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Study on strengthening during cold drawing of steel tubes

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Early information

Abstract: Study on strengthening during cold drawing was carried out on the samples taken from the steel tube before and after the cold drawing on drawing bench. Low carbon steel tubes were previously prepared and cold-drawn through the drawing dies with a different degree of reduction. During the process, the process is stopped and samples were taken in front of deformation zone, in the zone itself and behind the deformation zone. Detailed measurements on changes in the hardness and microstructure in the deformation zone were performed. The effect of the degree of deformation on the strengthening of the tested steel during the cold drawing was determined.

1. Introduction

According to the World Steel Association in 2017, global crude steel output was 1691.2 million tons of crude steel, by increase of 4.6 % in 2018 [1], from which 1587.4 million tons was in finished steel products. This makes about 70 % of total steel production. One part of this production refers to the production of seamless and welded tubes.

In order to improve mechanical properties and surface quality of finished products, hot or cold rolled tubes are drawn on drawing tables [2,3]. Cold drawn tubes, and other drawn products are used in different branches of auto and aviation industry, civil engineering and even in medicine. The main goals of cold drawing processes are reduction and / or calibration of outer diameter, reduction of wall thickness, increase in hardness, yield stress and ultimate stress [3-8]. The change of mechanical properties is due to the work hardening during cold plastic deformation [4,5].

Investigations on strengthening mechanisms during cold drawing of steel are explaining this phenomenon on the basis of fact that during plastic deformation part of mechanical energy is transformed in to the heat and one part remains as the internal stored energy in material itself [5-7]. The amount of stored energy depends on material itself, degree of deformation and on many other parameters during plastic deformation [5,7,9,10].

Some theories are that stored energy is in the way of multiplication of dislocations that are pined on interstices and vacancies in material [11]. Pined dislocations increase the stresses needed for further plastic deformation, i.e. dislocation movement, and this is the reason for the increase of yield stress, hardness and ultimate stress [11-12]. Due to the severe plastic deformation during drawing processes, the grains are stretched and directed in the direction of main deformation [13,14]. In this way the strengthening is due to the orientation of grains and limited paths for dislocation movement, due to the elongation of grains. Research conducted on pearlitic steel showed that during the drawing of steel there is the reduction in interlamellar spacing and the thickness of the cementite lamellae. By increasing the reduction there is higher thinning of the cementite lamellae, up to the point of their decomposition and carbon enrichment of ferrite [15]. From their findings, it can be concluded that the increase of dislocation density is one of the main mechanisms of strengthening during cold drawing.

So, depending on the used die angle, drawing with/or without mandrel and degree of reduction the strengthening can vary. There is always the question what degree of reduction should be used in each pass in order to achieve the desired final dimensions and mechanical properties. The goal is to reduce the number of passes in order to increase the production.

The aim of this paper is to investigate the amount of strengthening of steel at different degree of reduction during cold drawing steel tubes.

2. Experimental part

Research on strengthening during cold drawing of steel tubes was conducted on tubes from two steel grades E220+CR2S and E355. In the first part of the research, tubes from steel quality E220+CR2S were cold drawn in laboratory conditions on experimental cold drawing bench, Figure 1. The starting dimensions of tubes were 20 mm in diameter and 1.5 mm of wall thickness.

Symbols

HV10	- Hardness according to Vickers with test load of 10 kg	R_p/R_m	- ratio between yield point and tensile strength
R_p	- Yield point, MPa	*A*	- elongation, %
R_m	- Tensile strength, MPa		

Figure 1. Drawing of tube on the laboratory drawing bench

Laboratory drawing was performed with two different reductions of outer diameter, without using mandrel. The die angle of used dies was 16°. One tube was drawn from 20 mm on to 19 mm of outer diameter without change in wall thickness, and second was drawn from 20 mm on to 18 mm in single pass. This was the highest possible reduction on this drawing bench due to the limitation on drawing force of bench itself. Samples for tensile testing are taken from as received tube, and after each reduction. On the 200 mm long samples, Figure 2, tensile test was performed to determine the changes in mechanical properties of tubes after reduction.

Figure 2. Samples for static tensile testing

After the initial test performed on tubes drawn in laboratory conditions, drawing of tubes were repeated on drawing bench in firm Rohrwerk Maxhütte Sisak d.o.o, to repeat the tests under the production conditions. During production, tubes from E355 steel quality were drawn on two reductions. First, the tube with an outer diameter of 30 mm and 3 mm wall thickness, was drawn on diameter 25 mm and 2.5 mm thickness. The second reduction was from 25 mm diameter and 2.5 mm thickness on 20 mm diameter and 2 mm thickness. In both cases, during the laboratory drawing and at the factory, during drawing the process was stopped in one point. At this point the samples were taken from the area of the deformation zone, wherein the tube was in engagement with the die, Figure 3.

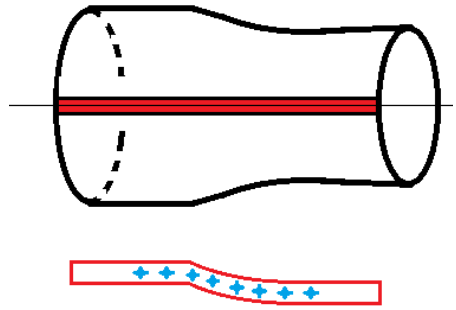

Figure 3. Place of sampling from the deformation zone and points for hardness measurement

Samples were taken in form of strips for measuring hardness and metallographic analysis, Figure 4.

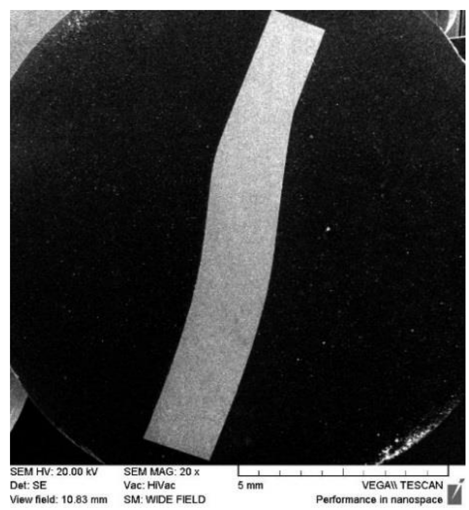

Figure 4. Sample put into the conductive mass for metallographic analysis

Hardness was measured using Vickers method, at 98.1 N of force and time of indentation was 10 seconds. Results of measured hardness are given in paragraph Results and Discussion. Subsequently, the samples were put into a conductive mass and metallographic analysis was performed using Scanning electron microscope (SEM) Tescan Vega 5136mm, Figure 5.

Figure 5. Scanning electron microscope Tescan Vega 5136mm

3. Results and discussion

3.1. Results of laboratory investigations

In the laboratory conditions tubes from E220+CR2S steel were drawn on laboratory drawing bench. Two different reductions were done in a single pas, with the same values of other drawing parameters. Results of measuring changes in hardness through deformation zone at those two different reductions are given in Table 1 and on Figure 6.

Table 1. Hardness changes in deformation zone at different reductions - laboratory conditions

Reduction / Point of measuring	20x1.5 → 19x1.5	20x1.5 → 18x1.5
1	126.4	129.4
2	133.7	133.3
3	134.4	140.2
4	144.9	144
5	148.9	151.7
6	150.3	154.1
7	151	154.9
8	151.5	155.3

As it can be seen from obtained data, at both reductions there is a sharp increase in measured hardness’s during the drawing of tube. By increasing reduction in single pass there is larger increase in hardness along the deformation zone. This confirms that by increasing the reduction of tube the strengthening of material increases. In order to determine the effect of increasing the reduction on other mechanical properties, samples were taken from as received tube and after each reduction. Static tensile testing was performed on these samples. The results are given in Table 2.

The results from measuring hardness and tensile test show that by increasing the reduction in single pass there is bigger increase in hardness, yield point, and ultimate stress. On the other hand, there is sudden drop in elongation of tubes, and decreases with increase of reduction.

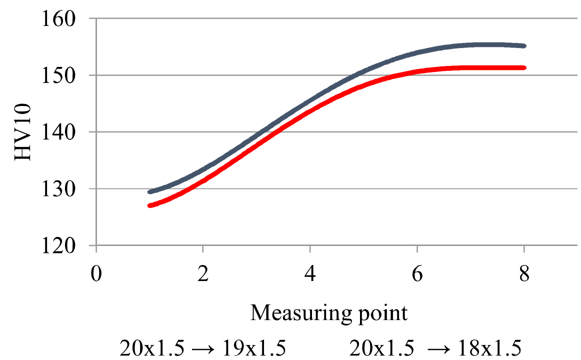

Figure 6. Strengthening along deformation zone during the reduction in laboratory conditions

Table 2. Measured yield stress, ultimate stress and elongations

	R_p / MPa	R_m / MPa	A / %	R_p/R_m
As received tube ϕ 20 mm	289.66	365.9	40.67	0.79
Draw from ϕ 20 on ϕ 19 mm	358.80	419.8	22.00	0.85
Draw from ϕ 20 on ϕ 18 mm	405.35	451.7	12.37	0.89

The yield point was determined and yielding was closely observed. This was done because during cold drawing of tubes, in case of low carbon steels, there is occurrence of Lüders bands just after yielding. In our case we did not have the occurrence of Lüders bands.

All the measured hardness, yield points, ultimate tensile strengths, and decrease in elongation, show that by increasing the reduction in single pass there is a greater strengthening of tubes during drawing. This is limited factor in production because, by increasing the strengthening there is a need in much higher drawing force. From R_p/R_m ratio, it is clear again that by increasing reduction in single pass, there is a need for much higher drawing foce, because this increase in ratio shoves that yild point increases more rapidly, and duing so there is a need fore higher stresses to begin plastic deformation.

Additional tests under the conditions during production of cold drawn tubes were carried out, in order to confirm the findings in laboratory research.

3.2. Results of investigations conducted on tubes drawn in plant during production of cold drawn tubes

For this part of research two degrees of reductions were chosen, first tube with outer diameter of 30 mm and 3

mm wall thickness was drawn on diameter 25 mm and 2.5 mm thickness. Second reduction was from 25 mm diameter and 2.5 mm wall thickness on 20 mm diameter and 2 mm thickness. The values of measured hardness are given in Table 3, and the trend of changes in hardness through deformation zone on Figure 7.
On the tubes drawn in production conditions, a more detailed analysis of changes in the hardness and structure was performed, in order to closely observe what is going on in deformation zone during the cold drawing of the tubes.

Table 3. Hardness changes in deformation zone at different reductions - production conditions

Reduction / Point of measuring	30x3 → 25x2.5	25x2.5 → 20x2
1	171.5	170.65
2	175.6	178.35
3	191.9	191.95
4	197.6	200.35
5	207	206.85
6	222.7	230.95
7	238.9	243.95
8	240	248.35

Measured values of hardness confirmed the laboratory findings.
During the process of drawing the tube through die as the deformation increases there in increase in hardness. This shows that during the tube drawing, and by increasing of pressure of the die on the material, there is the increase of strengthening all up to the end of the deformation zone.

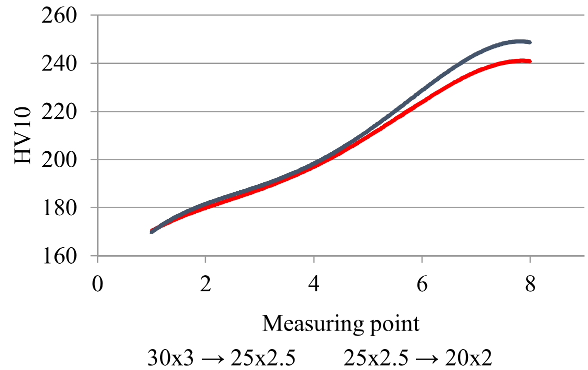

Figure 7. Strengthening along deformation zone during the reduction in production conditions

The maximum hardness is obtained on the end of the deformation zone, when the tube exits the calibration zone of the die. After the normalization heat treatment and re-drawing of tube, the increase in hardness is even more pronounced. From this it can be concluded that by increasing the reduction of steel tube there is increase in strengthening of steel. By increasing the reduction, the strengthening is even more pronounced.
To see what is going on in the structure of material during drawing, samples were prepared and closely investigated under the scanning electron microscope, Figure 8 and Figure 9.
From observed structural changes it can be seen that during cold drawing of tubes there is change in structural orientation. The structure is oriented in the direction of drawing of tubes. As the degree of deformation increases, in a single pass, there is more and more pronounced structural orientation in the direction of acting drawing force, as it can be seen from Figure 8 and Figure 9.

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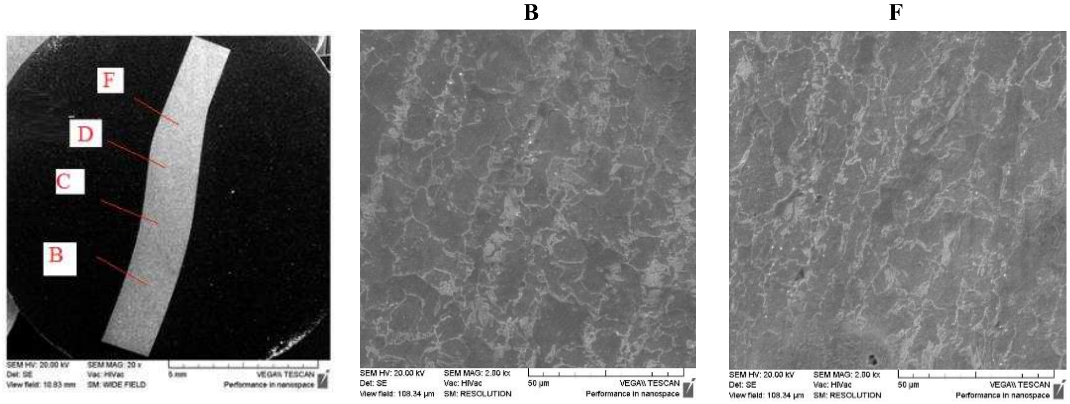

Figure 8. Metallographic photos of structural changes in steel during cold drawing of tubes from 30x3 mm → 25x2.5 mm

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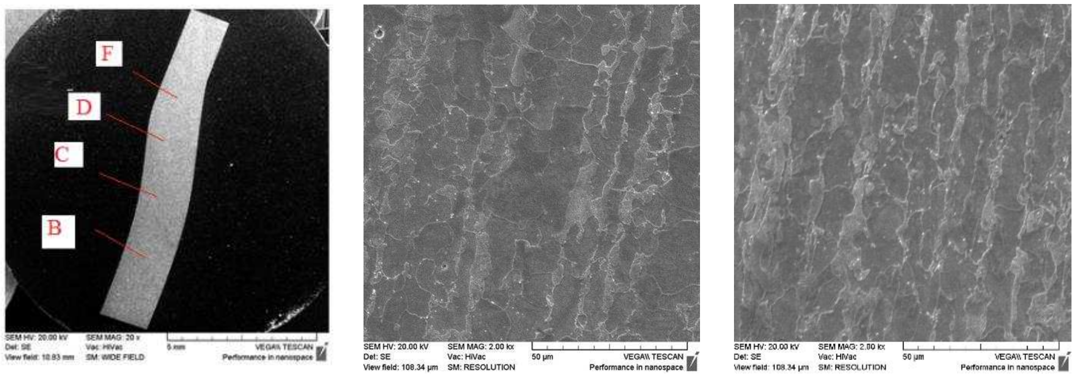

Figure 9. Metallographic photos of structural changes in steel during cold drawing of tubes from 25x2.5 mm → 20x2 mm

Similar findings have been reported in the research on drawing wires [13,14]. So the structural orientation is one of the strengthening mechanisms, but this cannot be the only one. From obtained microstructures it was determined that this steel has ferritic-pearlitic structure. Earlier reports on structural changes during wire drawing from this type of steel showed that during drawing there is the reduction in interlamellar spacing and the thickness of the cementite lamellae [15]. This was one of the mechanisms of for the increase of the strength of wires during drawing. In our research there are similar observations. The structural investigations showed that tested steel has ferrite and pearlite in structure, and there is severe orientation of structure after drawing. Figure 10 shows structure of deformed tube at maximum taken magnification.

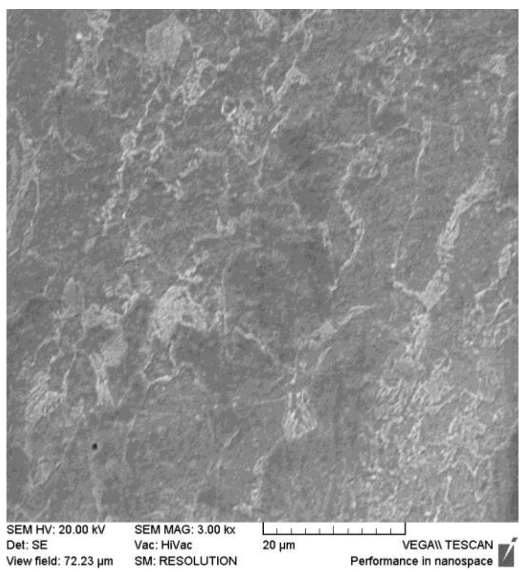

Figure 10. Dislocation accumulation in structure due to the reduction during deformation of tube

The earlier researches on cold drawn tubes [9,16] it was found that during tube drawing process there are mechanisms of dislocation multiplication and the density of dislocation increases with the increase in reduction. It is reasonable to assume that, along with the structural orientation, the increase in dislocation density is one of the main strengthening mechanisms during cold drawing of low carbon tubes.

4. Conclusion

Structural investigations showed that the tested steel had ferritic-pearlitic structure. During the cold drawing of tubes there are changes in structural orientation. By increasing the reduction there is increase in structural orientation in the direction acting drawing force.

The static tensile tests confirmed that there is increase in yield point, ultimate tensile strength, R_p/ R_m ratio and decrease in elongation by increased reduction in the single pass.

Measured hardness values show that by increasing the reduction, there is increase in strengthening of tubes during the cold drawing. The increase in hardness directly shows the strengthening of material during cold drawing. By increasing the reduction in the single pass the strengthening is even more pronounced.
From observed structural changes, measured changes in mechanical properties and earlier reports, it can be concluded that during the cold drawing of steel tubes there is sever strengthening of material. We believe that the main mechanisms of strengthening are change in structural orientation and increase in dislocation density.

Acknowledgements

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