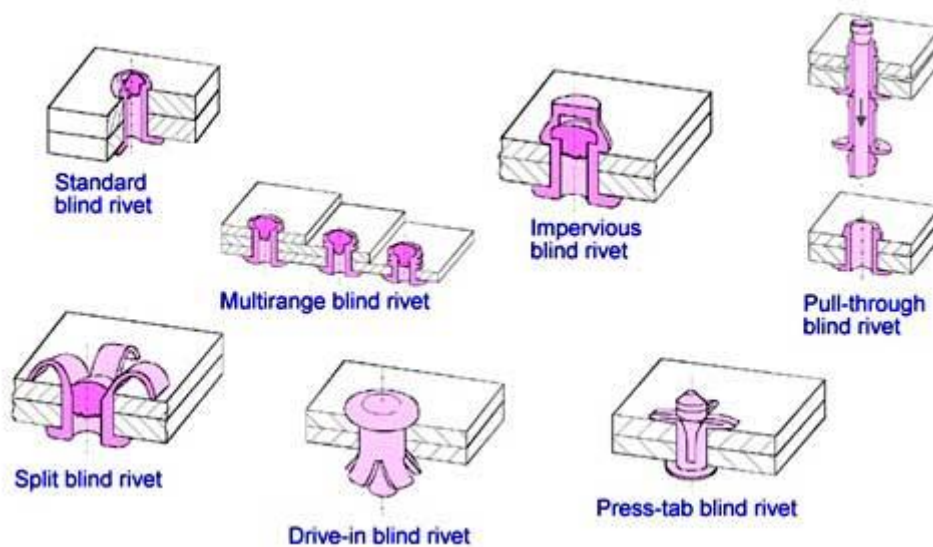
Installation of a solid rivet

Solid rivets are used in applications where reliability and safety are top priorities (e.g. in structural parts of aircrafts), but also in critical automotive components.

8.2.2.2 Blind rivets

A characteristic feature of blind riveting is the fact that the joining element is only inserted and closed from one side using pre-punched, pre-drilled or -laser cut holes. However, blind fasteners can be also used in joints with both-sided accessibility in order to simplify complicated assembly processes or to improve the visual appearance.

The application of blind rivets offers benefits in many joining applications. Fast and easy-to use blind rivets enable speed of assembly, consistent mechanical performance and excellent installed appearance, making blind riveting a reliable and economical assembly method. Blind rivets are available in different designs both for non-structural and structural applications. The selection depends on the respective requirements, e.g. component material and envisaged strength. Typical examples are shown below:



Different types of blind rivets

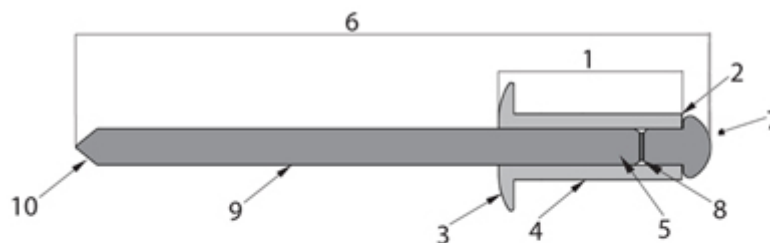
Structural blind rivets should be considered where:

- Access is not available to both sides of the assembly
- Speed of installation is required
- Skilled labour is not available
- Uniform clamping is desirable and consistency of appearance is desirable
- Fastener removal is not necessary for maintenance.
- Repair fasteners for field use by untrained personnel are needed.

a) Standard (break stem) blind rivets

Blind rivets (also called break stem rivets) proved to be an ideal joining process to support the increasing application of aluminium and the emergence of new materials as plastics in automotive design. Break stem blind rivets allowed the design and assembly of large, complex structures including tubular shapes and other closed systems.

The standard blind break-mandrel rivet consists of two components, a smooth, cylindrical rivet body (shell or sleeve) and a solid rod mandrel with a head (headed stem or tool pin) which runs through the hollow rivet shaft. Mandrels have weakened grooves where this separation occurs, and some have a mechanical lock that snaps into place. While the shaft of the mandrel is discarded after setting, the mandrel head generally remains permanently attached.

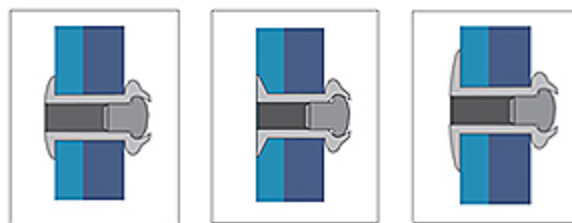


- 1-Rivet Body
- 2-Rivet body end
- 3-Rivet head
- 4-Cylindrical part of the rivet
- 5-Inner space of the rivet body
- 6-Mandrel
- 7-Mandrel head
- 8-Mandrel breaking point
- 9-Mandrel body
- 10-Mandrel end

Illustration of a standard blind rivet

(Source: BRALO)

Today, many types of standard break stem rivets are offered by various suppliers. Depending on the design of the rivet body, different functions can be fulfilled.



Three basic types of rivet heads: Dome head (left), Countersunk head (centre) and Large head (right)

(Source: BRALO)

With respect to the rivet head, there are three basic types:

- The dome head is the most versatile type of head. It provides enough bearing surface to retain all kinds of materials, except those extremely smooth and brittle.
- The countersunk head allows the riveting of a bigger thickness and it is designed to obtain a flat surface, free of projections.
- The large head provides a larger bearing area compared to the dome head and offers a great resistance. It is designed for applications where a soft or brittle material must be assembled to a rigid support material.

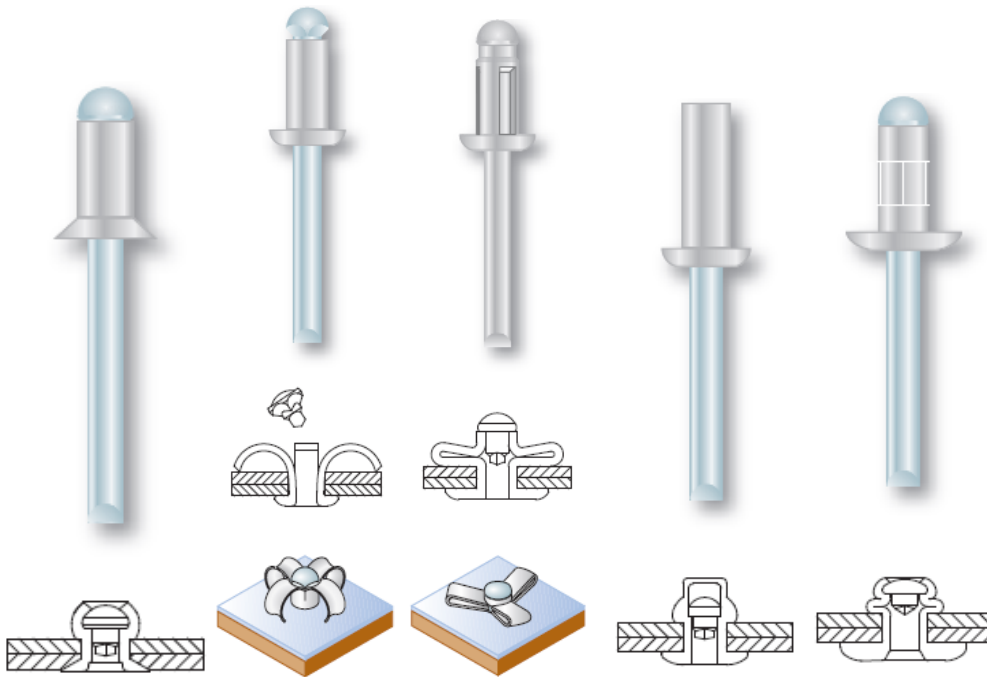
b) Blind rivets for non-structural applications

Most types of blind rivets are of the mechanical lock type. In specific cases, however, also friction lock blind fasteners can be used. In this case, the tail end of the rivet body is not deformed. The mandrel portion of the solid stem leads to an expansion of the rivet shank when the stem is pulled into the rivet. When the friction force is sufficiently high, the stem will snap at the break-off groove. The plug portion (bottom end of the stem) is retained in the shank of the rivet giving the rivet much greater shear strength than could be obtained from a hollow rivet.



Self-plugging friction lock blind rivet: Protruding head (left) and countersunk head (right)

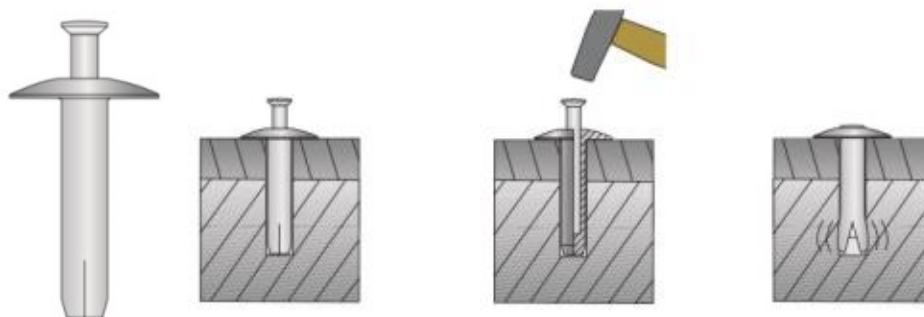
The main problem is that under vibrations, friction lock rivets tend to loosen and possibly fall out. In case of mechanical lock blind rivets, the stem is retained in the rivet sleeve by a positive mechanical locking collar at the tail end.



Standard break stem blind rivets for non-structural or lightly loaded applications: Standard blind rivet, Peel type rivet, Slotted rivet, Sealed rivet and Multi-grip rivet (from left to right)

(Source: Böllhoff)

A special type of blind rivet is the drive rivet. Drive-in blind rivets have a short mandrel protruding from the head that is driven in with a hammer. This causes the end of the rivet to split open. Components with through hole or blind hole can be riveted. All kinds of different material combinations are possible. However, drive-in rivets have less clamping force than most other rivets. It is an extremely effective method of joining sheets and profiles to soft and fibrous materials.



Blind drive pin rivets

(Source: VVG Befestigungstechnik)

Peel (split) rivets are break-mandrel blind rivets designed for the fastening of rigid materials to soft materials. They provide additional grip support and pull-out resistance by splaying out into three or four segments when inserted. Edges pressed onto the mandrel head that longitudinally cut the rivet body on the blind side. The rivet body is divided into four petals that bend outwards and come into contact with the material to be fastened, creating a locking head with a big diameter. The large expansion on the blind side distributes the load and the clamping force, reducing the risk of crushing and breaking of materials. Once the riveting process is finished, the head of the mandrel head falls out of the rivet body.



Split blind rivet (ARCO® split ends)

(Source: VVG Befestigungstechnik)

Analogous to the split rivet, a blind rivet with slotted shanks form a large bearing area in the shape of a clover. The large expansion on the blind side uniformly distributes the load and the clamping force, reducing the risk of crushing and material breaking. It is ideal for applications with soft materials or materials with a low resistance to pressure. The connection is splash-proof due to the locking of the remaining section of the mandrel.



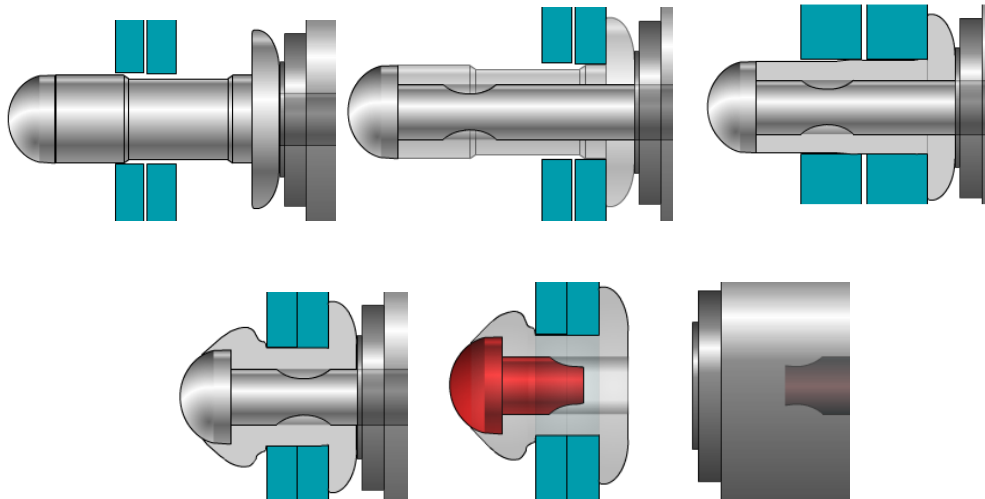
Slotted break-mandrel blind rivet

(Source: BRALO / VVG Befestigungstechnik)

The large load bearing surfaces on the blind side of the work piece also allow break stem fastening in thin gauge metals that require added fastener support. Together with large rivet heads, the joined materials are tightly clamped; an ideal joint for thin sheets or low strength material offering high resistance to pull-out loads.

Standard rivets are blind rivets with a breaking mandrel are designed for the fastening of all kind of materials when there is no need for an especially high torque force or vibration resistance. When a blind rivet is installed, the rivet is first placed into an installation tool and then inserted into the application. Activating the tool pulls the mandrel into the rivet body and through drilled or punched holes in the material layer.

When the mandrel head is drawn into the blind end of the rivet body, the rivet walls are expanded, compressing them firmly in the hole while forming a tightly clinched load bearing area on the reverse side of the material. The upset head on the rivet body securely clamps the application materials together. Finally, the mandrel reaches its predetermined break-load, with the spent portion of the mandrel breaking away and being removed from the set rivet. The remaining portion of the mandrel is captured inside the sleeve and plugs the opening in the rivet shell. The entire installation cycle takes about one second.



Installation of a blind rivet (Avex® multi-grip break stem blind rivet)

(Source: Stanley Engineered Fastening)

These types of break stem fasteners (open end blind rivets) are primarily found in non-structural and lightly loaded structural applications. The mandrel breaks off near the blind side head.

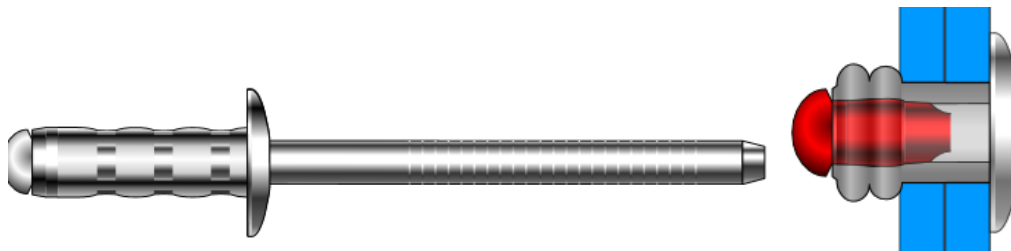


Standard blind rivets of the multi-grip design accommodate variations in material thicknesses

(Source: BRALO)

Standard blind rivets of the multi-grip design offer significant advantages. Unlike threaded assemblies, there are no concerns over tool clearance and secondary parts such as bolts and washers. Good bearing pressure characteristics are ensured by the expansion of the rivet walls in the hole. In addition, the edges of the machined hole are covered on both sides. Blind rivets also compensate for hole irregularities (e.g. misalignment or oversized holes). Even with hole diameters that vary within 1 mm, the fluently adjusting closing head ensures a tight fit of the rivet.

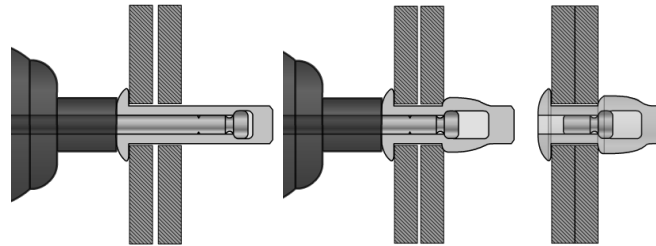
A special design of the rivet body even ensures the alternative forming of a simple or double closing head depending on the clamp area, thus allowing the bridging of a wide thickness range. For structurally loaded applications, the double closing head configuration should be chosen.



Standard blind rivets of the multi-grip design

(Source: GOEBEL)

A further variant are closed end blind rivets which seal the holes by closing off the tail end of the rivet body, preventing passage of vapour or liquid around or through the set rivet and safely capturing the mandrel inside the rivet bore. Closed end break stem rivets are not used as extensively as before. Today, they are largely replaced by improved open end designs which are optimised for high strength and seal the rivet body bore with equal effectiveness.



Installation of a closed end blind rivet (POP blind rivet)

(Source: Stanley Engineered Fastening)

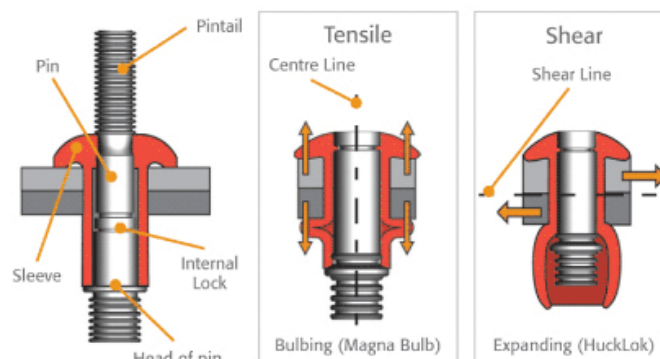
c) Blind rivets for structural applications

Selecting and installing the right blind rivet in the right hole is a systematic process that requires careful evaluation of the different factors affecting quality and durability of the joint. Among these are rivet diameters, grip ranges, hole preparation, head styles and corrosion resistance.

In order to prevent corrosion effects, rivet bodies and mandrels are generally made from identical materials. In all-aluminium designs, aluminium rivets are often used. However, often steel mandrels are chosen for strength reasons. Stainless steel is the preferred option, but also steel mandrels with protective coatings can be used.

For structural applications, the breaking point of the mandrel is generally shifted to the rivet head. Most important for structural applications is also the controlled expansion of the break stem rivet body. This is achieved through an appropriate design of the mandrel and selection of the rivet material. Uniform compression ensures proper locking of the stem and hole filling. The goal must be to consistently ensure that the rivet bodies deform precisely as specified and the mandrels break precisely at the planned forces.

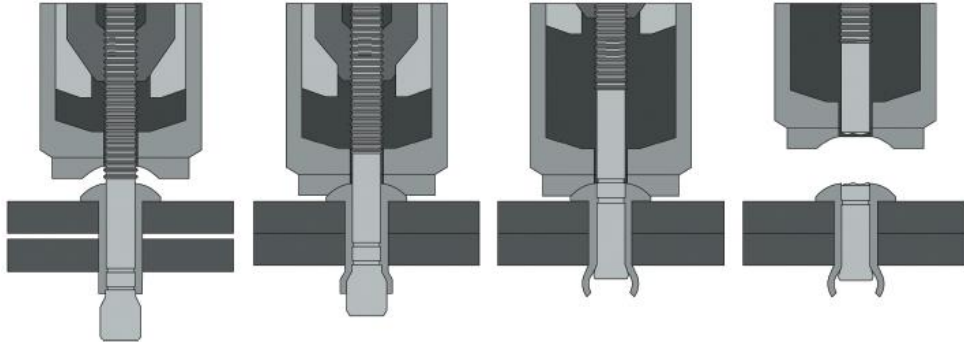
The most reliable blind fastening solutions are offered by structural blind fasteners where – during installation – an internal lock between pin and sleeve is created also at the rivet head. The shear strength of structural blind fasteners is generated by the combined resistance against failure of pin and sleeve. This takes place along the joint's shear line between the fastened plates. Since the blind fasteners form a blind side positive lock either by bulbing or expanding of the sleeve, the sleeve, assisted by the permanently secured pin, resists failure under tensile loads along its centre line. Different options for mechanically locking the pin to the sleeve have been developed.



Working method of structural blind fasteners

(Source: AFS Huck)

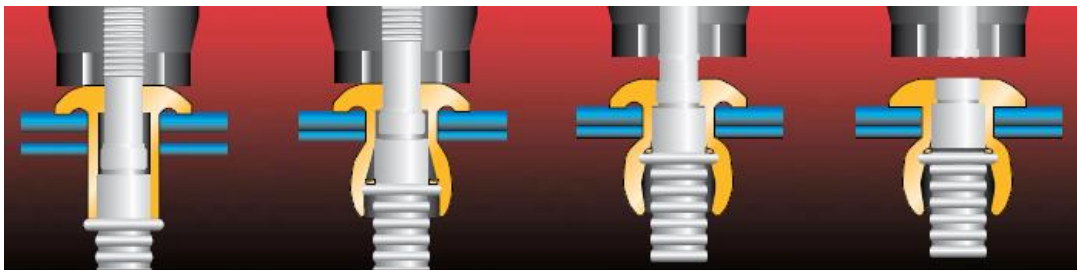
One possibility to ensure maximum strength and resistance to vibration is the introduction of a solid circle lock under the rivet head. As the tool pulls on the pintail, the pin (mandrel) expands the sleeve and begins drawing the work pieces together. Continued pulling on the pintail draws the hollow pin head inside sleeve. The pin extrudes itself inside the sleeve and the work pieces completely expand the sleeve to match the hole of the work pieces. A solid circle lock between the pin and sleeve is formed just prior to the pin breaking flush with the sleeve head, completing the installation.



Installation of a blind fastener with a solid circle lock (Huck Magna-Lok®)

(Source: AFS Huck)

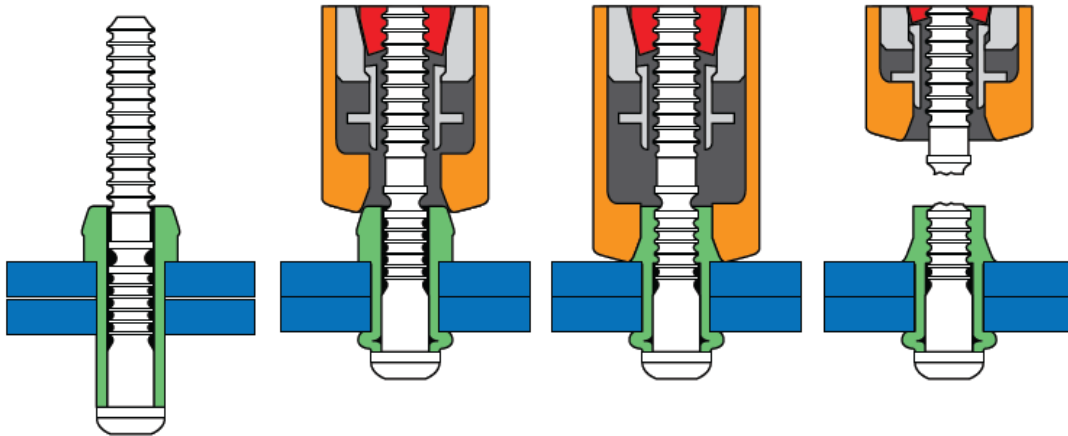
Another option is a double locking system which locks the assembly from both sides. The “breakaway” ring design lets the shear ring settle into an appropriate catch groove, ensuring a consistent clamp throughout the whole grip range. As the tool pulls on the pintail, the shear ring pushes the rivet sleeve outward, forming a bulb that compresses against and tightens the application. During bulb formation, the shear ring forms a support ring from the rivet sleeve by creating a build-up of material above the ring. The shear ring breaks free and is pressed onto the catch grooves. The pulling action continues until the internal rivet shoulder engages the lock groove on the pin and forms an internal lock. The pintail then breaks off, completing the installation. The solid pin provides an exceptionally high strength in the shear plane.



Installation of a “breakaway” ring design blind fastener (HuckLok®)

(Source: AFS Huck)

Most demanding high-tensile application (e.g. in auto suspensions) can be fulfilled with optimized mechanically locked blind fastening systems. Blind fasteners for high tensile and shear strength applications are installed using a push-and-pull design. The rivet body shows a collar which – in a second step – is locked to the pin through a “swaging” process, creating a high vibration resistant connection. Large bearing areas on both sides of the work piece ensure a permanent tamper-resistant joint.



Installation of a high tensile strength blind fastener (BOM®)

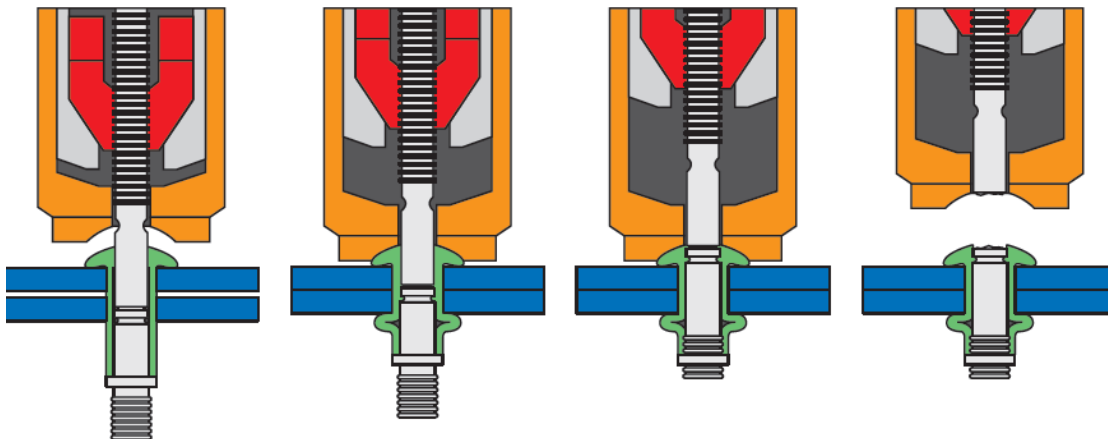
(Source: AFS Huck)

When the tool pulls on the pintail, the unique collar design delays the swaging action until the maximum allowable bulb is formed. Continued pulling on the pintail then draws the work pieces together and the swaging anvil overcomes the standoff. As it moves down the length of the collar, the collar is securely locking to the pin. Once the collar is swaged, the pin breaks.

A selection of other high strength blind rivets for various applications is shown below.

- **Bulb-forming blind rivets for thin sheet applications and the joining of softer materials**

The formation of a bulb in the rivet tail during installation spreads the load over a wide surface area. The increased bearing area makes bulb-forming blind rivets ideal for pull-out resistance in thin materials, and oversized or misaligned holes. The positive, mechanical pin-retention ensures structural integrity, supplying a strong, long-lasting connection. Also available are variants providing a fully sealed, visually attractive connection.



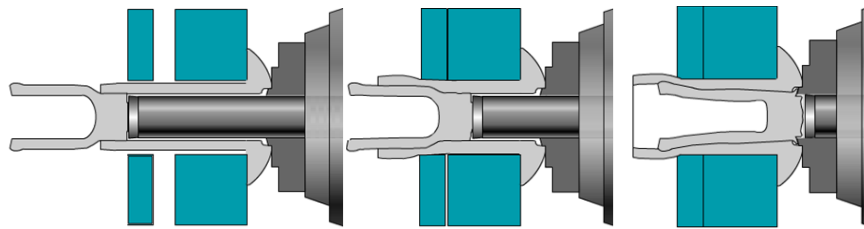
High strength break stem blind rivet for thin sheet applications (Magna-Bulb®)

(Source: AFS Huck)

The shear ring design promotes bulb formation and grip adjustment for flush break throughout the grip range. As the tool pulls on the pintail, the shear ring feature on the bolt acts to initiate bulb formation and draws the work pieces together. Continued pulling on the pintail expands the bulb to the maximum allowable diameter. The shear ring then breaks and catches on the annular grooves as the pin continues to draw down inside the sleeve. A solid circle lock between the bolt and sleeve is formed just prior to the pin breaking flush with the sleeve head, completing the installation. Breaking flush throughout the entire grip range, the Magna-Bulb fastener eliminates costly cosmetic finish work and ensures “visually” that the fastener has been installed correctly.

- **Hole-filling blind rivet**

Hole-filling blind fasteners are moisture-resistant. They offer a unique circle-lock feature, which means a simple visual inspection ensures it is installed properly.



Structural break stem blind rivet providing a fully sealed joint (Monobolt®)

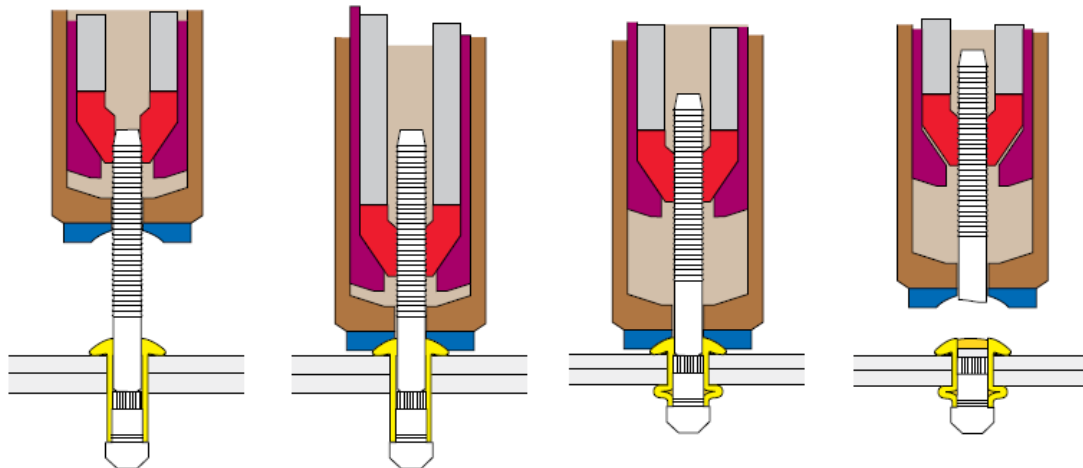
(Source: Stanley Engineered Fastening)

Pulling on the pintail draws the hollow pin head inside the sleeve. The pin expands the sleeve and begins drawing the work pieces together. Then the pin extrudes itself inside the sleeve and the work pieces and completely expands the sleeve to match the hole of the work pieces. A solid circle lock between the pin and sleeve is formed just prior to the pin breaking flush with the sleeve head, completing the installation.

- **Structural blind rivet with interference lock**

Exceptional shear and tensile strength can be achieved with an interference lock formed by a splined feature on the pin ensuring a strong vibration resistant joint whilst the large blind side bearing area spreads the load and prevents creep.

Continued pulling on the pintail after complete expansion the bulb brings a spline feature on the pin into contact with a step on the sleeve, creating an interference lock between the pin and sleeve. The pin will break close to flush in minimum grip and below flush as the grip increases.



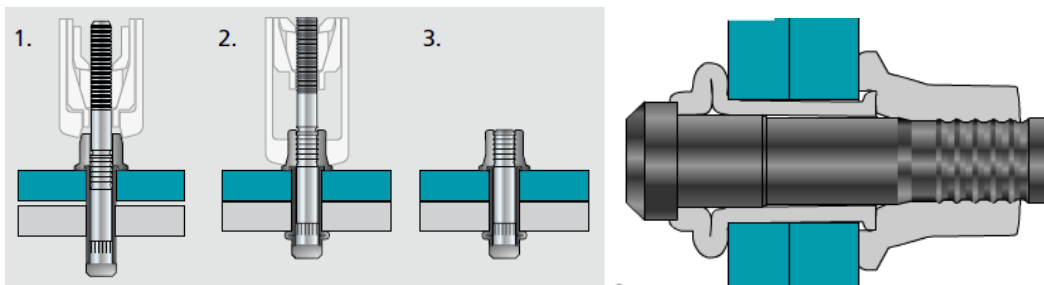
Structural blind rivet with interference lock (Huck Auto-Bulb™)

(Source: AFS Huck)

- **Three-piece blind fastener**

The same service performance can be realized with a three-piece blind fastener, i.e. using a separate collar similar to the lockbolt principle. In a first step, the installation tool pulls the pintail to form the bulb. Once the bulb has formed, the clamp up force is applied to the joint pulling the work pieces together. The collar material is then swaged into the pin lock grooves, trapping the clamp up load and

forming a tamper proof lock. At a pre-determined load, the pin breaker groove fractures; the pintail is detached and the joint is complete.



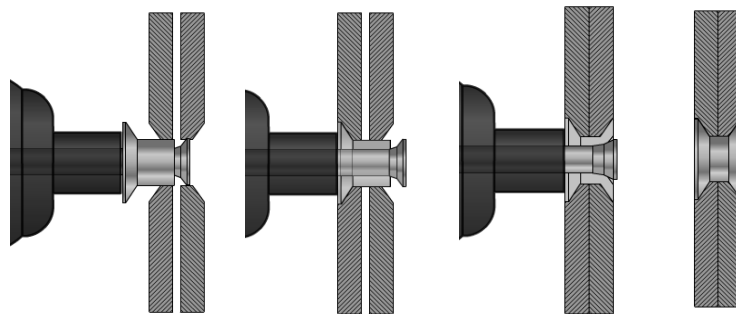
Installation of a three-piece Avbolt® structural blind fastener

(Source: Stanley Engineered Fastening)

d) Pull-through blind rivets

"Pull-through" or "hollow" type rivets are used where the high shear strength of the self-plugging type of rivet is not required. This design provides excellent clamp up characteristics, but possesses inferior mechanical characteristics.

An example is the Pull-Thru (PT) rivet, a steel countersunk blind fastener designed to set surface flush on both sides of an application. It is best used in the assembly of any product where clearance is extremely limited and protrusion of the rivet body from the application surface must be either minimized or eliminated. When the PT rivet sets, the mandrel head remains integral with the mandrel, i.e. there is no danger of loose mandrel heads.

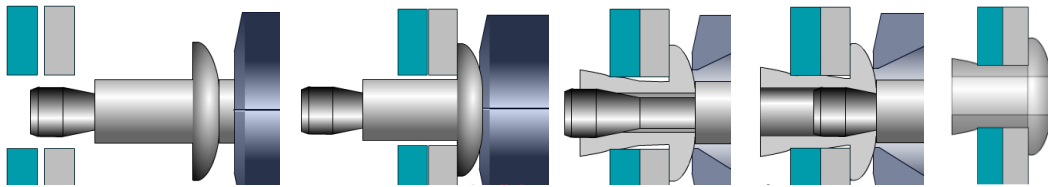


Installation of a "pull through" rivet (Pull-Tru (PT) rivet)

(Source: Stanley Engineered Fastening)

Based on this principle, the Speed Fastening® system for different types of blind rivets was developed. Speed fasteners are placed using a unique repetition mandrel system. The rivets are loaded into a special tool which also pulls the mandrel through the fastener body. The mandrel expands the rivet in the radial direction, ensuring clamp-up and hole fill. At the end of each cycle, the next rivet is automatically delivered to the nose piece ready for placement providing continuous feed with cycle times as low as 1.5 seconds.

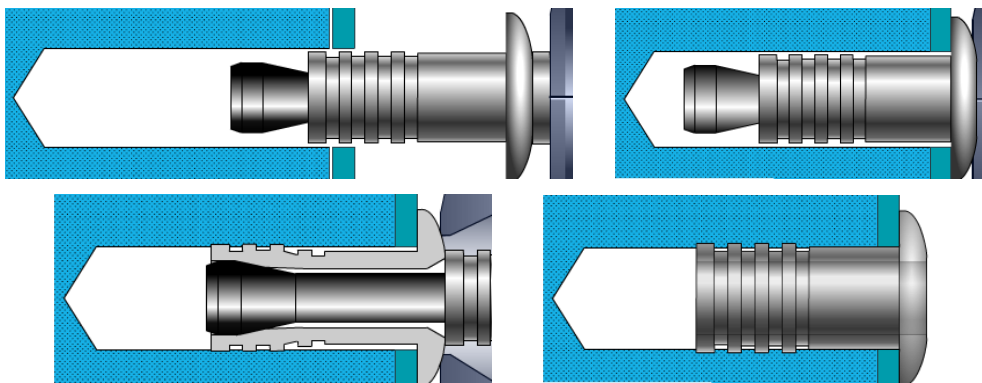
The following figure shows the installation of a Chobert® rivet. The Chobert® rivet is the original speed fastener which was developed in the 1930's. It is primarily a hole filling rivet, i.e. it expands radially into the application hole. The rivet does not collapse or shorten during installation. Maximum performance is realized by interaction of the tapered inner diameter of the rivet body and the flared shape of the mandrel head. The flared mandrel head passes through the tapered bore expanding the rivet fully against the application hole and surrounding material. This ensures consistent controlled light clamp and maximum hole fill without damaging soft or brittle materials.



Installation of the Avdel Chobert® speed fastener

(Source: Avdel)

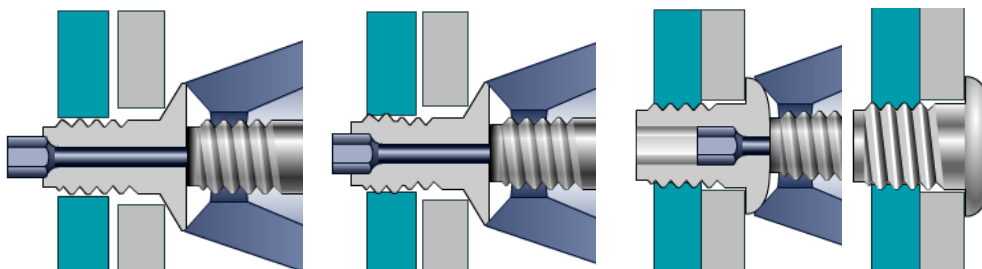
Also available are blind rivet variants that have a bulbed tail providing consistent high clamp and shear which are specifically useful for assembling softer materials. Most interesting is also the Grovit® rivet which was developed for blind hole applications in plastics, composites and aluminium (to be used specifically in cast components). The grooves on the Grovit rivet expand radially during installation to provide a vibration resistant joint and increased pull-out resistance.



Installation of the Avdel Grovit® speed fastener

(Source: Avdel)

The Rivscrew Speed Fastening® system has been developed for similar application areas. It is a threaded, removable speed fastener that combines the speed of rivet placement with the benefits of being able to remove and re-fasten. During installation, it expands radially to form a thread in host material.



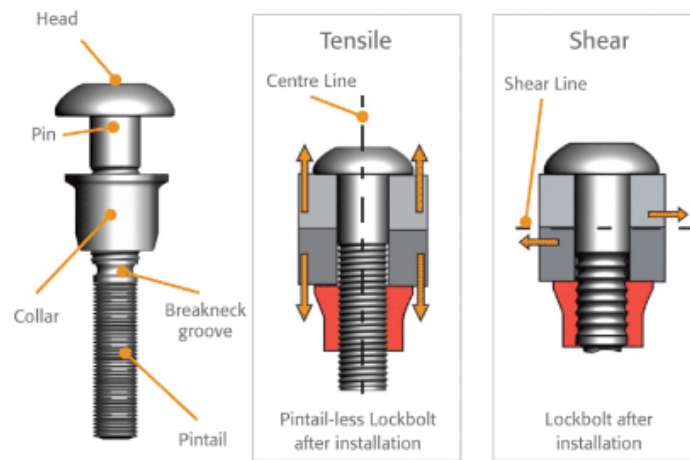
Installation of the Avdel Rivscrew® speed fastener

(Source: Avdel)

8.2.2.3 Lock bolts

Lock bolts allow the realisation of high strength joints with a high, controlled clamp. They are specified whenever robust and reliable fastening is desired. Lock bolts consist of two parts: a pin made of high strength materials and a closing collet (collar) which is fixed onto the rivet. The pin is inserted into one side of the joint material and the collar is placed over the bolt from the other side of the joint material.

Application asks for two-sided accessibility and pre-punched or pre-drilled holes. An installation tool is used to swage the collar materials into the grooves of the bolt providing a permanent and vibration resistant fastening.

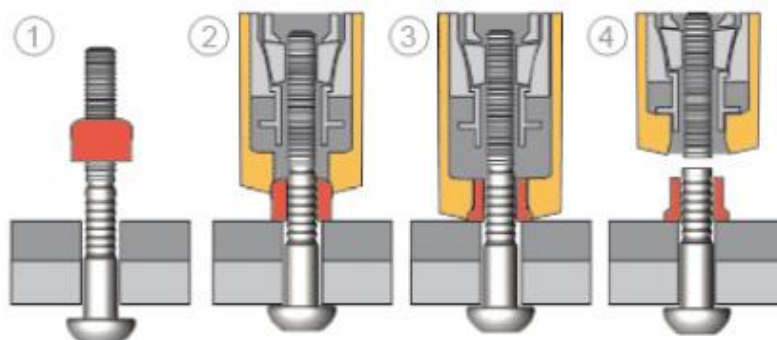


Working method of a lock bolt

(Source: AFS Huck)

The shear strength of lock bolts varies according to the material strength and minimal diameter of the fastener. By increasing the diameter or selecting a higher strength material, the shear strength of the fastener can be increased. The tensile strength of lock bolts is dependent on the shear resistance of the collar material and the number of grooves it fills.

In a first step, the pin is placed into the prepared hole and the collar is placed over the pin. In the initial stage of the installation process, the tool engages and pulls on the pintail. The joint is pulled together. At the same time, the conical shaped anvil is forced down the collar, pushing the collar against the joint and generating the initial clamp. In a second step, the tool swages the collar into the grooves of the harder pin. The squeezing action reduces the diameter of the collar, increasing its length. This in turn stretches the pin, increasing the clamp force over the joint. When the collar is fully swaged, the pin breaks and the installation is complete.



Installation sequence of a lock bolt

(Source: AFS Huck)

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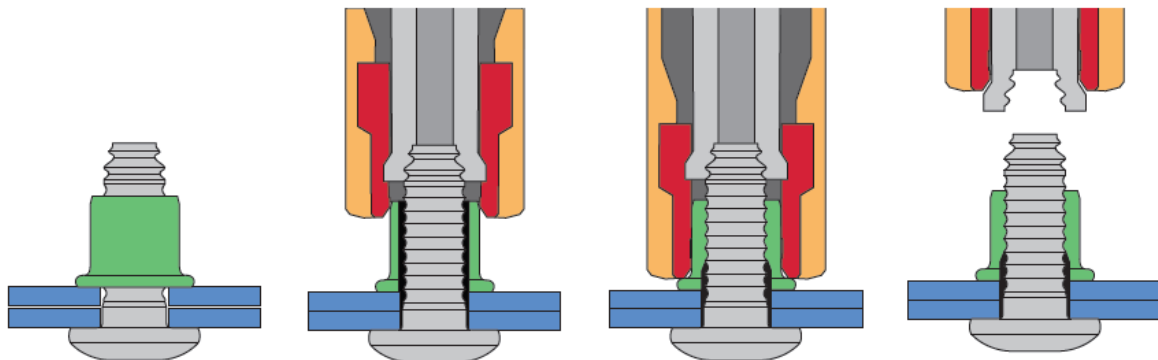
There are different designs of lock bolts, depending on the specific application. The original Huck design is shown below.



Original lock bolt design (Huck C6L®) (left) and the BobTail® lock bolt (right)

(Source: AFS-Huck)

The BobTail® system is a new style lock bolt with lower installation loads than previous style lock bolts, allowing for lighter and smaller installation tools and shorter cycle times. The standard lock bolt features such as vibration resistance, high and consistent clamp load, and high fatigue strength are still provided. Lock bolts can be also installed in tight access areas since the pintail, the part of the bolt that the tool holds onto, is so small that it now remains on the pin after swaging the collar. This eliminates bare surfaces that can corrode, tail break off noise, and picking up discarded pintails.



Installation of the BobTail® lock bolt

(Source: AFS Huck)

In case of the BobTail® system, the installation tool is applied to annular pull grooves. When the tool is activated, a puller in the nose assembly draws the pin into the tool, tension loading the joint and drawing up any sheet gap. At a predetermined force, the anvil begins to swage the collar into the pin's lock grooves. Continued swaging elongates the collar and pin, developing precise clamp. When swaging of the collar into the pin lock grooves is complete, the tool ejects the fastener and releases the puller to complete the sequence.

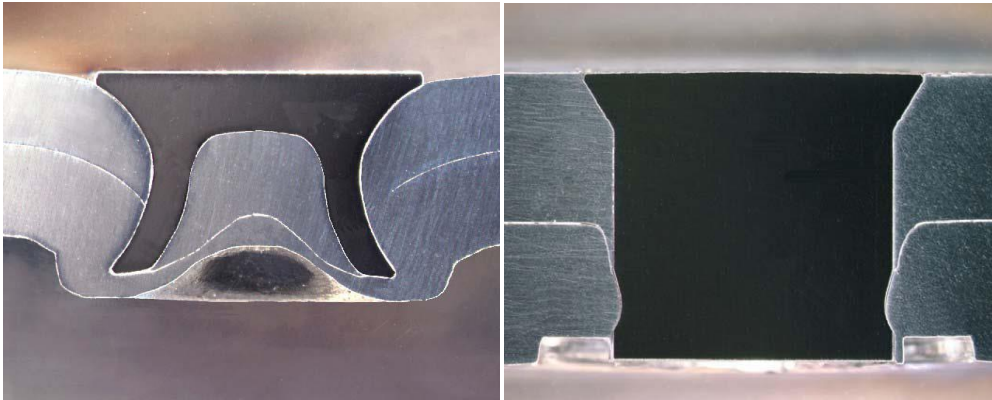
8.2.2.4 Self-piercing rivets

Self-piercing riveting can be classified as a single-step joining process where the prior formation of holes, necessary for conventional riveting processes, is unnecessary and replaced by a combined cutting-riveting process. It is a high-speed mechanical fastening method for point joining of two or more material layers. Two-sided access to the work piece is necessary. Depending on the type of

rivet, two technologies can be differentiated. Mainly semi-tubular (half-hollow) rivets are applied, but there are also solid self-piercing rivets.

Self-piercing rivets pierce and fasten the components to be joined in one operation, eliminating the need for insertion holes and alignment and minimizing distortion and other material changes. The process can be used on a wide variety of materials including steel, aluminium and other metals, plastic and composites, and rubber. Also dissimilar materials and pre-coated, pre-painted or pre-plated materials can be joined. Furthermore, also joining of material layers with intermediate compounds (e.g. adhesives) or materials covered with oil or other surface contaminants is possible.

With solid rivets, the punch drives the rivet which pierces the sheet plies completely. Using semi-tubular rivets, the punch drives the rivet which pierces the top sheet and is set into the work-piece by partially piercing the bottom layer. The lower sheet layer is not penetrated in the process. A shaped die on the underside reacts to the setting force and causes the rivet tail to flare within the bottom sheet. This produces a mechanical interlock which includes the added rivet joining fastener and creates a button in the bottom sheet.



Self-piercing riveting with half-hollow (left) and solid rivets (right)

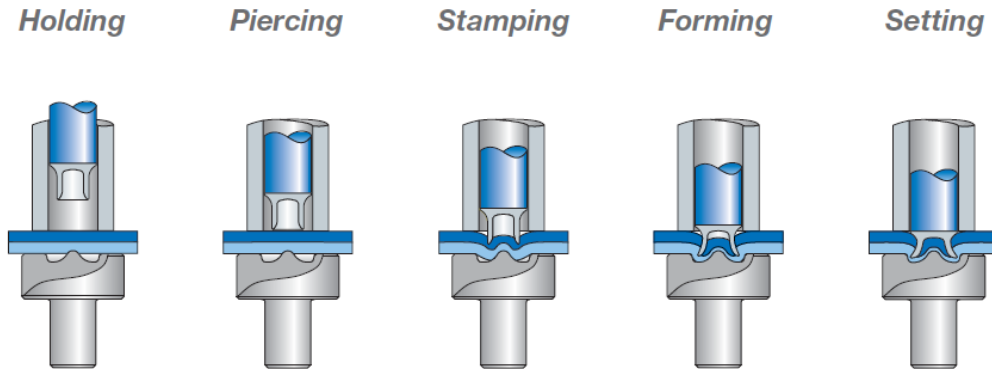
(Source: Novelis)

Although aluminium self-piercing rivets are available, steel elements are generally used which are covered with a special protective layer to prevent galvanic corrosion.

Assembly equipment can be stationary, robotic or integrated into an assembly cell, depending on production rates and complexity of parts joined. Typically, equipment is comprised of a support structure engineered to endure setting forces up to 50 kN, ensuring rivet alignment with the die. The force used to install the rivet is generated by a hydraulic cylinder that drives a plunger against the rivet head. Approximately 70 % of self-piercing rivet applications use robot-mounted equipment. Typically, the rivet setter and die are mounted in a C-frame, which must be large enough to allow access into the areas to be riveted. In automated application, the punch rivet is separated out from a bin and conveyed to the setting tool through a feed tube. A magazine can also be used for the feeding process.

a) Semi-tubular self-piercing rivets

Self-pierce riveting is done by driving a semi-tubular rivet through the top material layers and upsetting the rivet in the lower layer – without piercing this layer – to form a durable joint. The entire process takes less than 1.5 seconds, depending on cylinder stroke and feed tube length.



Process sequence for self-piercing riveting with a semi-tubular rivet

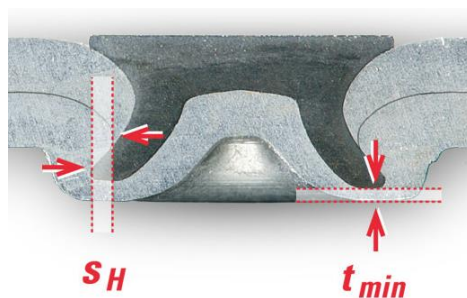
(Source: Böllhoff)

The process starts by clamping the sheets between the die and the blank holder. The semi-tubular rivet is driven into the materials to be joined between a punch and die in a press tool either at a controlled force or speed. The rivet is forced to pierce through the punch-side sheet and while driven into the die-side sheet, it is plastically formed and forced to penetrate laterally into this sheet by the special shape of the die. The resulting rivet collar in the plastically formed lower layer acts as a mechanical interlock. The rivet may be set flush with the top sheet when using a countersunk rivet head.

The length of the rivet, the diameter of the inner die contour, the ratio of the depth of the inner die contour to the diameter of the rivet shank, and the design of the tooling mainly determine the final result of the joint and the button on the underside of the joint. Self-piercing rivets and process equipment are offered by various system suppliers. Although the operation principles are basically the same, there are variations from one system to another in, for example, rivet and die shape. Since the joints are generated by local plastic deformation the fastener and the work-piece, the joint properties may depend strongly on the chosen tooling and fastener parameters.

The combination of rivet, die and material must lead to a virtually form-fit joint. To ensure optimum conditions, an analysis of the riveting conditions and material properties is necessary, i.e. tests have to be carried out to determine:

- Appropriate rivet length
- Suitable die contour for optimum joint conditions
- Required setting force.

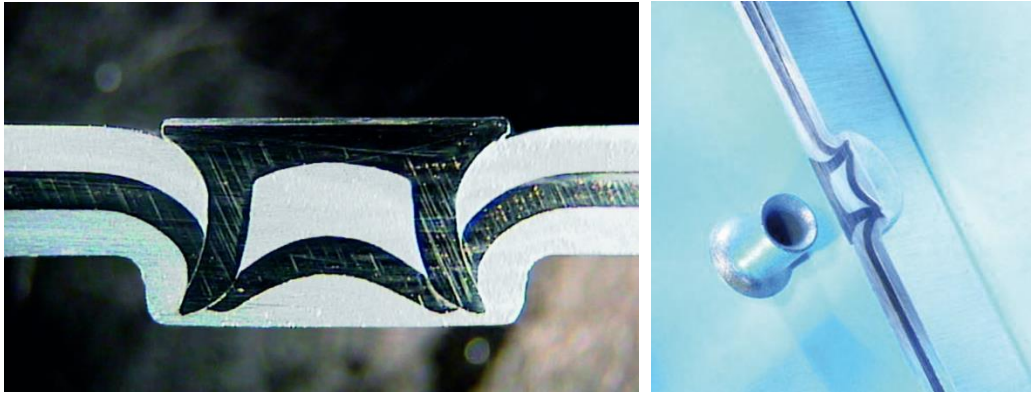


Quality features of a self-piercing rivet joint

(Source: Tucker)

A most important part is the determination of the proper die design. Apart from destructive tests to determine the mechanical properties of the joint, relevant quality features such as undercut (S_H) and remaining base thickness (t_{min}) are determined in a cross section.

Semi-tubular rivets can fasten stacks of two or more layers. Current applications include up to 12 mm total thickness in aluminium (6 mm in steel). A joint made with self-piercing rivets is both leak proof and has a very high degree of joint integrity. It will not damage coated or painted surfaces; also it is compatible with adhesives or sealants. Furthermore, the joint has a higher dynamic strength in comparison to a spot welded joint. For these reasons, self-piercing riveting is more and more used in automotive applications.

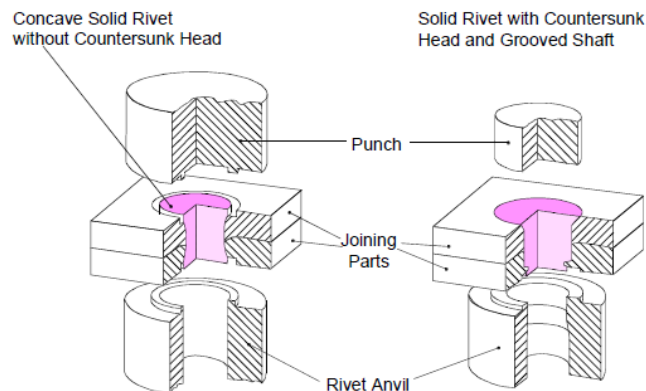


**Three layer Al/steel/Al joint produced by self-piercing riveting
(Source: Böllhoff)**

b) Solid self-piercing rivets

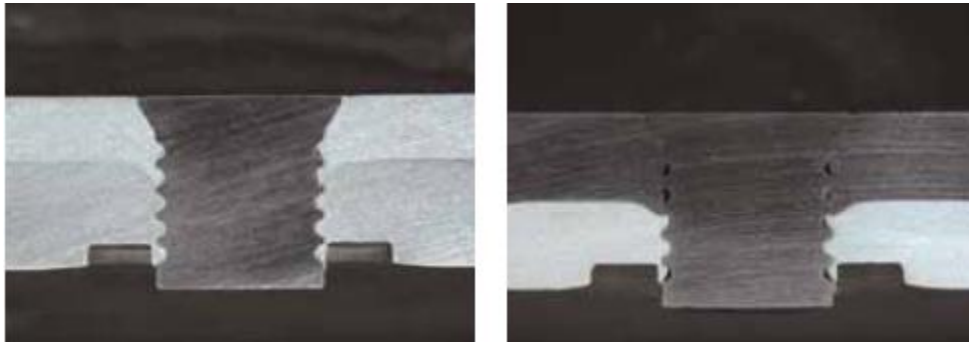
During self-piercing riveting with solid rivets, the rivet sits flush with the sheet and almost fully retains its original geometrical form. In contrast to punch riveting with semi-tubular rivets, the rivet is punched through both sheets to be joined. The parts of the sheet punched out during the punch process do not remain in the hollow shaft and has to be removed. Thus, the tools used must have an arrangement for allowing the removal of the punched out parts.

Two variants of self-piercing riveting with solid rivets are used industrially. One possibility is that the material in the region of the cut joint is forced to flow around the concave rivet due to the compressive action of the shoulders both on the punch and the die. In the other case, the applied rivet offers one or more grooves in the rivet shaft. The punch-side rivet is flat while the die plate has a ring-shaped contour that presses into the bottom sheet layer in order to create the undercut necessary for the connection strength.



Different form-locking methods when self-piercing riveting with solid rivets

In addition to the geometrical parameters, the selection of the rivet material is most relevant for a high-quality riveted joint; the material used for the rivet depends on the parts being joined and determines the strength and corrosion behaviour as well as the punching performance and formability during processing. Solid punch riveting involves the use of aluminium, coated steel or stainless steel rivets.



Cross sections of punch rivet joints:

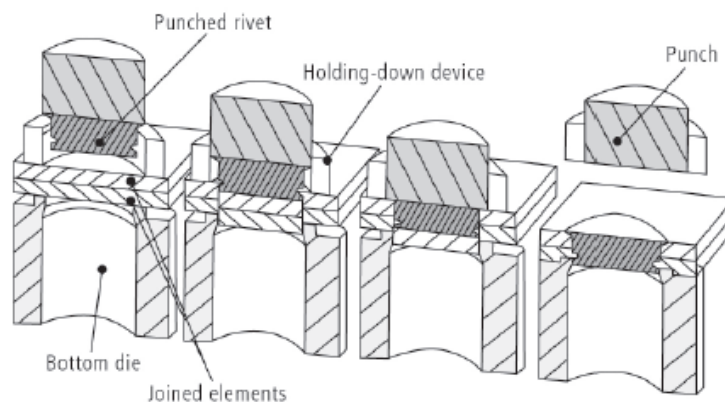
EN AW-6181A (1.5 mm) in EN AW-5754 (2.5 mm) (left) and St1203 (2.0 mm) in EN AW-5754 (2.0 mm) (right)

(Source: Kerb-Konus)

The solid punch rivet can be placed by C-bow or column presses, hand held or robot tongs as well as by custom made devices. Two or more material layers of the same or different materials up to a combined sheet thickness of approximately 9 mm can be automatically joined. Solid punch rivets offer large tolerance allowances regarding sheet metal thickness and strength variations, i.e. high strength steel grades (R_m up to approximately 1700 MPa) as well as less ductile materials (e.g. aluminium castings or fibre reinforced composites) can be also riveted if they are placed on the punch side. However, the strength of solid punch riveted joints is inferior to that of semi-tubular riveted joints.

On the other hand, solid punch riveting is suitable for visible applications; there is minimum piece part distortion and a flush surface on punch and die side is possible. When aluminium solid punch rivets are used, they can be even reworked mechanically.

In punch riveting, the work pieces are clamped to the bottom die by the hold-down device. They are then punched by the solid rivet that acts at the same time as the blanking die. The punching waste that is created with the through punch is removed automatically. When the stop-point is reached, both the hold-down device and rivet punch are flush with the work piece surface. In the last phase, the contour of the bottom die and the compressive force applied by the rivet punch and hold-down device cause the material to flow in the opposite direction of the punch movement, pressing the material into the peripheral shank groove(s) in the rivet.



Process sequence for self-piercing riveting using solid rivets

(Source: Kerb-Konus)

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The rivet is not deformed in this process. Rivet shaft diameters between 3 and 5 mm are generally used, the standard rivet length varies between 3.5 and 9 mm.

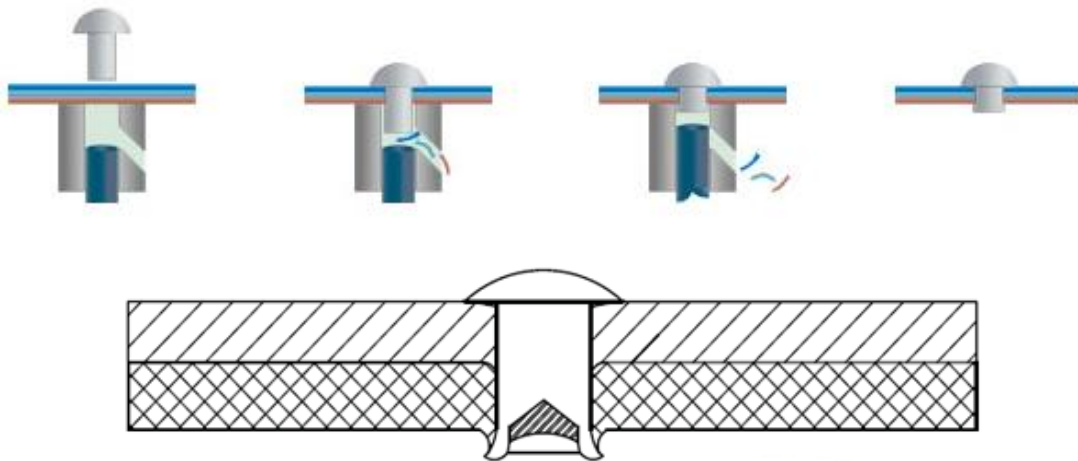


Typical shapes of Tuk-Rivet® solid punch rivets (left) and an aluminium heat shield assembly consisting of a sheet and a die casting (right)

(Source: Kerb-Konus)

The obvious difference between semi-tubular and solid punch rivets is that the semi-hollow rivet creates an elevation (“button”) on the die side, whereas the solid punch rivet shows a level surface. Moreover, almost no distortion of the work piece takes place with the solid punch rivet. Solid punch rivets are, in addition, better suited for joining high-strength and ultra-high-strength materials (tensile strengths higher than $R_m = 1600$ MPa) and aluminium castings with lower ductility. With regard to joining directions, the only restriction with solid rivets refers to ultra-high-strength materials saying that the brittle/hard material must be put on the punch side.

The self-piercing rivet technologies outlined above involve using special patented rivets. In specific applications, the auto-piercing technology offered by Capmac Industry which is based on the use of standard solid rivets could be also used.



Auto-piercing riveting process (above) and finished joint (bottom)

(Source: Capmac)

c) Practical application

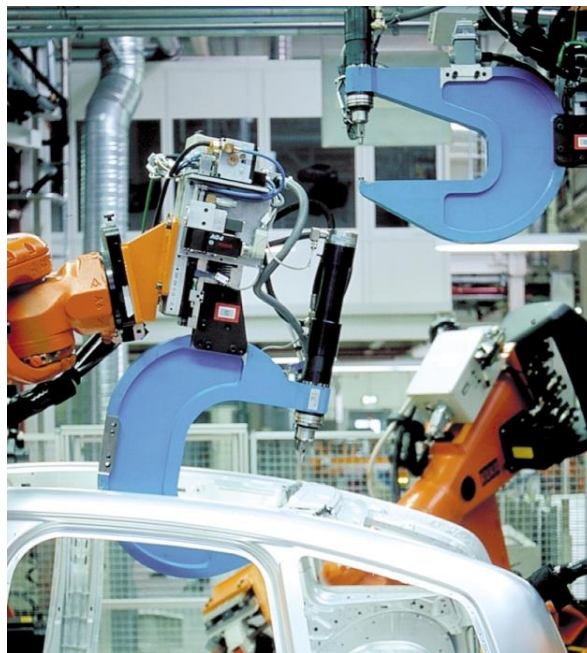
Self-piercing rivets can be used to fasten not only similar and dissimilar metals, but also different type of materials, as long as the bottom material layer is a ductile material. Actual ranges are dependent on application requirements and material types. Two conditions are required for the successful use of self-piercing rivet systems:

- Access for tooling on both sides
- Material thickness, strength and ductility need to fall within the practical range for self-piercing technology.

Generally, the range for sheet metal applications is a total joint stack thickness of up to 6 mm for steels, and 12 mm for aluminium. However, there are many exceptions in production, such as for high-strength steels, aluminium castings, and multi-layer joints with metallic and non-metallic layers. Furthermore, new requirements are constantly expanding fastening capability ranges.

The minimum thickness for steel and aluminium is 1.6 mm. For best results – when dissimilar materials are being joined – the rivet is generally applied from the direction of the **thin sheet into the thick sheet**, or from the **low strength material into the high strength** material. If this is not possible, it is recommended that the bottom layer thickness is not less than one-third the joint stack thickness.

Self-piercing rivet joints have virtually the same static strength (in tensile and peel loading) as resistance spot welded joints. However, self-pierce rivet joints generally show higher strength and stability under dynamic load. The joints need to be of a lap-type configuration. In terms of part size or configuration, the only condition is that the rivet actuation cylinder and C-frame can access the joint. It is important to allow for die clearance, to specify adequate flange dimensions and to avoid closed box sections.



Car body assembly by self-piercing riveting

(Source: Audi)

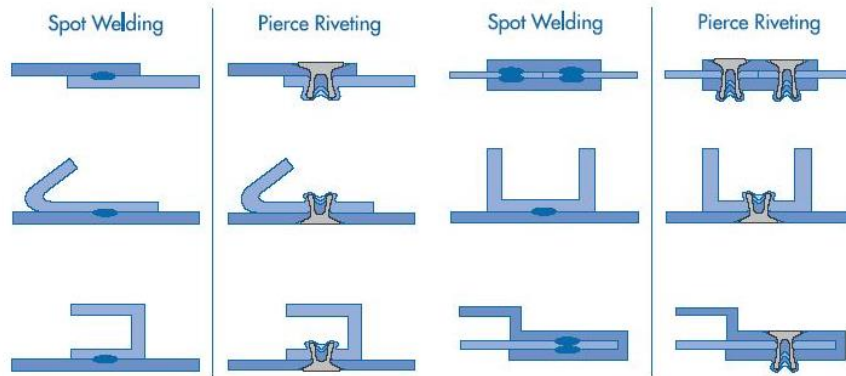
Just as in the case of conventional riveting, different head forms are used for simple and complex components and for varying loads. The rivet elements can be stored in magazines or supplied directly. The rivets can be protected against corrosion by surface coating. Today, chromate and galvanised steel rivets are generally used for self-piercing riveting aluminium. If necessary, also aluminium self-piercing rivets made from special high-strength aluminium alloys can be applied.

The cycle time for a self-pierce riveting system is generally the same as for spot welding. The process can be easily automated; it offers high productivity and consistent joint quality. Self-piercing rivets are generally installed with a servo-driven or hydraulic tool allowing proper control of the rivet-setting process.

A process load monitoring incorporated into the installation tooling system allows tracking and notifying the operator of any variance in joint quality.

d) Joint design

In principle, joint configurations suitable for resistance spot welding can be also used for self-piercing riveting.



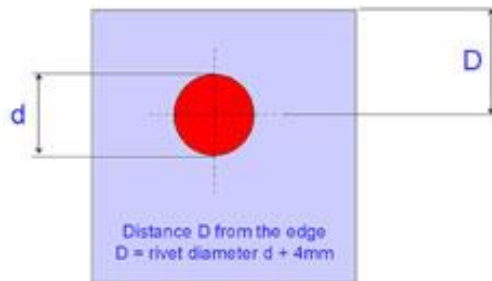
Possible joint configurations

(Source: Avdel)

The following recommendations for joint design should be observed:

- Flange width should be sufficient to contain the deformation zone
- Adequate spacing between rivets must be maintained
- Ensure good fit up of components.

In case of semi-tubular rivets, the flange width (D), i.e. the distance from the edge to where the rivet is placed, must be sufficient to ensure that there is enough material to contain the deformed rivet as well as the surrounding deformed material.



Otherwise, the button may break out of the edge of the flange or cause distortion of the component. Proper overlap of the material layers to be joined and a correct flange width also help to ensure proper alignment between the work-piece, punch and die. A pre-clamping step may be helpful if joining a flange width close to the minimum width. Similar considerations are also applicable to solid punch rivets. As an example, for a rivet with a diameter of 4 mm, the minimum flange width should be about 12 mm.

The length of a solid punch rivet should correspond to the thickness of the material ply. In case of semi-tubular rivets, the rivet length L can be estimated as follows:

- 3 mm rivet diameter: $L_3 = \text{thickness of sheet plies} + 2.5\text{mm}$
- 5 mm rivet diameter: $L_5 = \text{thickness of sheet plies} + 3.5\text{mm}$.

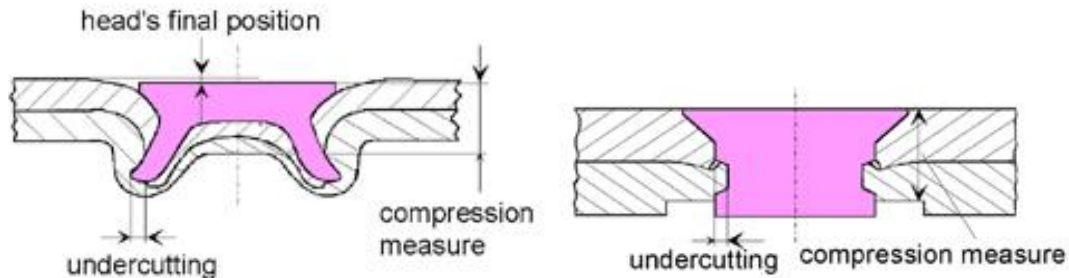
Rivets should be spaced to avoid contact with neighbouring rivets or the strained area immediately around them. Since the rivets are made of harder material than the work pieces, riveting over an existing joint may result in serious damage to the tooling. Placing several rivets too near to each other may cause distortion of the joint. A pre-clamping step can help to minimise this. Poor fit-up and alignment may reduce joint performance and accelerate tool wear.

A precise relationship between part fit-up, alignment and joint quality is not easy to quantify. However, good control of these two variables will help ensure that the layers of material to be joined are drawn together properly as the rivets are driven and set.

e) Quality criteria

In self-piercing riveting with semi-tubular rivets as well as solid rivets, the strength of the joint is determined by the amount of undercutting.

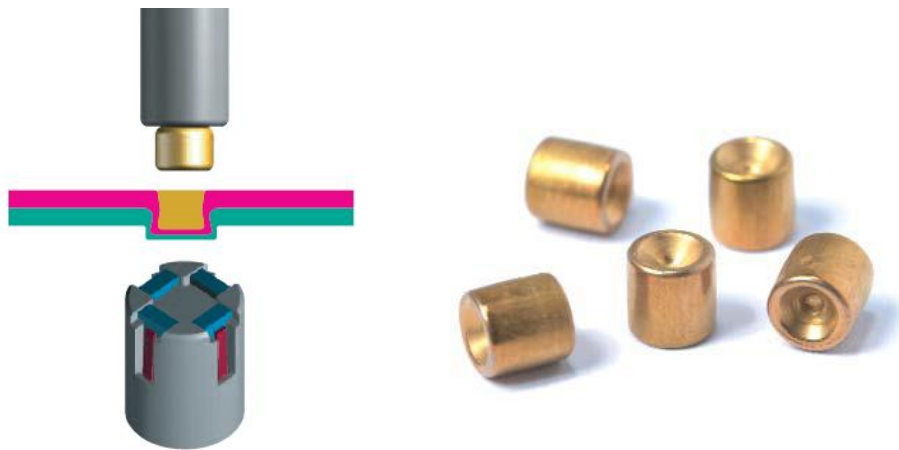
Since the tool and rivet dimensions are carefully tuned to each other and to the joint thickness, the amount of interlock is determined by the "compression measure", which can also serve as a non-destructive quality criterion when compensated for the position of the rivet head within the joint.



Quality criteria for semi-tubular (left) and solid rivets (right)

8.2.2.5 Clinch riveting

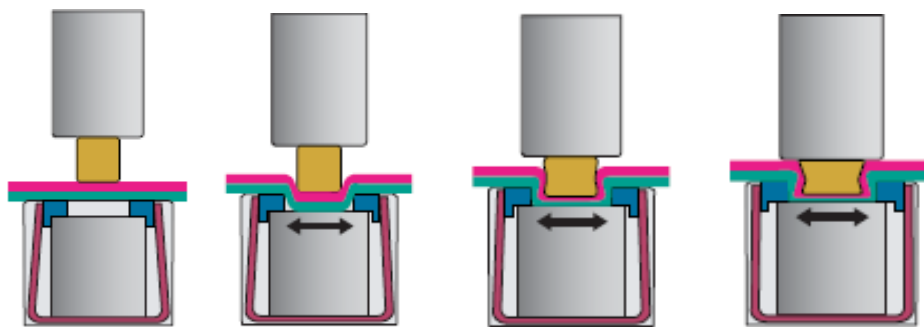
With the introduction of the solid punch or clinch riveting technology, the clinching technology was further developed. The materials to be joined are complemented with an additional retaining member. Clinch riveting has its preferred application in the field of automotive lightweight constructions, respectively for the joining of hybrid components.



Clinch riveting, a spin-off development of clinching

(Source: TOX Pressotechnik)

The actual rivet connection is made using a simple cylindrical rivet in a joining process including a combined deep drawing/pressing operation. A simple, cylindrical rivet is pressed-in and formed during the clinching process. Just like with the clinch joint, the materials to be joined are not cut, but only deformed inside a die cavity. The result is a very strong joint, even when used with thin materials.

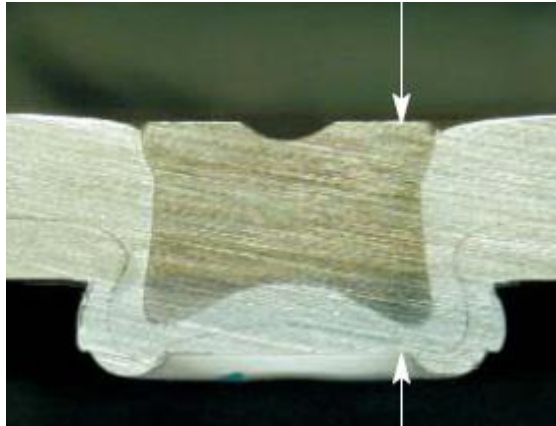


Installation of the TOX®-ClinchRivet

(Source: TOX Pressotechnik)

The special advantage of the clinch riveting technology is the simple, symmetrical and inexpensive rivet. This provides for a trouble-free feeding and pressing operation.

The high strength values of the TOX®-ClinchRivet joint result from the formed full rivet firmly positioned in the joint and the work hardening of the sheet metals in the neck zone created during the deep-drawing process. The die with solid and flexible elements enables a closely controlled guidance of the rivet, ensuring higher process reliability even with unfavourable production conditions (e.g. when applied with gaps and adhesives between the metal layers). An additional benefit of the closed rivet shape compared to the “open” forms of semi-tubular self-piercing rivets lies in the absence of any adhesive or air pockets, and their potentially higher risk of corrosion in the riveted joint. Furthermore, the essentially smaller die diameter permits the utilization of significantly smaller flanges when clinch riveting is used instead of self-piercing riveting.

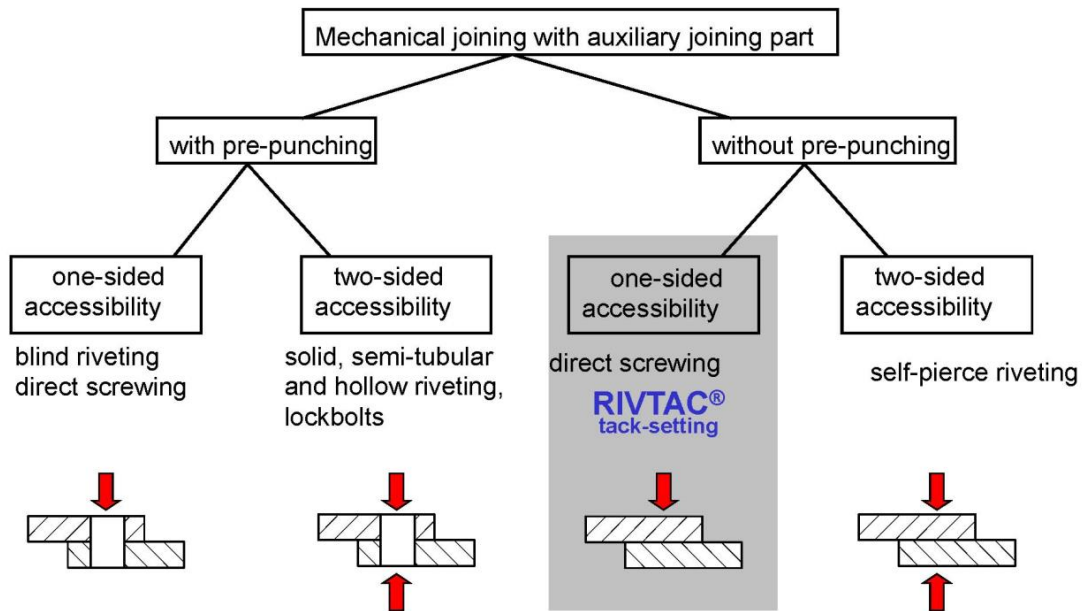


Quality control of TOX®-ClinchRivet joints
 (Source: TOX Pressotechnik)

The quality control dimension “Remaining rivet height + remaining bottom width” can be easily and non-destructively determined and provides an excellent quality measure. It is proportional to the shear and tensile strength of the joint, provided that the joining parameters have been appropriately observed.

8.2.2.6 Tack high-speed joining

The name “tack joining” describes a simple and fast joining process. It requires only one-sided access; however, there is a need for a relatively stiff counterpart. Therefore a preferred application is a sheet/profile joint. No pre-punching of holes is required. Especially advantageous are the very short joining and cycle times of less than 1 second.



Classification of RIVTAC® high-speed joining within the mechanical joining processes
 (Source: Böllhoff)

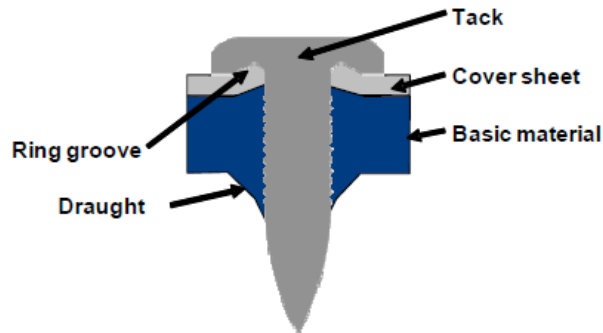
In the tack joining process, a nail-like fastener is accelerated to high speed and driven into the parts to be joined. In a single step, the tack penetrates both components and joins them efficiently without pre-punching. The ogival tip of the tack displaces the material without forming a slug. The component material

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flowing in joining direction forms the draught. Material flowing contrary to the joining direction is taken in by the ring groove or lower head ring groove of the tack.

The speed, which can be controlled via the adjustable pressure, is optimised to suit the material type and the wall thickness. An important prerequisite is a sufficient stiffness of the joining parts, ensuring that the joining parts can sustain the penetration impulse of the tack without major deformation.

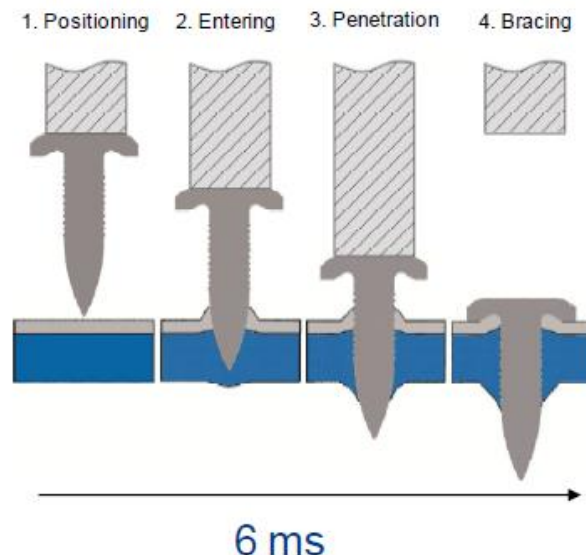
Joint stability in the lower joint section is achieved by a combination force fit (resulting from the restoring force of the displaced material) and of form fit. During penetration, the material experiences a momentary temperature rise in the joining zone and the locally heated material flows into the knurled shaft of the tack leading to a high form fit.



Tack joining element (RIVTAC®)

(Source: Böllhoff)

In the tack setting process, the joining energy is transferred onto the tack via a punch piston which accelerates the tack to high speed. Only a single process step, concluded in a split second (approx. 6 ms), is required, which has a positive effect on the processing time. A wide range of different applications can be joined with only one tack geometry. A disadvantage is the inevitable impulse noise during joining, in particular when the components favour a large-scale sound radiation. Also required is a sufficient support which can be achieved by a sufficient inherent stiffness of the components or by a temporary rear support.

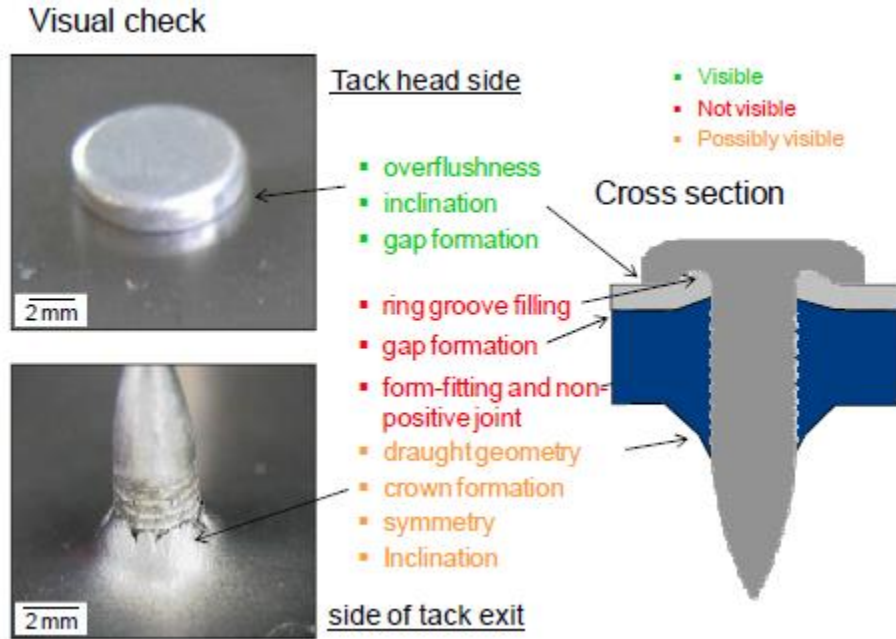


Process sequence of the tack high-speed joining process (RIVTAC®)

(Source: Böllhoff)

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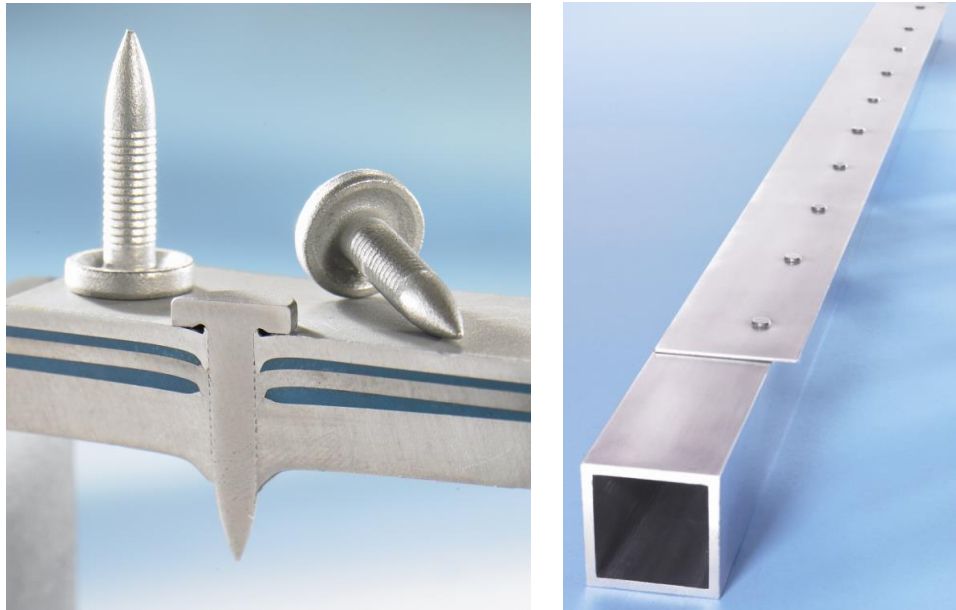
A tack joint is characterised by the tack head which is directly placed on the cover sheet and a draught on the back which tightly encloses the tack shaft. For this joining process a preferably consistent and complete contact of tack head and cover sheet is desired, which can especially be attributed to optical and corrosive aspects. The following illustration also indicates test criteria for joint quality, which can be examined by visual inspection or in a cross-section. Another quality control measure is on-line process monitoring the joining process.



Joining zone formation and test criteria for joint quality

(Source: Böllhoff)

The material combinations which can be joined with a single tack geometry reach from aluminium materials to a wide range of plastics (including fibre-reinforced plastics) to ultra-high strength and press hardened steel. Multiple-layer joints can also be realized. In combination with adhesive, joints can be achieved for which a constant thickness of the adhesive layer in the joint flange is specified. Due to the high tack setting speed, the adhesive layer acts as a third rigid layer, preventing the adhesive from spreading uncontrollably.



Three-layer aluminium profile joint with adhesive produced by RIVTAC® high-speed joining (left) and sheet-profile joint (right)

(Source: Böllhoff)