

Defects, their source and detection in wire drawn products

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Wire drawn products are very susceptible to defects. At the end of the process, this product can have a very small resistant section, and, for this reason, even small defects can lead to the wire failure or scrap. Moreover, the wire finishing must be very high to match aesthetic criteria and to improve the fatigue life. Flaws can originate in each part of the process, and in this paper some examples of defects in wire drawn products caused by melting, casting practice and metallurgical sources are reported.

KEYWORDS: WIRE DRAWING – DEFECTS – LIQUID STEEL – CASTING

INTRODUCTION

In wire drawing, the cross section of a long rod or wire is reduced or changed by pulling it through a die called draw die. During the process some defects can arise, and they can be classified as surface and internal defects. Moreover, because they undergo non-uniform deformation during drawing, cold drawn products are usually featured by the residual stresses. They cause the component to warp. Internal defects due to the wire drawing process are usually represented by cracks caused by the tensile hydrostatic stress in the centerline and they can be avoided using a right die design and reducing the non-metallic inclusion fraction in the steel. The so-called seams are surface defects that can be originated during cold drawing and they are constituted by longitudinal scratches or folds in the material. Several other surface defects (such as scratches and die marks) also can be caused by improper selection of the process parameters, i.e. poor lubrication or poor die condition [1].

However, many defects spring up during the process or during the subsequent forming operations, due to defects already existing inside the raw material. Some examples of these flaws are scabs, laminations, slivers, seams, embedded scale and laps [2]. These problems can be attributed to different sources: melting and casting practice, metallurgical sources, heating and rolling practices [3]. For example, scabs are associated to melting and casting practice. Scabs are irregularly shaped, flattened protrusions caused by splash, boiling or other problems from teeming, casting or conditioning [4]. Non-metallic inclusions are originated from a metallurgical source: they are produced during the steel secondary metallurgy. Some residual inclusions, like alumina or silica, proximal to the surface, give rise to seams and slivers. These two types of flaws can be also originated by another metallurgical source: the high concentration of Cu, Zn or Sn in the steel. These chemical elements are considered as detrimental because they can cause many cracks to form on the

surface during mechanical working at high temperatures such as hot rolling. This phenomenon has been known as surface hot shortness: selective oxidation of Fe at the steel/scale interface occurs while portions of steel featured by Cu, Zn and Sn form during the heating and melt at low temperature [5,6]. Actually, the phases enriched by Cu, Zn and Sn are featured by a low melting point, so they tend to liquefy at the austenite grain boundaries and under stress during hot rolling such phases cause cracks on the steel surface. The concentration of Cu, Sn e Zn is continuously increasing in scraps and this problem can only worsen in the future [7]. Embedded scale can be due to an excessive scale formation during the heating operations. Finally, laps can be ascribed to pass overfilling during the rolling: the

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Drawing

roll pass is not adequately filled, and part of the section falls over in the roll pass [2].

The previous list is not exhaustive, but just a brief overview of the blemishes that can be detected in drawn products. These defects can be found during non-destructive tests. Usually, a rotating-type ultrasonic unit is used, in the form of a phased-array, to detect internal defects but this method is not yet sufficiently reliable for surface flaws [8]. However, a flawless product cannot be ensured neither in the billet before the rolling and wire drawing nor in the wire. Thus, this kind of defects

results in failure during the deformation process or in service. In the following, some examples of defects in wire drawn products examined during the PoliMi Lab activities are reported. In particular, the focus has been on defects caused by melting, casting practice and metallurgical sources.

Example 1

On several wire rods, after the first pass of drawing, some defects were detected after visual examination. These defects appear like slivers (Figure 1).



Fig. 1 – Slivers detected on the wire after the drawing

Some metallographic sections were obtained, and the samples were analyzed by means of SEM-EDS.

In Figure 2 the micrographies are reported and also the points in which the chemical composition is measured.

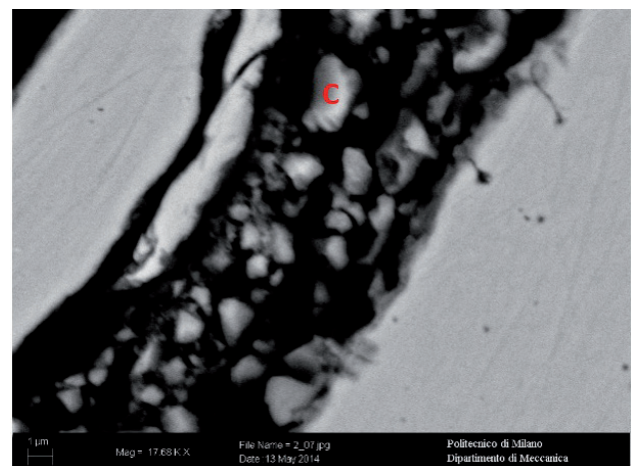
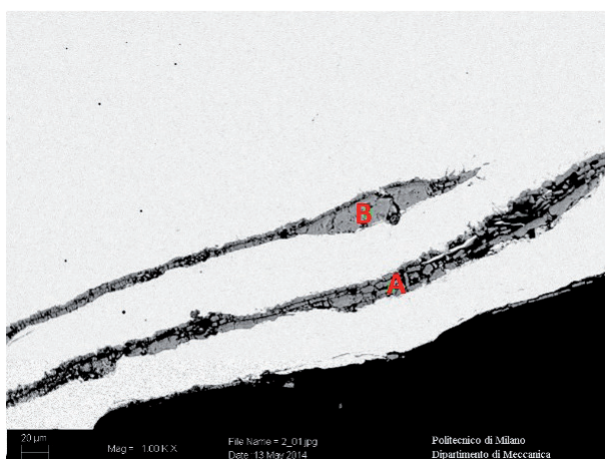


Fig. 2 – SEM-EDS analysis on the metallographic sample: (a) at low magnification and (b) at higher magnification. In A, B and C chemical analysis was performed (Table 1).

Tab. 1 – Chemical composition in A, B and C in Figure 2

% by weight	C	O	Ca	Mn	Fe	Cu
Fig.2 A	30,68	20,50	0,52	-	45,44	2,86
Fig.2 B	8,04	13,86	-	-	78,10	-
Fig.2 C	12,78	15,31	0,71	-	69,74	1,47

Figure 2 shows long inclusions under the surface of the wire. The inclusions, using the BSE probe, appear oxidized. The EDS analysis suggest that this defect is mainly iron oxide but, in some points, a high concentration of copper was detected. This flaw is due to a hot shortness phenomenon: the high concentration of copper creates a liquid film between the grain and some cracks are formed. The defect origin is probably related to the deformation processes prior to the wire drawing (i.e. hot

rolling) as a consequence of the high oxidation level featuring the observed crack.

Example 2

On several wire rods, at the end of the drawing process, some defects were detected after visual examination. These defects appear like laminations (Figure 3) pointing out the typical shape similar to the tool chipping.



Fig. 3 – Laminations on wire drawn products (diameter 7mm).

In order to understand the origin of the observed defects a metallographic section normal to the wire axis has been analyzed.

Optical and electronical microscopy were used to understand the defect genesis.

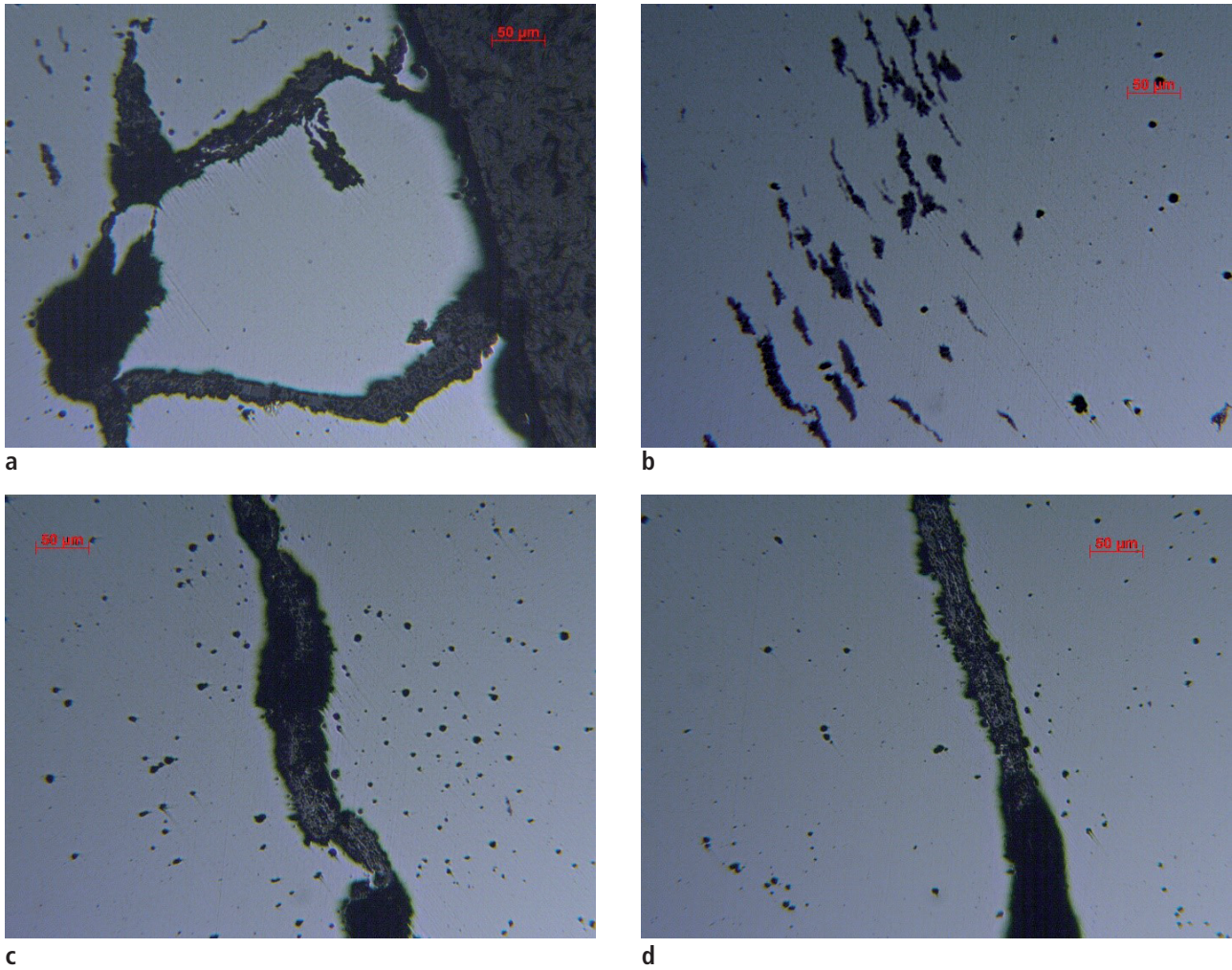


Fig. 4 – OM of the defects

Figure 4 shows many flaws in the sub-cortical zone of the sample: there are some cracks (Fig.4-a), some non-metallic inclusions (b) and a huge number of porosities proximal to the cracks. All these factors could have given a contribute to the lamination formation. Sub-superficial cracks are often oxidized and, during the drawing process, they tend to open. Moreover,

deformable inclusions tend to align and because of their poor ductility (if compared to the matrix) they tend to break under the high stress and strain generated by the process.

The SEM-EDS analyses shows a relevant cracks oxidation and the chemical composition of the nonmetallic inclusions (Table 2).

Tab. 2 – Non-metallic inclusion chemical composition (Fig.4-b)

% by weight	O	Si	Ca	Mn	Fe
Inclusion (fig. 4-b)	20,83	29,33	2,04	44,24	3,56

These inclusions can be originated by the re-oxidation of the steel in the tundish or in the mold during the continuous casting process. This phenomenon creates the Si and Mn oxides and promotes the gas formation inside the molten metal.
Example 3

On several wire rods, at the beginning of the drawing process, some defects were detected after visual examination. This defects can lead to failure or scarp at the endo of the drawing. These defects appear like seams (Figure 5).

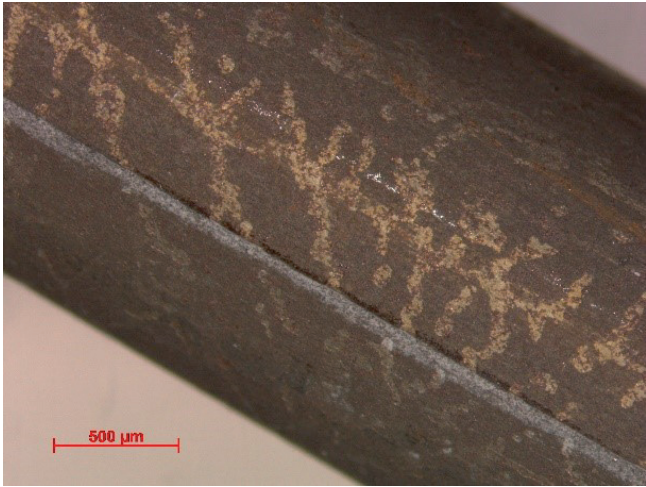
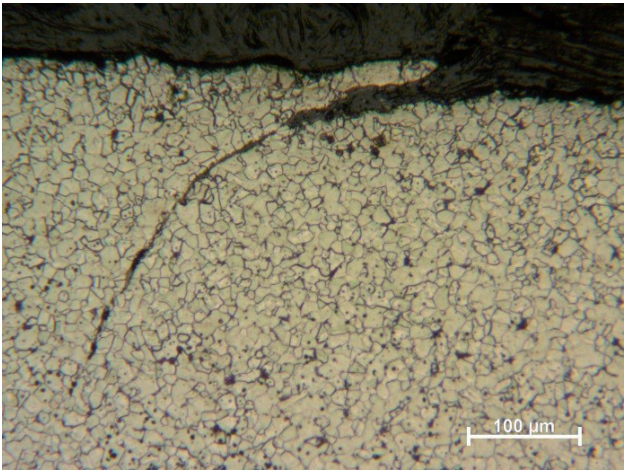
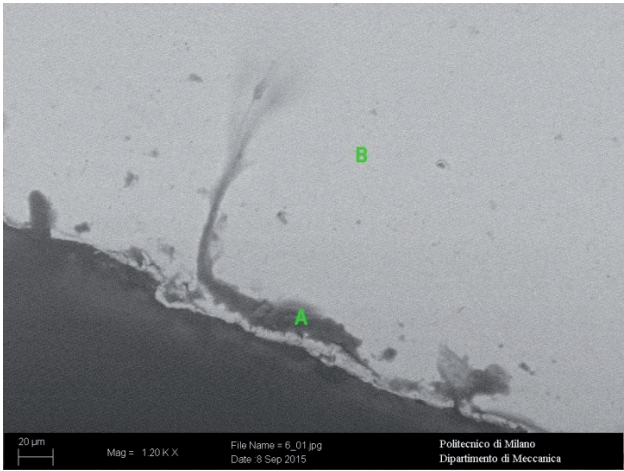


Fig. 5 – Seams on a wire before the wire drawing

Also in this case, the flaw analysis was performed by means of OM and SEM.



a



b

Fig. 6 – Micrographic investigation on transversal section of the wire in Figure 5: (a) optical microscopy and (b) SEM-EDS analysis.

Figure 6-a shows some non-metallic inclusions featured by a particular curvature. This "hook" is peculiar of lubricant entrapment due to pronounced oscillation marks arisen during

the continuous casting. SEM-EDS supports this hypothesis because of the detected chemical composition (Table 3).

Tab. 3 – Local chemical composition: figure 6-b point A

% by weight	O	Na	Al	Si	Cl	K	Ca	Fe	Mo
Fig.6 A	35,64	12,15	2,81	15,58	12,78	5,09	1,91	8,99	5,05

As a matter of fact, this chemical composition is typical of the powder used in the mold during the continuous casting. The lubricant viscosity, the oscillation frequency and the mold stroke have to be taken into account for the formation of such a defect [9].

Conclusion

In this paper a brief overview about the defects revealed on the wiredrawn products was presented.

Defects can have many origins, but a high-quality rod can help

for decreasing the failure during and after the wiredrawing. During the steel production, many metallurgical defects can arise, and they cause the final defects or the product failure. Some defects can be detected by NDT but, unfortunately, a complete control on the whole production is not sustainable. For this reason, a good metallurgical practice, in all the parts of the steelmaking process, can decrease the defect formation (in particular the sub-surficial zone) and give rise to a contained failure and waste of the final wiredrawn products.

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