MICROSTRUCTURE AND TEXTURE EVOLUTION DURING COLD DRAWING OF SEAMLESS STEEL TUBE

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Abstract

Cold drawing of steel tubes is the manufacturing process characterized by anisotropic material flow during drawing. In this paper, the microstructural of the E235 hot rolled steel tube after normalizing and cold drawing were characterized by optical microscopy, EBSD (Electron BackScatter Diffraction) analysis performed on scanning electron microscope. The input feedstock with dimensions of Ø 31.8 mm × 2.6 mm (O.D × W.T.) was cold drawn in one drawing passes with fixed plug to the final dimensions of Ø 25.0 mm × 1.5 mm. The development of grain texture in 3 different regions was analyzed on a longitudinal section of the tube. The stress state in the tube material during drawing was calculated by finite element software and the development of the texture depending on the stress state in three different directions using cylindrical coordinates with respect to the drawing direction was evaluated.

Keywords: Precision steel tube, texture, cold drawing, finite element modelling

1. INTRODUCTION

Metals are crystalline in the solid state. In a polycrystalline aggregate each grain is an individual crystal differing from its neighbouring grains in lattice orientation. At any stage of the manufacturing process, it is seldom that the crystals are oriented completely at random. In castings, columnar grains can form along a specific crystallographic direction during solidification. During subsequent plastic deformation, the crystals rotate toward certain stable orientations. Upon recrystallization, new crystals form and grow preferentially at the expense of the deformed matrix crystal. All these processes lead to the development of non- randomness of the grain orientations in a polycrystalline aggregate, known as preferred orientations, or textures. There are many types of textures or distributions of orientations and several reasons for them. The two main reasons for texture formation are annealing and deformation, this thesis will focus on deformation texture. To make it simple deformation texture can be divided in rolling texture and fibrous texture. As the names imply one is normally formed when rolling and one when deforming in one direction [1, 2].

Many of the physical, mechanical, and even chemical properties of single crystals vary with the crystallographic direction or plane. Accordingly, a textured material usually exhibits anisotropic properties. Depending on the nature of the texture and the intended use of the material, property anisotropy may or may not be a desirable feature from the practical point of view. To fully utilize the property anisotropy to advantage, it is often necessary to "tailor-make" a texture for a particular purpose [3, 4].

The aim of this investigation is to be to determine the evolution during cold drawing of seamless steel tube by EBSD analysis.

Table 1 Chemical composition of E 235 steel grade (wt. %)

C	Mn	Si	P	S	Cu	Cr	Ni	Al	N
0.078	0.430	0.220	0.014	0.006	0.130	0.030	0.070	0.021	0.008

2. MATERIALS AND METHODS

The material used in this study is E235 steel grade with ferrite and pearlite (8.9 %) microstructure. Chemical composition of the used steels is in **Table 1.** Microstructure was mechanical polished down to 0.25 µm. The input hot rolled tube with dimensions of Ø 31.8 mm × 2.6 mm (O.D × W.T.) was the normalization annealing at temperature 900 - 930 °C. The input feedstock was cold drawn in one drawing passes with fixed plug to the final dimensions of Ø 28.0 mm × 2.0 mm (reduction 31.51 %) at the drawing speed 625 mm / s. The stress state in the material tube during drawing was calculated by finite element software - 3D Deform. Numerical simulation setup has been published in work [5]. 3D Deform expresses the stress state in cylindrical coordinate system [*R*, *θ*, *Z*], **Figure 1**. The stress state is expressed by the effective stress σ_i:

$$\sigma_i = \sqrt{\frac{1}{2}[(\sigma_1 - \sigma_2)^2 + (\sigma_2 - \sigma_3)^2 + (\sigma_1 - \sigma_3)^2]} \qquad (1)$$

where:

$\sigma_1, \sigma_2, \sigma_3$ – normal stresses (MPa)

The crystallographic orientation of grains with individual orientations was examined by means of EBSD method. High resolution ESBD images were prepared on an area ~ 200 x 150 µm using a step size of 1 µm and applying a tilt angle of 70° at accelerating voltages 20 kV. The obtained EBSD data were analyzed by HKL Channel 5 software. The crystallographic orientation was measured in 3 different areas with respect to the thickness of the wall of tube**, Figure 2**.

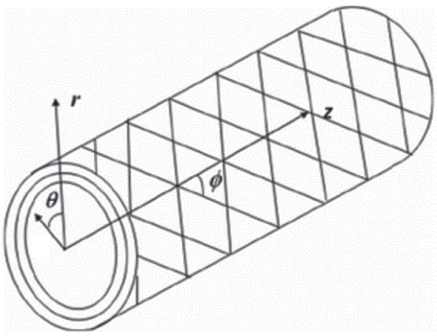

Figure 1 Illustration of cylindrical coordinate system on a tube

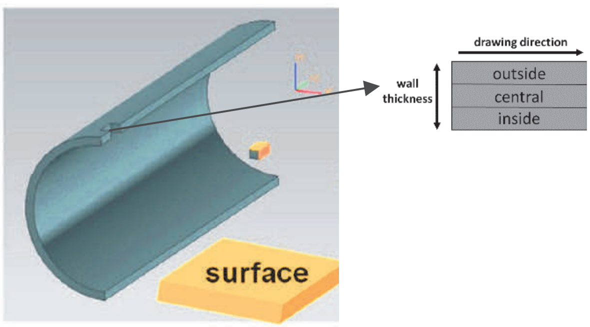

Figure 2 Schematic representations of surface and thickness direction

3. RESULTS AND DISCUSSION

The EBSD analysis was conducted to understand the development of textures. The development of textures is shown using inverse pole figures (IPF) in sample longitudinal, rolling and transverse directions. The intensity of IPF is shown by the mean uniform density (MUD). MUD value above unity indicates that more data points of a particular orientation than would be expected from a sample that is totally random are there.

Figure 3 - **Figure 5** shows IPF after hot rolling (on the left) in the different directions with respect to the deformation direction. The crystallographic texture is not the same with respect to the thickness of the wall and to the tube deformation direction. Texture is stronger in the radial direction than in the tangential direction because total reduction in cross-section (77.42 %) in stretch reducing mill at hot rolling is greater than the total reduction in wall thickness (19.49 %).

Texture is stronger under the inner surface than under the outer surface and in the central of the tube because strain is higher under the inner surface than under the outer surface and in the central of the tube in stretch reducing mill at hot rolling, **Figure 6**.

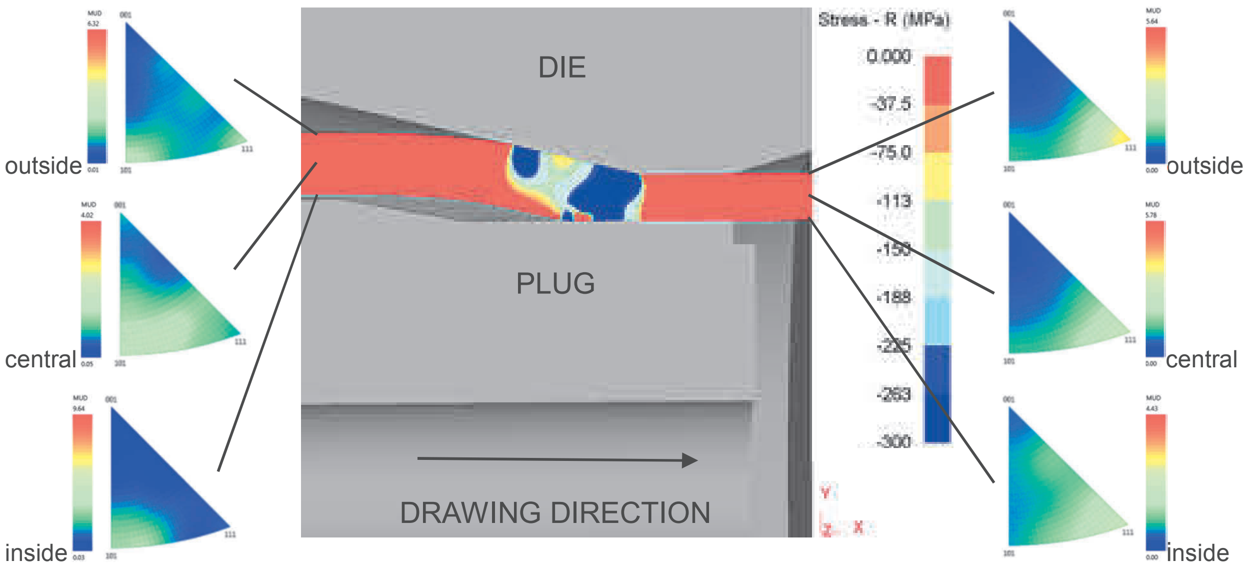

Figure 3 Distribution of effective stress in the radial direction during drawing (in the middle) and IPF before drawing (on the left) and after drawing (on the right)

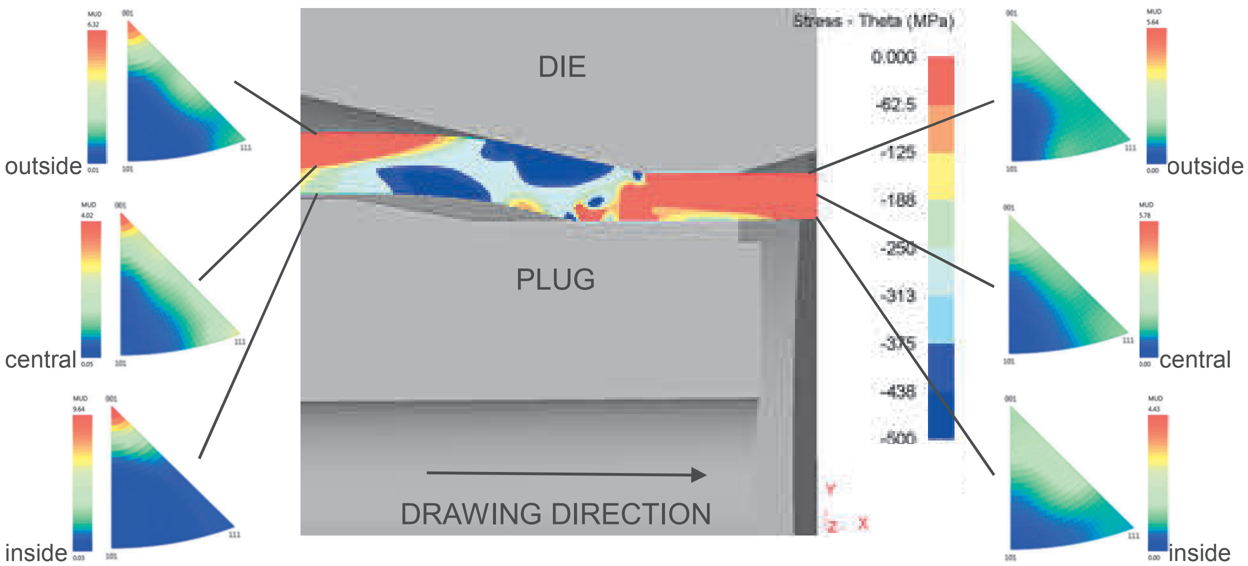

Figure 4 Distribution of effective stress in the tangential direction during drawing (in the middle) and IPF before drawing (on the left) and after drawing (on the right)

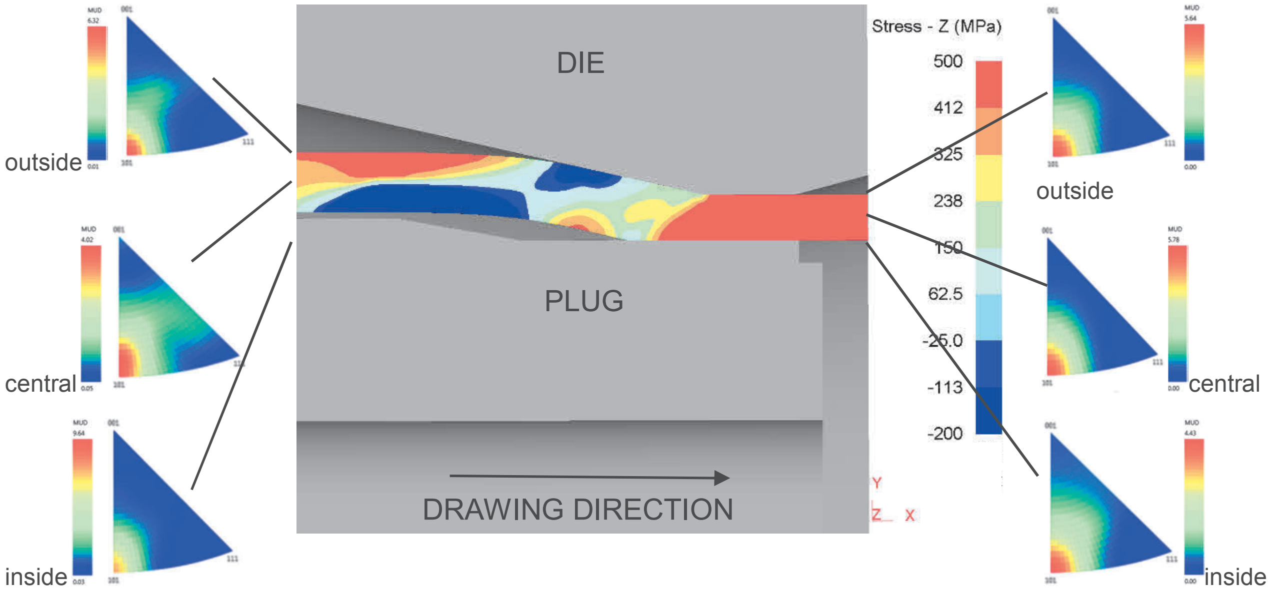

Figure 5 Distribution of effective stress in the axial direction during drawing (in the middle) and IPF before drawing (on the left) and after drawing (on the right)

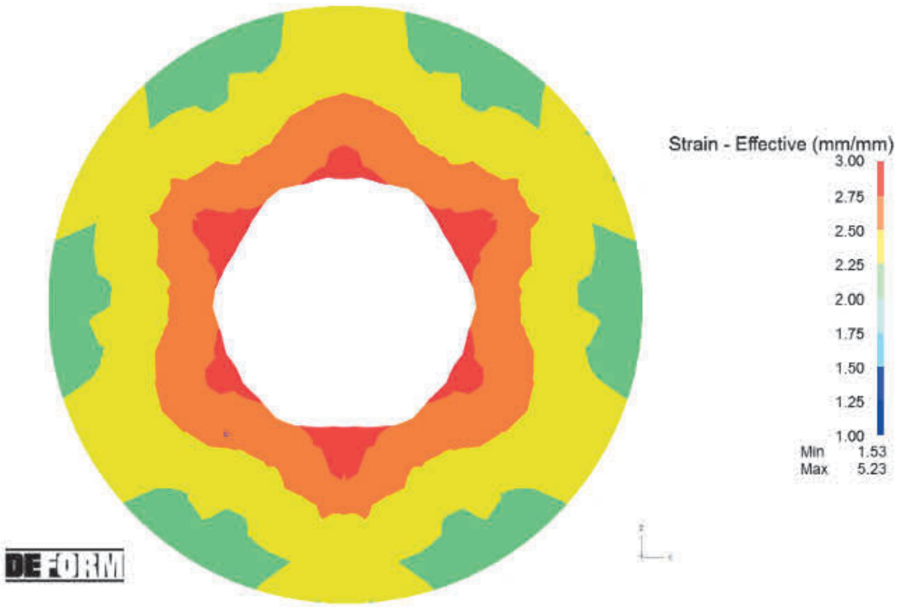

Figure 6 Distribution of effective strain at hot rolling in stretch reducing mill (radial direction)

The material after rolling and standardization is completely recrystallized but the original deformation texture was retained, **Figure 3** - **Figure 5** (IPF on the left). Deformation texture is stronger. Texture in the radial direction is in (101), in the tangential direction is in (001) and in radial axial direction is in (101).

Grains shape after rolling and standardization are equiaxed in the longitudinal direction with the minimum content of grain with small-angle grain boundaries, **Figure 7, Figure 8**, **Figure 11**. The microstructure has average grain size in the transverse direction 7.5 ± 0.4 μm. During the drawing of the tube increases the number of grain with small-angle grain boundaries. Grains shape after drawing is elongated in the drawing direction in longitudinal section. The microstructure after drawing has average grain size in the transverse direction 5.4 ± 0.4 μm, **Figure 9**, **Figure 10**, **Figure 12**.

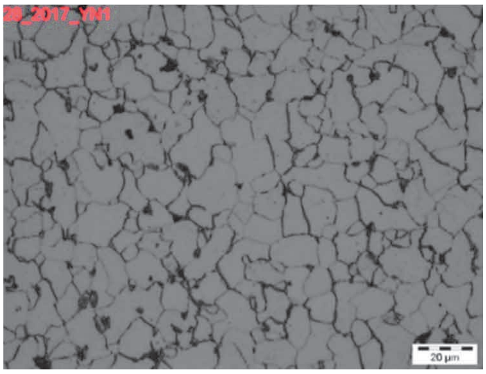

Figure 7 Microstructure before cold drawing (cross-section)

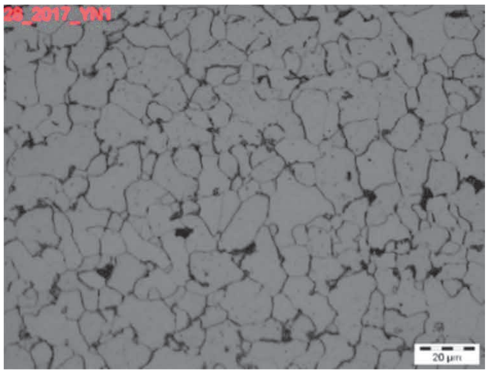

Figure 8 Microstructure before cold drawing (longitudinal section)

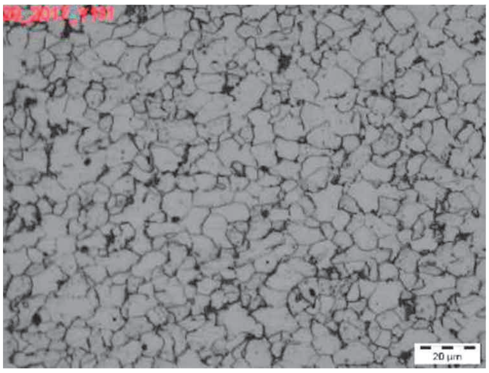

Figure 9 Microstructure after cold drawing (cross-section)

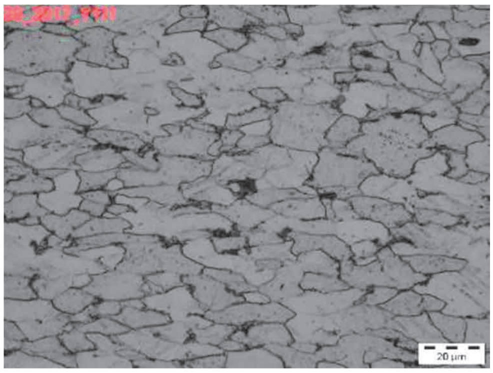

Figure 10 Microstructure after cold drawing (longitudinal section)

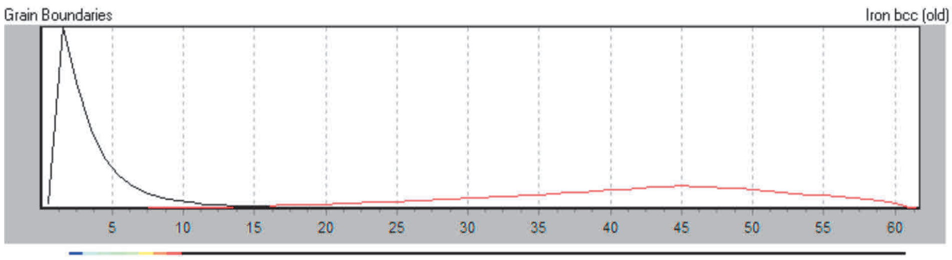

Figure 11 The distribution of angular grain boundaries before drawing

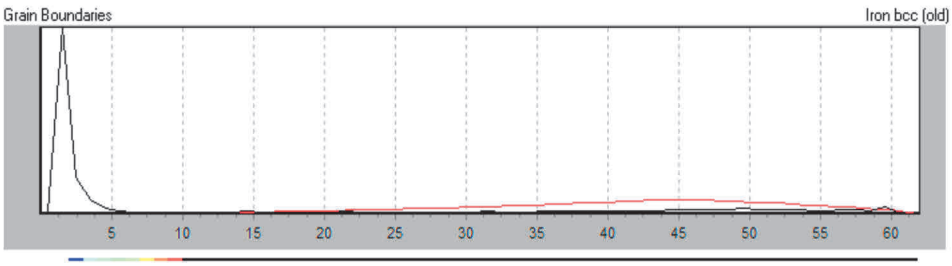

Figure 12 The distribution of angular grain boundaries after cold drawing

The distribution of the effective stress in the individual drawing direction at drawing tube is shown on **Figure 3** - **Figure 5**. Texture has changed during tube drawing compared to the rolling state. The texture after drawing is approximately the same by the thickness of the wall of the tube in all directions of drawing.

Material in the radial direction is at drawing tube loaded the dominant pressure component of the stress in the deformation zone. The pressure stress in the radial direction causes reduced the thickness of the wall of tube. Maximum pressure the stress is approximately σ = - 300 MPa. We see in IPF that the density of the poles in the individual planes effect the pressure is changing from (101) to (111).

Material in the tangential direction is at drawing loaded the dominant pressure component of the stress in the deformation zone. The pressure stress in the radial direction causes a reduction cross section of tube. Maximum pressure the stress is approximately σ = - 500 MPa. We see in IPF that the density of the poles in the individual planes effect the pressure is changing from (001) to (101) / (101).

Nevertheless, in the tangential direction has higher pressure component of the stress than in radial direction so the rotation of the crystal is less pronounced in the tangential direction. Braking of texture development in the tangential direction is caused high content plane (001). Plane (001) causes the texture to deform during deformations because of high critical slip stress required to rotate the plane (001) compared to other planes in the BCC (Body-Centered Cubic) grid [6].

Material in the axial direction is at drawing loaded the dominant tensile component of the stress in the deformation zone (calibration band). Maximum tensile the stress is approximately σ = 500 MPa in the calibration zone. We see in IPF that the density of the poles in the individual planes effect the tensile increasing the portion of the plane (101).

4. CONCLUSION

The microstructure and texture characteristic of a E235 steel grade tube is investigated based on electron backscattered diffraction results, this analysis enabled us to reach the following conclusions: Grain size of seamless tube decreased by 28 % during drawing tube compared with the input rolling feedstock at 31.51 % reduction. The texture after the drawing is homogeneous to the thickness of the wall of the tube in all directions of drawing. Crystals in radial and tangential direction rotated by effect pressure the stress into a stable texture (111) that is at pressure stress in BCC grid. Crystals in the axial direction rotated with effect tensile stress into a stable texture (101) that is at tensile stress in BCC grid.

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