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Critical comparison of different techniques for producing profiled wires

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Abstract. Profiled wires manufactured by the drawing and rolling processes are widely used for production of industrial screens used in the particles separation processes. The main goals in the production processes of such screens are to obtain increased durability and surface quality due to its demanding working environment i.e. high abrasive wear and aggressive condition. The present studies were focused on the analysis of the effects of applied wire drawing and rolling processes on the mechanical properties and surface quality of the produced profile wires. The differences in the schedules of the metal forming processes as well as in the deformation inhomogeneities in the drawn products were analysed. As a result of the applied deformation methods, different surface quality and mechanical properties were obtained. The rolling process has been shown to provide better surface quality and a lower YS/TS ratio, which is critical for further deformations such as the bending process of round industrial screens. The investigations were preformed using austenitic stainless steel.

Introduction

Changes in the mechanical properties of the metallic materials are one of the main effects of plastic deformation processes. They become particularly important in drawing and rolling processes of the profiled wires where the effects of inhomogeneity of plastic deformation play a crucial role [1]. Controlling of the mechanical property distribution at the cross-section, especially in the case of profiled wires, creates new opportunities in the applications of such products. However, this requires a good knowledge of the relationships occurring between strain or strain rate and individual mechanical properties [2-4]. The development of such relationships is a part of the thermo-mechanical description of deformation process like drawing or rolling. Those can be considered as a crucial aspect in the case of multi-step deformation. The possibility of prediction of the level of yield stress (YS), tensile strength (TS) and the so-called yield ratio (YS/TS) [5] for the individual deformation steps have to be taken into account in the development of the metal forming processes [5-6]. Therefore, the main aim of the present work is to critically assess the effects of drawing and rolling on the mechanical properties, especially yield ratio, as well as the quality of precise profiled wires (Ra) aimed for filtration screens [7,8].

Experimental Procedure

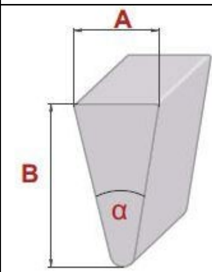
In the present study AISI 304L austenite stainless steel was used in order to determine the differences in the mechanical as well as the microstructural behaviour of the material using different deformation process routes i.e. drawing and rolling processes. The chemical composition of the tested steel grade is presented in Table 1.

Table 1. Chemical composition of the tested steel [wt. %].

Material	C	Mn	Si	S	P	Cr	Ni	N
AISI 304L	0.02	1.54	0.37	0.006	0.035	18.16	8.10	0.075

The tests were focused on the analysis of the influence of the deformation method i.e. wire drawing and rolling processes, on the mechanical properties as well as the microstructure development. Additionally, both analysed effects cause changes in the surface quality, which is very important in the case of the profile wires due to their application [8]. Schematic presentation of the process is shown in the Fig. 1. The final shapes and dimensions of the wires were similar. The dimensions of the profiled wires are presented in Table 2.

Table 2. Dimensions of the final thin profile wire.

Shape	Initial wire rod diam. [mm]	A [mm]	B [mm]	α [°]	
28Sb	3.55/3.43	2.20	4.50	23	

The rolling process was performed in three steps while the drawing process was conducted as four step process. In the case of rolling, the first step was performed on a duo rolling mill with flat rolls, followed by profile rolls. In the case of drawing, the first step involved flattening the wire rod in a two-roll drawing machine, while the second and third deformation passes were carried out using profiled roller dies - the so-called Turks head [9]. The samples after the rolling and drawing processes were tested for mechanical properties in tensile tests on the Zwick Z250 tensile machine with a strain rate of $0.1s^{-1}$. Roughness of the surfaces was measured using optical profilometer VykoNT9800/9300 from Veeco. The roughness was measured in three to five places in order to obtain average values.

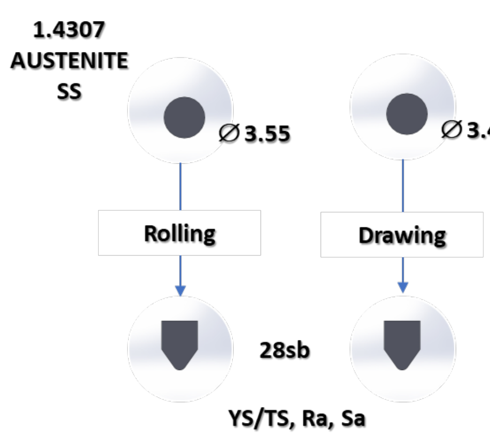


Fig. 1. Schematic presentation of forming schedule.

The microstructural changes were analysed using optical ZEISS Axio Imager M1m microscope. The microstructure analysis was performed in the initial wire rods and after last step of deformation, both in the drawn and rolled specimens.

Results and Discussion

The results of testing the mechanical properties of profiled wires obtained in the rolling and drawing processes are presented in Table 3. The profile wire was rolled from the initial diameter of 3.55 mm while the wire drawing process was conducted using initial wire diameter of 3.43 mm. The differences in diameters were caused by the conditions of the industrial process, where different diameters of wire rods were used in the rolling and drawing processes. The final mechanical properties of the finished products were measured to obtain the YS/TS ratio, since good formability is required for further bending of rounded filter screens. In both cases an increase of the mechanical properties was observed. The obtained results indicate that in the rolling process the YS/TS ratio was 91%, while in the drawing process it was 96%. These results clearly show that after the rolling process, the further stages of the screen manufacturing process (resistant spot welding and bending), especially in the case of cylindrical screens, will run more efficiently. In the case of drawn profile wires intended for further deformation (bending), an annealing process may be necessary to improve the ductility of more hardened materials.

Table 3. Mechanical properties of the AISI 304L stainless steel after rolling and drawing process.

Deformation Method	**Profile**	**YS** [MPa]	**TS** [MPa]	**YS/TS** [%]
Rolling	ϕ3.55 [mm]	637.0	863.8	73.75
	28sb	1313.1	1441.8	91.08
Drawing	ϕ3.43 [mm]	623.5	805.3	77.43
	28sb	1346.4	1399.9	96.18

The deformed wires were analysed both in terms of shape evaluation and microstructure development. Based on the analysis of the shape accuracy and macrostructure obtained from each stage of the drawing process (shown in Fig. 2), it can be observed that the plastic flow of the material, forced by the process conditions, gives the correct shape of the corners of the profile wires.

Fig. 2. Analysis of the shape of drawn profile wires after each stage of deformation.

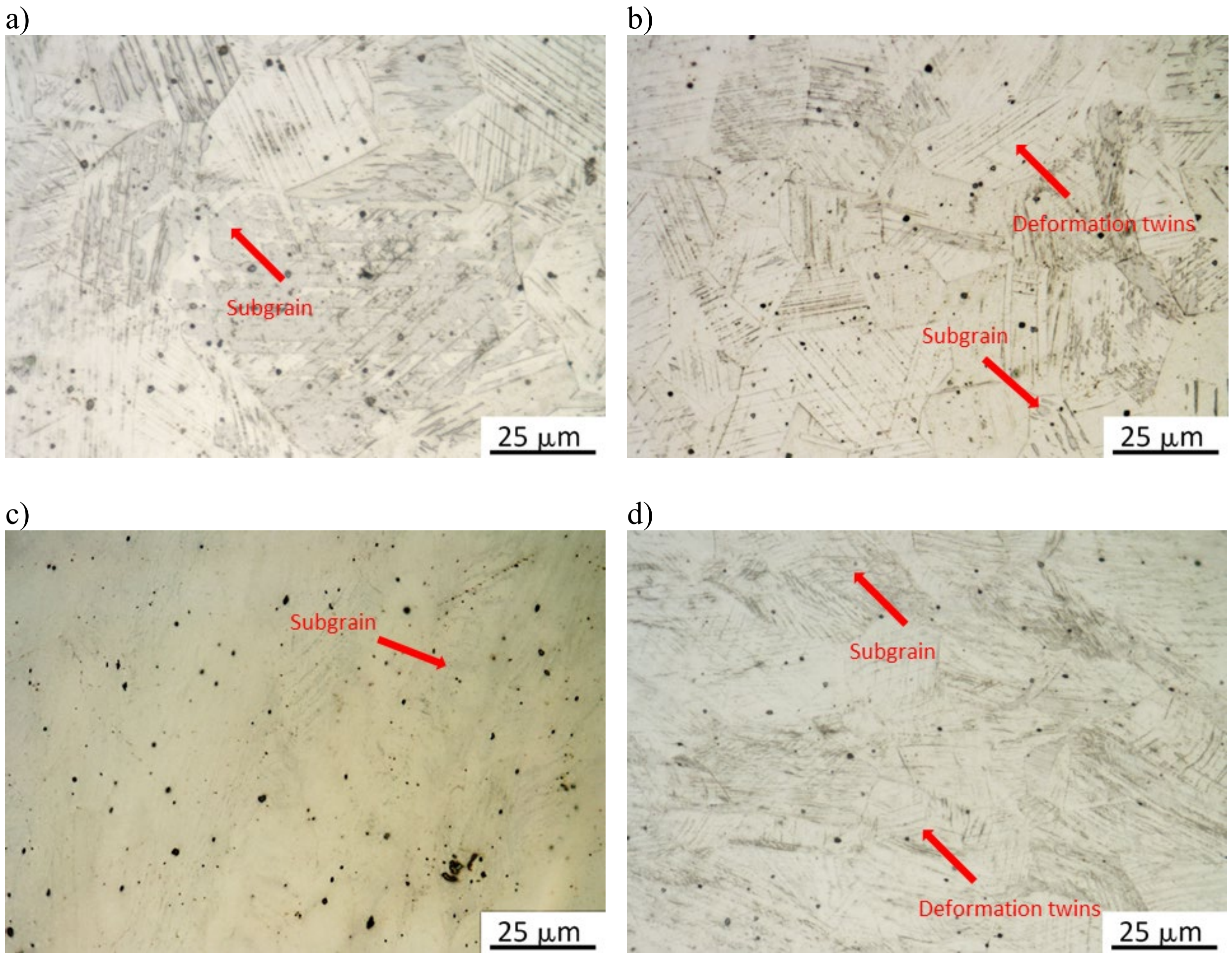


Fig. 3. Microstructures of the AISI 304L Austenitic Stainless Steel at the initial stage, in the centre -a) and close to the surface -b); profile wires after drawing process in the centre-c) and top surface of profile wired -d).

The initial material was characterized by equiaxial austenite grains with visible annealing twins. It was also observed that structural effects related to the martensitic transformation occurred (Fig. 3a, b). In the microstructures of the materials after drawing process it can be seen that the effect of the deformation caused forming the deformation twins (Fig. 3c). There are also visible areas where the deformation was initiated in two planes of slip (or twinning). However, no shear bands which are crossing grain boundaries can be observed. In the case of the near-surface areas of the layers, the microstructure of the deformed material indicates a more significant deformation, which can be estimated on the basis of a stronger deformation of grains and a larger amount of subgrains in the microstructure (Fig. 3d). Also, it can be seen that formation of the microstructure of the so-called lenticular structure, indicating a high degree of deformation of the material (about 80 %).

Fig. 4. Shape analysis of the rolled profile wires after each step of deformation.

The deformation degree during rolling process is significantly larger in each step of rolling due to higher reduction. The final shape, without deviations can be obtained in 3 step process (Fig. 4).

The microstructure of the initial wire rod is characterized by a high degree of homogeneity of austenitic structure (Fig 5a,b). In the microstructures of the material after rolling process, a slight degree of grain refinement can be observed, mainly in the central zone of the profile wire (Fig 5c). Final microstructure after rolling process in the top surface area of the profile wire can be characterized by high refinement of the grains without additional microstructural effects such as twinning or slip planes (Fig 5d).

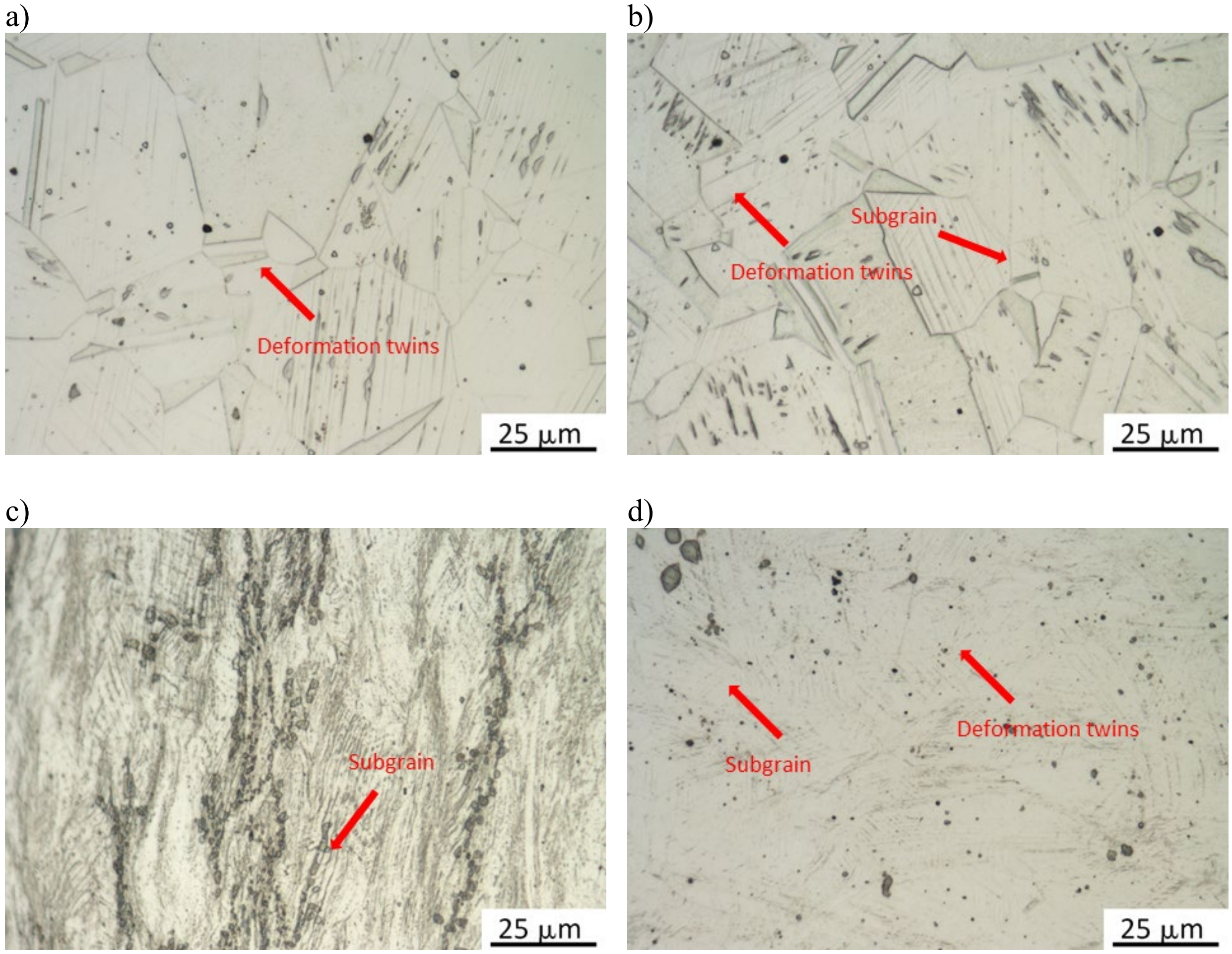


Fig. 5. Structure development of the AISI 304L Austenitic Stainless Steel at the initial stage, in the centre -a) and close to the surface -b); profile wires after rolling process in the centre-c) and top surface of profile wire -d).

According to customers' requirements the profiled wires used for industrial filtration screens must meet the requirements regarding the roughness of the surface, especially in the screens used in the offshore applications. The initial roughness Ra of the wire rod aimed for the rolling process was equal to 0.17 µm and in the case of wire rod aimed for the drawing process it was equal to 0.18 µm. After rolling Ra decreases to about 0.16 µm while after drawing process Ra increased to 0.25 µm. Such high increase was caused most likely by the low quality of die surface and the mechanical (stress and strain) state obtained in the drawing process. The obtained results suggest that the rolling process is more suitable for the profiles tested in the present study (28sb). All of the results of the roughness measurement are presented in Table 4.

Table 4. Surface roughness of the profile wires produced by two different metal forming processes.

Deformation Method	**Profile**	**Ra$_{avg}$ [μm]**	**Sa$_{avg}$ [μm]**
Rolling	ϕ3.43 [mm]	0.17±0,03	0.33±0,05
	Profile wire	0.16±0,01	0.51±0,04
Drawing	ϕ3.55 [mm]	0.18±0,03	0.34±0,03
	Profile wire	0.25±0,02	0.78±0,11

Summary
In the presented research results, the influence of two different metal forming processes on the surface quality, mechanical properties and microstructure of the produced profile wires was analysed. Based on the conducted research, it can be concluded that:
As expected, the applied metal forming process has a significant impact on the surface quality of finished products. Nevertheless, the presented studies have shown that in the current production conditions, the rolling process allows to obtain a lower, required surface roughness, mainly due to the mechanical state (state of deformation and state of stress) occurring during deformation. It should be expected that with sufficiently high surface quality of the tools used and changes in the deformation schedules (e.g. thanks to the use of the so-called smoothing threads - skin pass), these relationships may change. Such research will be the focus of further studies.

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