THE INFLUENCE OF TIG WELDING JOINT ON PLASTICITY OF SEAM TUBES

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Abstract

This article is focused on analysis of state formation which influences the tubes production process from austenitic stainless steels with diameter ∅ 0.34 mm in a negative way. The problems have been concentrated on factors monitoring which affect the drawing process stability of seem tubes where the desired final dimensions - a diameter ∅ 0.34 mm and a wall thickness 0.057 mm have been limited factors. The seem tube from steel 1.4306 and 1.4301 from producers KRUPP THYSSEN and ERGSTE WESTIG with longitudinal weld line created by TIG welding has been used as a blank for constituent drawing operations. By means of a weld analysis it has been determined that a thermal field creating during a weld formation can cause such material changes which influence to plasticity in a negative way during constituent drawing operations. There is a danger of chromium carbide precipitation along grain boundary in heat affected zone if a weld thermal field isn´t sufficiently cooled. These carbides cause plasticity degradation during technological operations with the most intense strain. It is desirable to provide intense inert gas circulation during a weld creation in air protective chamber.

Keywords: Austenitic steels, seem tubes, TIG welding, stability drawing process, strain

1. INTRODUCTION

The seam tubes from austenitic stainless steels are used as a workpiece to medical needles production. There are produced through the use of combination of forming and welding technologies - by continual bending of blank in a sheet metal roll form with dimensions 10 x 1 mm, by TIG welding method, by drawing over floating mandrel in diameter and thickness reduction of wall and by tube drawing without mandrel in diameter reduction. Deep-drawing processes are continual where drawing length in depending on the blank dimension can be up to 300 m. However, there is creating of technological fracture during the drawing process which influences in negative way on production.

The stable technological process is running continually according to predetermined and minimally changeable parameters without a technological fracture creating which can cause a production process interruption. Among factors affecting a technological fracture creating belong:

1) geometry of functional tools parts:
   - geometry of a drawing die and a mandrel - in ironing with wall thickness reducing with a floating mandrel (the first two operations),
   - geometry of a drawing die - in tube drawing (following operations) [1],
2) stress conditions in compress and size fixing area of functional tools parts [2],
3) influence of tool parameters on the deep-drawing process [2, 3],
4) geometric tubes similarity and a heavy-walled criterion [3, 4],
5) influence of the weld and the heat-affected zone on tube eccentricity and deep-drawing process [5],
6) influence of lubrication [2],
7) influence of stress-strain parameters of formed material on a initial dimension of workpiece [6, 7].

From these present factors the focus have been concentrated on the effect of the weld on plastic properties of formed material.

2. MATERIAL CHARACTERISTICS

The seam tubes used as a workpiece to needles production are made from austenitic stainless steels corresponding to the norm 1.4306 LA, resp. EN 1.4301 and EN 10088-2. These norms describe chemical composition of materials - 1. ERGSTE WESTIG, ARGESTE 4306 LA, PAPPE-300, DIN 17 441 and 2. KRUPP THYSSEN NIROSTA 4306, 1.4306 X2CrNi19 -11 which are described in **Table 1** [6].

The maximal permissible of a burr size on the edge is 10% from strip thickness. The surface of the starting material is high-bright, without surface protrusions, scales and pores with prescribed roughness.

Table 1 Chemical composition in wt.%, of material ERGSTE WESTIG, ARGESTE 4306 LA, PAPPE-300, DIN 17 441 and material KRUPP THYSSEN NIROSTA 4306, 1.4306 X2CrNi19 -11

Material	C	Si	Mn	P	S	Cr	Ni
ERGSTE WESTIG	0.027	0.56	1.07	0.019	0.001	18.02	10.05
KRUPP THYSSEN	0.012	0.52	1.56	0.022	0.05	18.25	10.08

The presented steels correspond to the norm EN 10 088-2 and DIN 17 441. There are in cold rolled state with high-bright surface.

3. TECHNOLOGICAL PROCESS OF TUBE PRODUCTION

The workpiece is a metal strip with optimized thickness and width 0.1 x 10 mm for final dimension of tube ϕ0.34 x 0.057 mm. The semi-product of tube with ϕ3.2 mm has been made by means of technological process according to **Figure 1**. It is rolled up to roll after continual bending and welding. The dimensional changes are achieved through following drawing operations on draw benches Bougrad Toolmatic with the purity degree „E“. The reduction of diameter and wall thickness with a floating mandrel has been ϕ2.84 x 0.075 mm in the first drawing and ϕ2.52 x 0.063 mm in the second drawing. The following operations are used to diameter reduction and they are realized by means of tube drawing without mandrel.

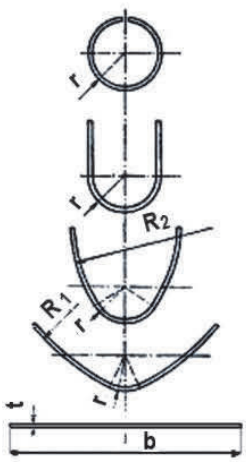

Figure 1 Technological process of seam tubes production by bending proces

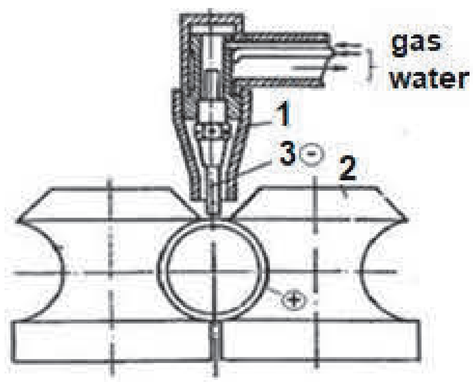

Figure 2 Seam tubes welding by TIG method
1 - gas jet, 2 - calibration pulleys creating additional pressure, 3 - non-melting tungsten electrode

3.1. Welding assembly

The austenitic stainless steels tubes has been arc welded by Tungsten Inert G*as method (TIG) -* ***Figure 2****. The tungsten electrode is used to creating and keeping electric arc and a gap filling. The gap dimension has been minimized through the* calibration *pulleys pressure. The aim has been to create a totally tight weld without* additional material and cracks. The favourable weld root forming has been secured by a pressure also presence of an inert gas. This way assigned the conditions for a perfect compact weld creating without pores and cavities. As an inert gas was used argon with a purity 99.95 % and the welding direct current with a straight polarity when a tungsten electrode is on a negative pole of the voltage source. In this way the TIG welded seam tube has been used as a workpiece to medical needles production [5].

4. MICROSTRUCTURE ANALYSIS

Microstructure of stainless steel X2CrNi19-11 grade produced by two companies Thyseen Krupp Nirosta and Ergste Westig was analysed. The microstructure of tubes made of stainless steel produced by Ergste Westig observed in both longitudinal and transversal cross-sections was created by high strained austenitic matrix with deformation texture and fine dispersed carbide phase as can be seen in longitudinal cross-sections in **Figure 3**. The cross-section of ribbon semi product produced by Thyseen Krupp is depicted in **Figure 4**. The microstructure consists of austenite matrix, but without carbide phase or other microconstituents. The grain size of matrix was slightly higher compared to stainless steel produced by Ergste Westig. However, the austenite grain size of both steels was in the interval from 0.015 to 0.025 mm and match the standards.

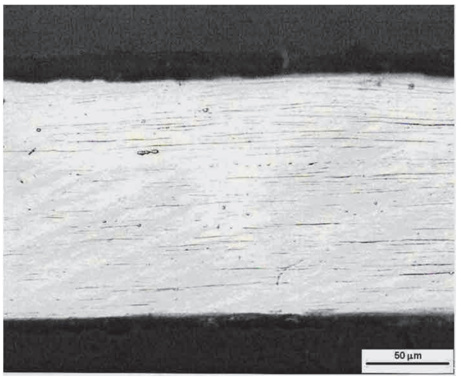

Figure 3 The tube WESTIG longitudal section

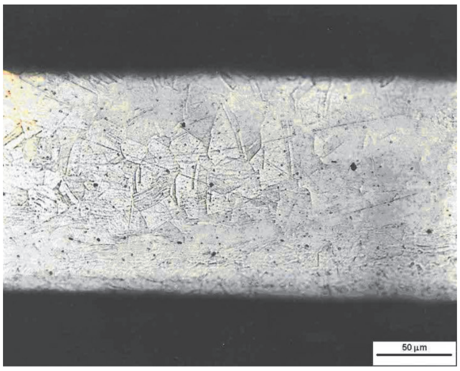

Figure 4 The strip blank THYSSEN section

5. MICROSTRUCTURE OF SEAM TUBE WELD

Tubes after continuous bending and longitudinal welding using TIG method present a semi product for following drawing operations. The presence of weld with heat impact during the welding process can cause some changes in heat affected zone of the weld that influence the plasticity in a negative way. The joint after welding is documented in **Figure 5a**. The same weld joint after the first draw with floating mandrel and final tube diameter of 2.84 mm is in **Figure 5b**, and after the second draw with final tube diameter of 2.52 mm is in **Figure 5c**. The geometrical nonuniformity can be seen after seam welding in **Figure 5a**, but this was eliminated by floating mandrel drawing, see **Figure 5b** and **Figure 5c**. No defects were found in seam welds. Both the microstructure changes of seam weld and wall thickness reduction were the consequence of strain generated during the floating mandrel drawing process and they can be seen when comparing **Figures 5a,b,c**. The effect of temperature on chromium-nickel austenitic stainless steel microstructure in heat affected zone of seam weld is documented in **Figure 6** is in **Figure 7**. The diagram shows the creation of chromium carbides $Cr_{23}C_6$ at the austenite grain boundary in the heat affected zone of the weld [7] when the cooling speed from the welding temperature is slow. These chromium carbide precipitates worsen plasticity during process steps with the highest strain at drawing with floating mandrel. Sufficient protective gas flow during seam welding in protecting camber can be utilised to restrain the creation of chromium carbide precipitates.

The SEM micrographs of inner side of tubes made of stainless steels produced by Ergste Westig and Thyssen Krupp are in **Figures 8 and 9**, respectively. The inner surface of tube made of stainless steel produced by Ergste Westig in **Figure 8** is characterised with carbide precipitates in austenitic matrix creating significant relief. The microstructure of stainless steel produced by Thyssen Krupp in **Figure 9** is characterised without carbide precipitates, but with coarser grain compared to steel produced by Ergste Westig.

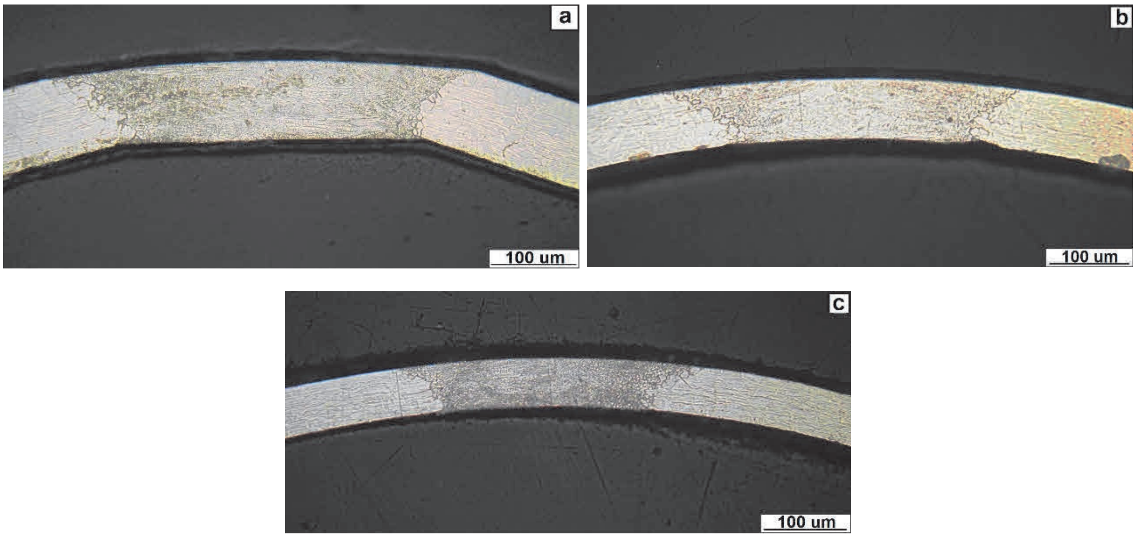

Figure 5 The weld joint of tube THYSSEN after a) welding, b) the first draw, c) the second draw

Hard carbide precipitates negatively influence formability. They cause misalignment of outer geometry with inner circle. Floating mandrel deflect during the drawing process toward the side without carbide precipitates a therefore the wall thickness reduction of the side without carbide precipitate is more significant. Significant deformation strengthening in this part lead to plasticity depletion and creation of conditions for instability during the drawing process with braking of tube.

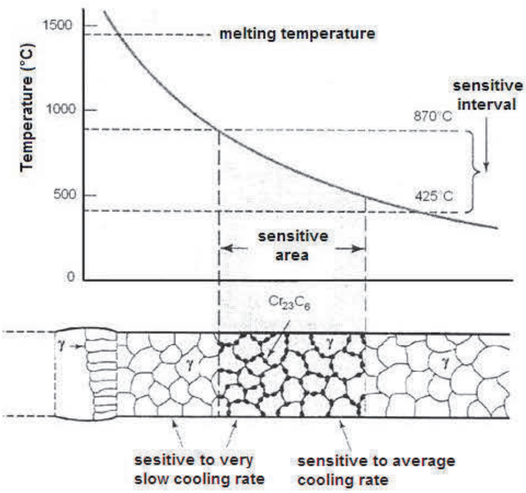

Figure 6 The effect of temperature on Cr-Ni austenitic stainless steel microstructure in HAZ (left) [8]

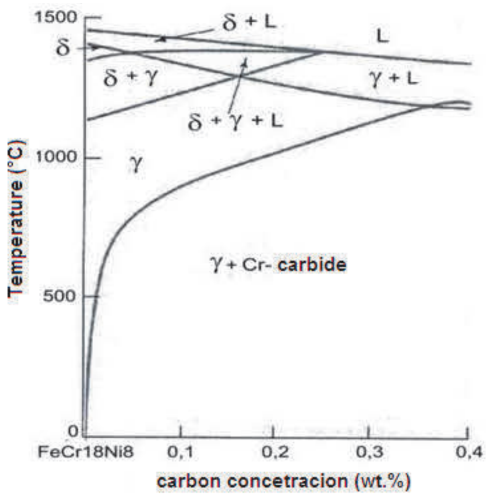

Figure 7 The pseudo binary diagram of Fe18Cr8Ni and carbon (right) [8]

Figure 8 The tube inner surface of material WESTIG 0.65 mm

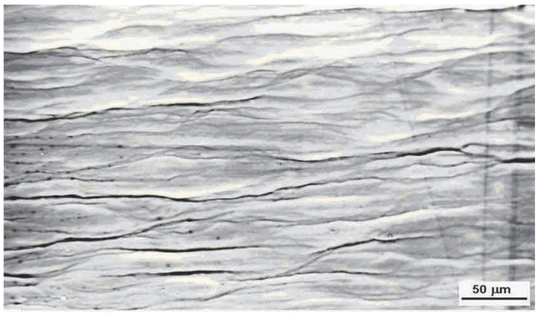

Figure 9 The tube inner surface of material THYSSEN 0.8 mm

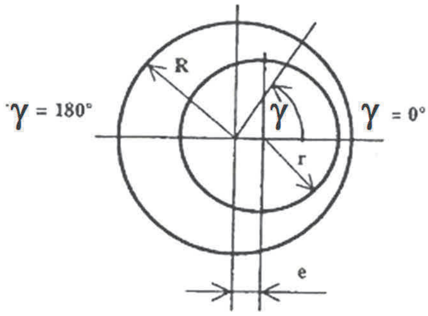

Figure 10 The tube eccentricity [4]

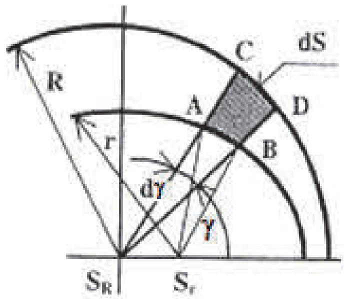

Figure 11 The elementary surface on cross section of eccentric tube [4]

6. THE EFFECT OF TUBE ECCENTRICITY ON DRAWING PROCESS

Geometrical imperfections related to misalignment of outside and inner diameter of tube are characterised by eccentricity of centres, **Figure 10**. This imperfection significantly influences both the stability during drawing process and creation of technological fracture.

At drawing of tubes at the ideal conditions, thus with eccentricity *e* = 0, the normal stress at the perimeter of tube can be express:

$$\sigma_t = F_t / S \quad \text{resp.} \quad \sigma_t = F_t / \pi\left(R^2 - r^2\right) \tag{1}$$

where: σ_t - the normal stress (MPa)
F_t - drawing force (N)
S - cross-section (mm^2)
R - outer diameter (mm)
r - inner diameter (mm)

The wall thickness is depending on angle γ. Unit force is applied on different planar elements, therefore tensile stress change continuously depending on angle γ **Figure 11**. For this reason, stress σ = f (γ) is designated σ_t and S_o

$$\sigma_\gamma = \frac{1}{2} . \sigma_t . \left(R^2 - r^2\right) / \left(dS / d\gamma\right) \tag{2}$$

The final value of normal stress distribution created by drawing force across cross-section of tube with eccentrical hole in dependence on geometry is

$$\sigma_\gamma = \sigma_t.(R^2 - r^2)/\left(R^2 - r^2 - e^2 + 2.e^2.\sin^2\gamma - 2.e.\cos\gamma.\sqrt{(r^2 - e^2.\sin^2\gamma)}\right) \quad (3)$$

If we substitute $e = 0$, we get $\sigma_\gamma = \sigma_t$, tensile stress for ideal tube is independent from angle γ and is equal to medial normal tensile stress.

Behaviour of tensile stress across cross-section is less important than its minimal and maximal value. They will be positioned against each other at angle $\gamma = 180°$. I we assume the maximal value for $\gamma = 0$, then

$$\sigma_{max} = \sigma_t.(R^2 - r^2)/(R^2 - (r + e)^2) \quad (4)$$

the minimal stress σ_{min} will be at angle $\gamma = 180°$

$$\sigma_{min} = \sigma_t.(R^2 - r^2)/(R^2 - (r - e)^2) \quad (5)$$

If tensile strength is a boundary value, then critical value of eccentricity is

$$e_{crit} = \sqrt{R^2 - (\sigma_t/R_m).(R^2 - r^2) - r} \quad (6)$$

After depletion of steel plasticity fracture propagates [4].

The position of floated mandrel during drawing process changes in the direction of smallest resistance of material. This effect is the most significant at first draw, when material isn't influenced by plastic strain caused by drawing process. The tube properties will be influenced only by facts which lead to their acquirement.

- processing of ribbon
- continuous bending of seam tube
- TIG welding with risk of hard carbide precipitation

These operations result to creation of such non-homogenous properties across the cross-section of tube wall which cause eccentrical shape of cross-section with following complexities.

7. CONCLUSION

The microscopical material analysis confirmed the base of structure is constituted austenitic matrix. In the case of material ERGSTE WESTIG ARGESTE 4306 LA the fine-grained carbide phase in thermal field of weld is during large strain deformation dispersed and this flows around austenitic matrix. According to certificated values a carbon content in this steel is 0.027%. Supposing a carbon content and carbide phase cause the problems during greater strain deformations and this can be a initiator of drawing process interruption. For this reason, a steel KRUPP THYSSEN NIROSTA 4306, 1.4306 X2CrNi19 -11 with 0.012 %C appears as more suitable material. Although, this steel contains a coarse-grained structure, it is less sensitive to formation of carbidic phases. A weld quality of seam tube is entering drawing process is appropriate to applied technology. It is necessary to prevent a undesirable phases creation (e.g. carbide phase $Cr_{23}C_6$) along grain boundaries because these can noticeably affect the first two drawings and particularly from an outer and inner shape eccentricity point of view. This eccentricity is caused by structural inhomogeneity which affect to non-uniform distribution of true strain and the fracture formation on the side of eccentricity. If carbide phases are a product of temperature changes during welding it is necessary to analysis temperature proportion in a welding chamber where the seam weld is forming by TIG method in protective atmosphere. It is possible using secondary function of argon as a coolant securing of sufficient inert gas flow rate. Thereby the spot formation with chromium heightened concentration would repress where $Cr_{23}C_6$ carbides are forming along the grain boundaries. This unidirectional carbide orientation on the cross-section (in HAZ) in view of its properties can cause floating broach guiding eccentricity during drawing operation and by reason of this a technological fracture origins.

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