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Computer Aided Design, Analysis and Manufacturing of Hot Rolled Bulb Flat Steel Profiles

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Abstract: In this study, roll-pass designs were designed and controlled rolling simulations were realized by using of Simufact Forming simulation tool based on finite element method for acquiring an asymmetrical profile with low carbon- micro alloyed steel used in ship buildings. Simulation aided manufacturing studies have been realized for eliminating the manufacturing defects and obtaining stress-strain curves, forces acting on the rollers and torque requirements at the inlets and the outlets of the rolling stands. Optimization studies of the production parameters to improve the final product mechanical properties. Mechanical tests and metallurgical tests have been applied to the production samples obtained by ensuring that the production parameters obtained in simulated support activities are used in prototype productions and the improvement of the mechanical properties of the profile with asymmetric section is provided.

Keywords: Asymmetric Profile; Controlled Rolling; Finite Element Method; Micro Alloyed Steel; Ship Building; Simulation Aided Design.

Sıcak Haddelenmiş Çelik Hollanda Profillerinin Bilgisayar Destekli Tasarımı, Analizi ve İmalatı

Öz: Bu çalışmada, kalibreler tasarlanmış ve gemi yapılarında kullanılan düşük karbon-mikro alaşımlı çelik ile asimetrik bir profil elde etmek için sonlu elemanlar metoduna dayanan Simufact Forming simülasyon aracı kullanılarak kontrollü haddeleme simülasyonları gerçekleştirilmiştir. Üretim kusurlarının ortadan kaldırılması, gerilme-gerinim eğrileri, merdanelere etki eden kuvvetler ve merdanelerin giriş ve çıkışlarındaki tork gereksinimlerinin sağlanması için simülasyon yardımlı imalat çalışmaları yapılmıştır. Nihai ürünün mekanik özelliklerini iyileştirmek için üretim parametrelerinin optimizasyon çalışmaları gerçekleştirilmiştir. Simülasyon destekli faaliyetlerden elde edilen üretim parametrelerinin prototip üretiminde kullanılması ve asimetrik profilin mekanik özelliklerinin geliştirilmesi sağlanarak elde edilen üretim numunelerine mekanik testler ve metalurjik testler uygulanmıştır.

Anahtar kelimeler: Asimetrik Profil; Kontrollü Haddeleme; Sonlu Elemanlar Metodu; Mikro Alaşımlı Çelik; Gemi Yapımı; Simülasyon Destekli Tasarım.

1. Introduction

The development of new designs in parallel with technological advances in the shipbuilding sector has increased competition in the sector. In order to meet the demand for the planned commercial design, it is of great importance to provide sea transportation in economic terms. In addition to the

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economy of the ship, the long service life is an important feature expected from commercial ships [1,6].

Determination of the main dimensions of the ship; determination of the dimensions requires a complex design step while design phase that requires high carrying capacity and high speed, low power requirement and dead weight. These features are expected from the ship; it is possible to design and use elements with high specific strength in the design phase [1,5,11].

With increasing expectations in the shipbuilding industry, designers needed asymmetric sections of the application type with the aim of avoiding the unnecessary use of symmetrical section elements in the design phase.

The difficulty of providing asymmetric sectional elements specific to the application type has led designers to produce asymmetric section elements either with the use of symmetrical sectional elements or welded constructions increasing the cost of labor and materials.

Figure 1 shows the asymmetric profiles used on the ship, during the ship's construction phase.

Figure 1. Asymmetric sectioned profile used in ship frame construction [13]

The demand for these types of products has increased because of the use of asymmetric sectioned structural elements in place of symmetrical sectioned semi-finished elements in their design, resulting in material savings and reduced dead loads resulting in indirect energy efficiency [2,3,7]. The rolling technique, which is a plastic forming method for mass production, made possible the production of asymmetric section steel profiles with sufficient market share, even though initial investment costs were very high in new product production, and triggered the production of such profiles [4,8].

In this study; we aimed to produce the ship profile with the asymmetric section by the hot rolling technique, which enables the vessel specific strength to be increased by reducing the ship dead loads when compared with the use of the symmetrical section profile by providing the saving hand from the welding operations in the shipbuilding operations during the period in which the projects related to ship production are increasing in our country using national resources. In this scope, as-passed designs of the asymmetric section profiles are made with reference to the rolling equipment in the infrastructure of the foundation and it is modeled with Simufact Forming software and verification of roll pass design is provided by simulating. Simulation - assisted productions have been provided to eliminate the process draw - off defects by examining the section changes, the amount of strain - deformation and temperature distributions of the billet roll inlet and outlet [9,10,12]. Asymmetric section profile production has been realized by using the parameters obtained in simulated support productions in real production. Tensile and impact tests were applied to the samples obtained from the products, and metallurgical examinations were carried out.

2. Material And Methods

Because the welded joints of the elements are used in shipbuilding, steels containing low carbon (0.15% - 0.23%) and high manganese are generally used. Since the steel affects weldability, the sulfur and phosphorus ratio must be less than 0.05% [12]. When the content of sulfur in the raw material structure is high, the cracks may come into play during the rolling. For this reason, in the process of asymmetric section profile production, Table 1 and Table 2 shows the chemical composition and mechanical properties of the alloy.

Table 1. Chemical composition of asymmetric profile

Alloy Name	Chemical Composition (Weight Percent)						
	% C	%Si	%Mn	% P	% S	% V	Other
Prototype	0.15-0.2	0.2-0.3	0.6-1.2	0.035	0.035	0.01-0.1	98.1-99

Table 2. Mechanical properties of asymmetric profile

Product Name	Yield Strength (MPa)	Tensile Strength (MPa)	Elongation (%)	Impact Energy (J)
Prototype	355-410	490-550	21	0 34

In the scope of the study, the HP100 profile, which is defined as the asymmetric product section, is calculated by Equation 2.1 with respect to the logarithmic volume stability constant of the raw material to be used in production with reference to the sectional area (HP100 Profile Standard Values according to EN 10067: 1996). In Figure 2, during the hot rolling process, plastic deformation is performed in order to determine the volume stability.

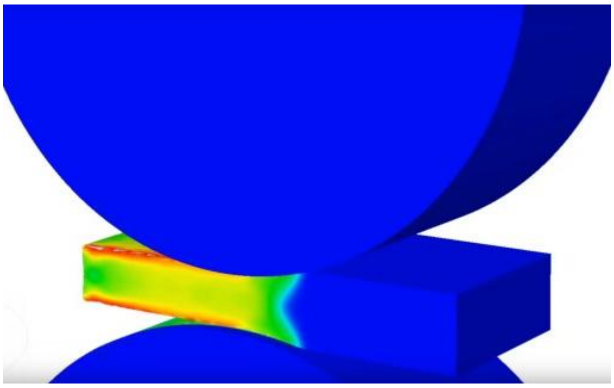
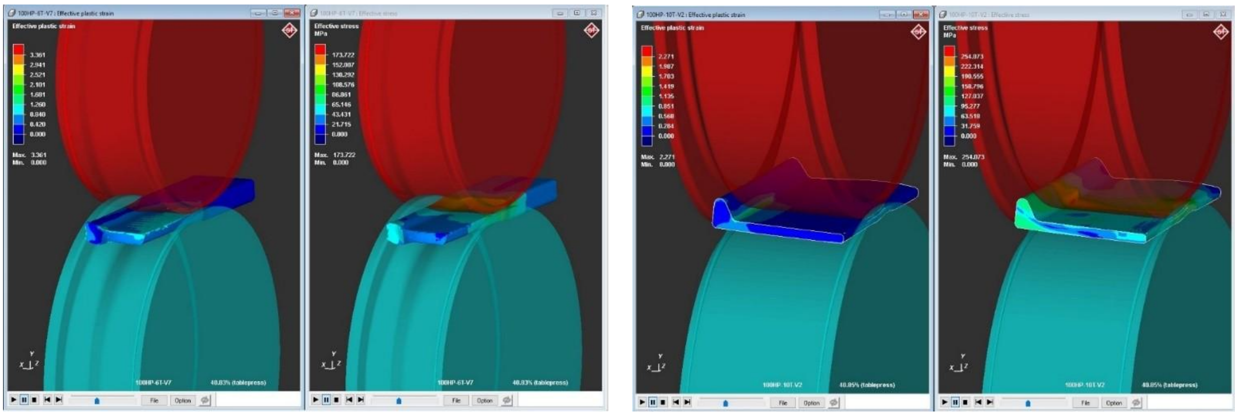


Figure 2. Schematic view of the rolling process [14]

$$h_0 w_0 l_0 = h_f w_f l_f \tag{2.1}$$

3. Results and Discussion

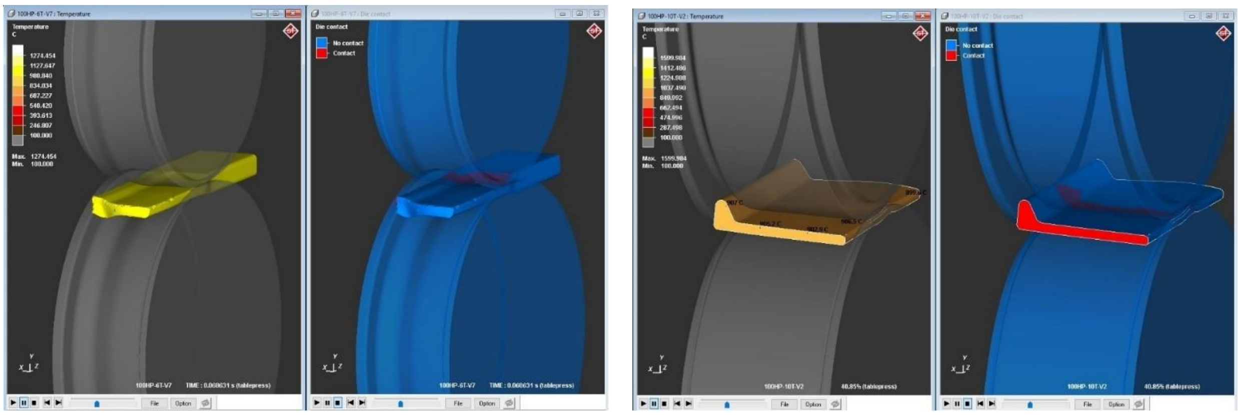
The figures shown in Figure 3 a and b show how much effective stress is required on which stand and how much effective plastic strain occurs with this effective stress. From these graphs, it is seen that the production raw material, which has yield strength in the range of 350-400 MPa at room temperature, is subjected to diffusion annealing and at which temperatures it reaches the appropriate levels.



(a) (b)

Figure 3. Stress-strain distribution at the end of the simulation studies on (a) 6 th Stand and (b) final Stand

The process here determines the motor power, roller diameter and reducer exchange ratio specific to the characteristics of each rolling mill. According to the analyzes, the ratios which are appropriate to the existing infrastructure of the facility were obtained.



(a) (b)

Figure 4. Input-output heat values at the end of simulation runs on (a) 6 th stand (b) final stand

Figures 4 a and b show the temperature of the workpiece between the rollers and the area in contact with the roll. The contact area varies according to the gap between the rollers during setup. Elongation increases with the reduction of this gap. The elongation given in each stand is limited according to the specific infrastructure to the facility. However, the values in the temperature graph show the distribution depending on the value of the initial diffusion annealing. Although the temperature value varies according to the power of the plant, it can be between 850 ºC - 1000 ºC. Due to the insufficient annealing temperatures of the workpiece, it can cause deformation in the rollers since it cannot hold its temperature until it reaches the finish stand.

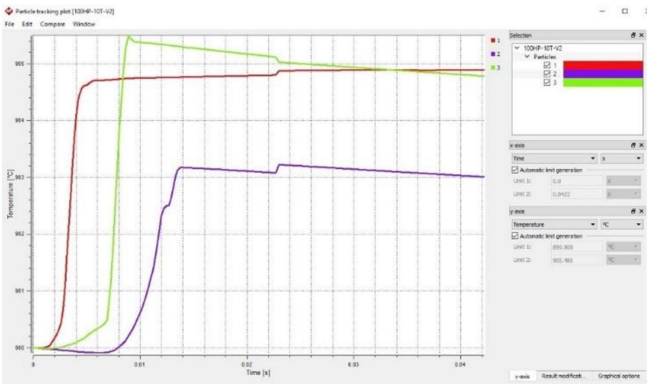


Figure 5. Graphs showing, inlet-outlet temperature values at the end of simulation studies

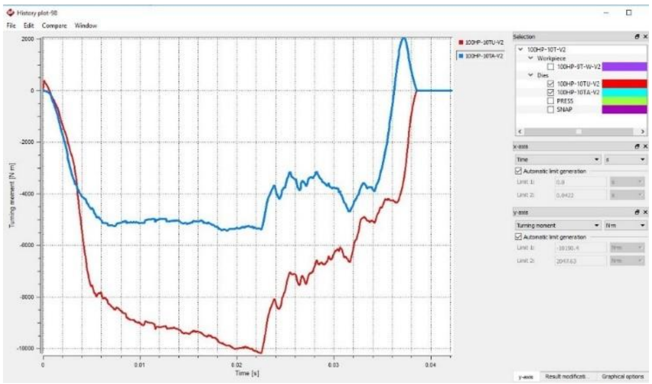


Figure 6. Graphs showing Turning Moment at the end of simulation studies

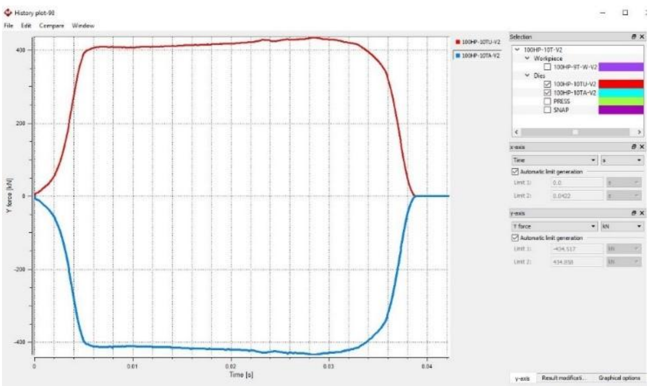


Figure 7. Graphs showing stress-strain distribution at the end of simulation studies

As a result (Figure 5-6-7) of the simulations, the torque values required for the rolling process and the force data affecting the rolls during the plastic deformation process were obtained by obtaining the stress - deformation distributions of the workpiece at the inlet and outlet of the rolling stand, and the flow values of the motors were determined by engineering calculation methods.

In the scope of Finite Element Method simulation activities, rolling defects shown in Figure 8 are determined. The root problems that make up the defects are eliminated by repeated simulations before prototype production by interfering with the roll pass design. Rolling machines such as rollers, runners and scrapers are designed with reference to the plastic deformation process.

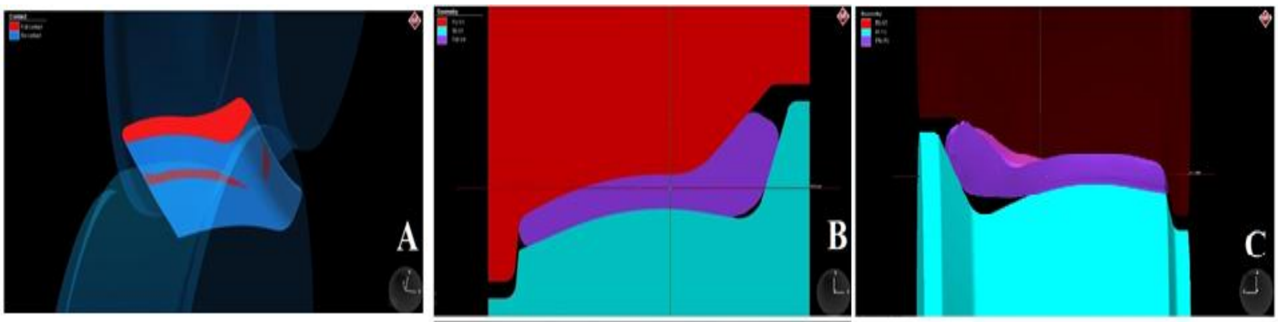


Figure 8. Rolling Defects (A, B=Non-Contact, C=Wick of Material)

In order to check the accuracy of the numerical data obtained from the simulations performed, the line shown in Figure 9 a is produced. The illustration shows the moments when the workpiece is rolled between the stands.

(a) (b)

Figure 9. (a) Prototype production stage and (b) Profiles produced after prototype production stage

Figure 10. Comparison of the produced and simulated section

In Figure 10, the profile after the simulation activities and the profile after the production are compared. After comparison, the overlap ratio was found to be higher than 98%.

After the prototype production, the product's dimensional controls were carried out with a calibrated digital caliper with a 300 mm lead of "Mitutoyo / CD-30PPX" brand.

The tensile tests carried out in Table 3 and in Fig. 11 of the results are carried out with the device "Zwick / SP T600" 60 tonne maximum pulling capability.

Table 3. Tensile test results of samples

No	S_0 mm^2	$Rp_{0,2}$ N/mm^2	Rm N/mm^2
1	161.2	401	537
2	162.1	421	536
3	161.4	417	537

According to the results of Table 3 and tensile test given in Figure 14; desired values were obtained in the final product according to standards. Even small variations in parameters on the production line have been found to affect the results. Changes in parameters such as rolling temperature, elongation rate, rolling speed, type of cooling after rolling and post-straightening heat treatment will determine the mechanical properties of the final product.

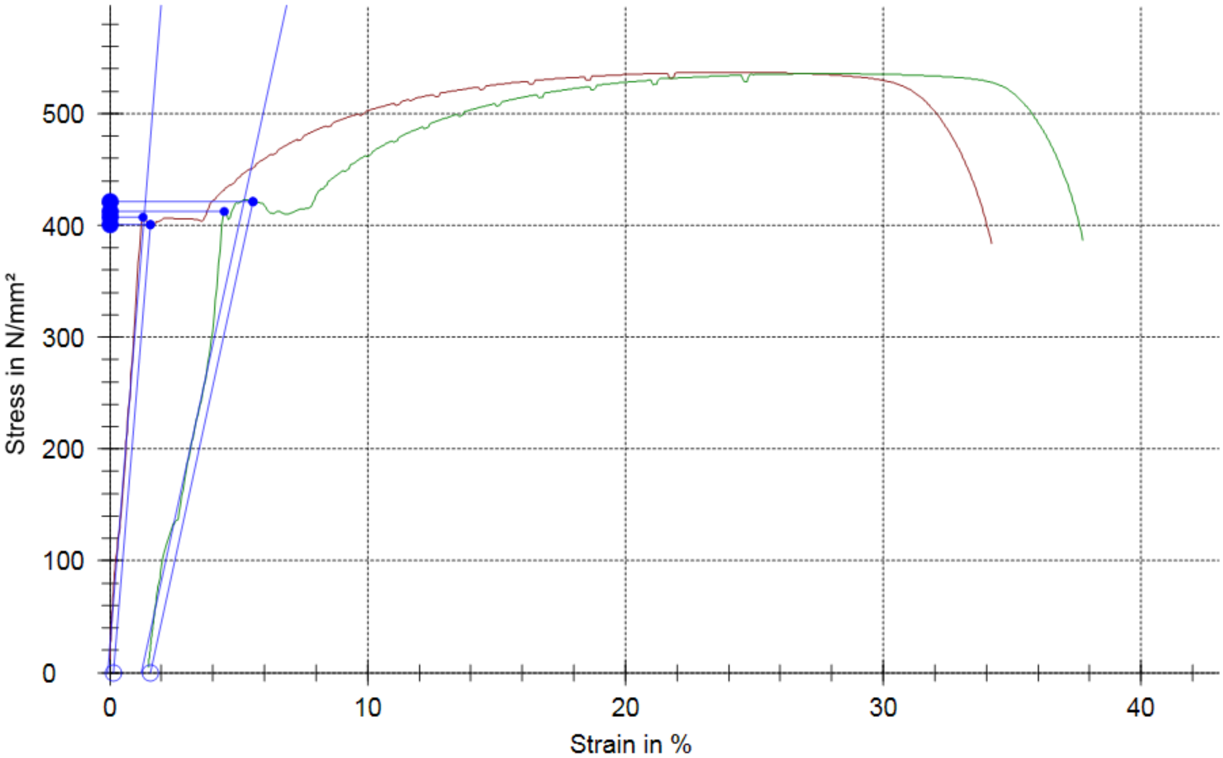


Figure 11. Samples of tensile test results

It is possible to change these parameters within the limits specific to the characteristics of each rolling mill.

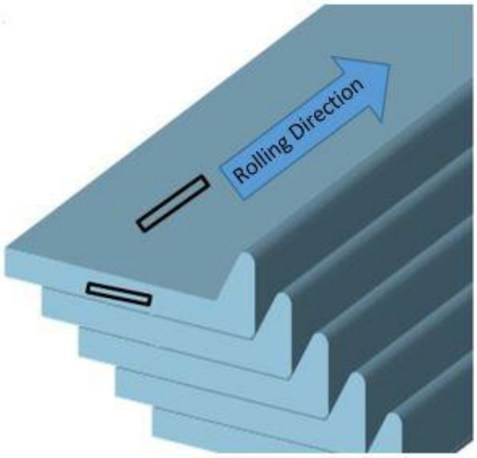
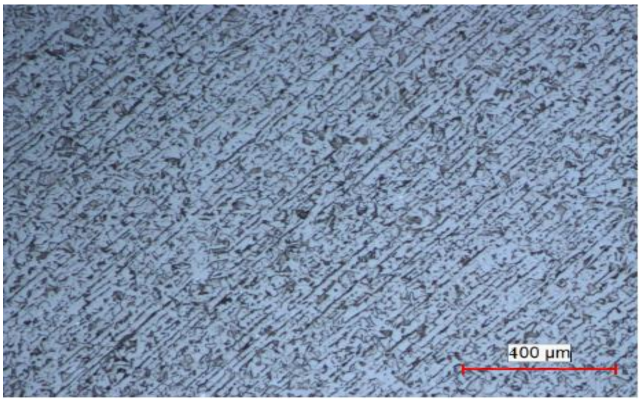


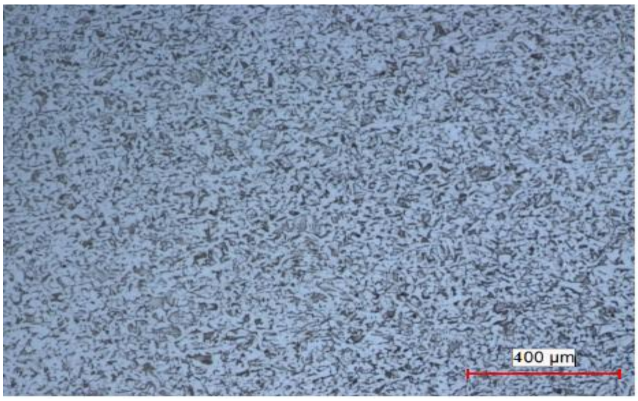
Figure 12. Extraction zones for microstructure examination

In Figure 12, images were taken from the longitudinal and cross section of the rolling direction in order to examine the internal structures formed after rolling. In the hot rolling process; "as rolled" internal structures must be provided on the delivery conditions it has been investigated. "ATM / BRILLANT 200" brand cutting device, "ATM / SAPHIR 520" polishing device and "ATM / OPAL 410" branding device were used to prepare samples before microstructure examination. "Nital (1-10 ml HNO 3 + 90-99 ml methanol)" solution was applied for shaking.
The microstructure images given in Figure 13 (a, b, c)were taken at different magnification ratios in the direction of the rolling direction of the final sample. As can be seen from the pictures, a banded structure parallel to the rolling direction was obtained. In the Ferritic structure, elongated perlite grains were detected. As the magnification ratio goes from 50X to 200X, the structure at the boundaries of the ferrite-perlite grain is seen more clearly.

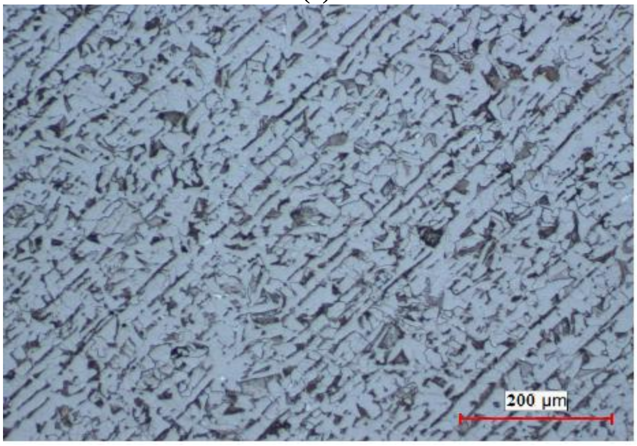
The longitudinal section **The cross section**



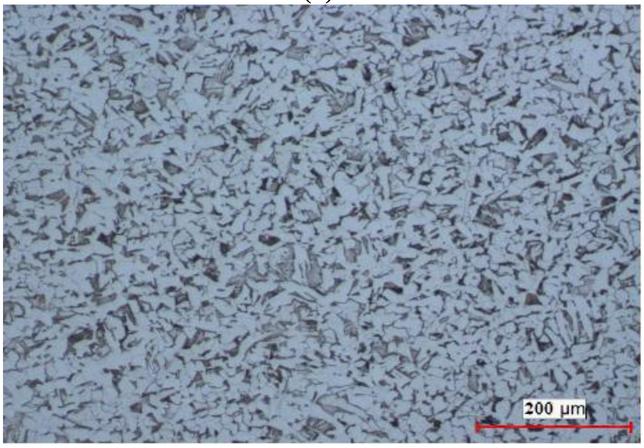
(a)



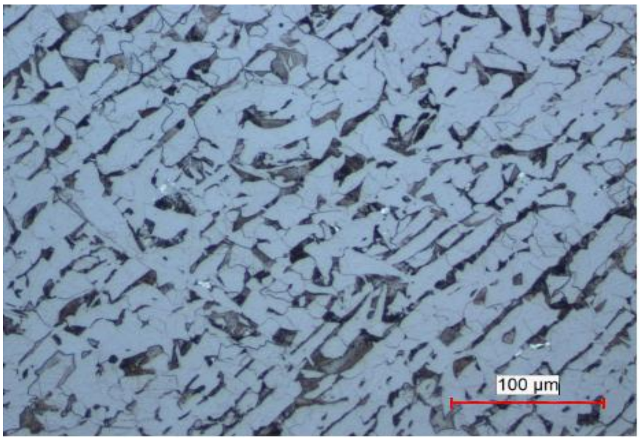
(d)



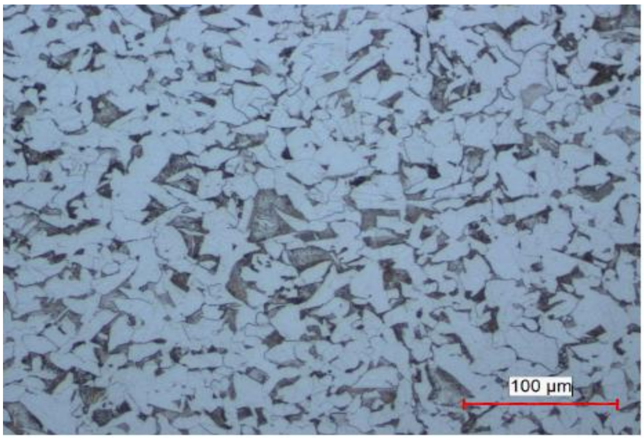
(b)



(e)



(c)



(f)

Figure 13. (a) 50X (b) 100X (c) 200X magnification microstructure image taken from the longitudinal section (left) and (d) 50X (e) 100X (f) 200X magnification microstructure image taken from the cross section (right).

Decarburization caused by annealing was not observed in the investigations. This shows us that the annealing regime and the rolling process are performed in optimum time. The profile is allowed to cool by itself on the cooling platform. Under these conditions, martensite was not observed as a third phase in the structure.

The microstructure images given in Figures 13 (d, e, f) are taken from the cross-section of the final product. As expected, no banded structure was observed in the cross section. In the material which is left to cool by rolling from austenitizing temperature; perlites formed at the boundaries of ferrite were observed. When the grain sizes of ferrite and perlite grains were measured, it was found to be ASTM 8. It has been found that this grain size is also a function of rolling parameters.

Starting from Fig. 13a, the microstructure images, including Fig. 13f, were made with the device "NIKON / ECLIPSE MA 100".

4. Conclusions

Roll pass designs obtained as a result of engineering calculations made according to the principles of plastic shaping have been realized and defects under finite element supported simulations were determined before prototype production. This resulted in 88% reduction in labor and raw material costs in prototype production studies compared to prior simulation programs.

Prototype productions were carried out with the parameters obtained in simulated assisted productions and the current values taken by the motors during the production were recorded online and the torque data affecting the rolls using the current data were found to overlap with each other to a great extent.

In the dimensional controls of the samples obtained at the end of the prototype productions where the rolls manufactured with reference to the roll pass designs of the most efficient deformation process obtained within the scope of simulation activities are used; it is determined that the sample sizes are within the standard tolerance limits.

Tensile tests were carried out in the direction of the TS EN ISO 6892-1 standard by obtaining tensile test specimens from the asymmetric section profiling which were produced at the end of the prototype production and it was found that the asymmetric section profile was improved to the average 410 MPa levels by exceeding 355 MPa which is the lower limit of the target yield strength. It was determined that the target tensile strength lower limit of 490 MPa was improved to 536 MPa.

In the microstructure studies of the samples taken in the direction of the length of the asymmetric section profile obtained at the end of prototype production; ferritic matrix was observed in the scattered pearlitic structures, and the grain structure was found to have the pancake structure as deformation due to the effect of the rolling forces. Examination of microstructure of samples taken from profile cross section; it is seen that ferrite-perlite structures are homogeneously distributed and structures such as martensite are not present.

In a study conducted by Komori K. et al. They proposed a mathematical calculation model for the analysis of deformations and temperatures in the rolling pass stages of the H-shaped profile. The method they use in their studies forms the basis of the software used for analysis today [15].

Kwon, H.-C. et al. They have created an interactive computer aided design algorithm for the rolling pass designs of square and round shaped profiles. By means of software, it is to save time and cost by preventing trials and errors on the production line. The software recommends the optimum values by making iterations according to the entered limit rolling mill conditions [16].
Iankov, R. `s in his study; He examined the MSC.MARC program used in the analysis of the wire rolling process. The author compared 3D finite element numerical simulation and 2D general plane strain approaches in the software for analysis. He stated that 2D general plane strain method can be preferred because of the short solution time where high precision results are not desired [17].

Lee, S.-J. et al. investigated the use of 3D-EFA and BWT methods together for the analysis of complex shaped profiles. When they compared the results of the simulations with laboratory-scale experiments, they obtained a high degree of accuracy. They carried out their laboratory studies with the same material which shows the same flow pattern at the rolling temperature [18].

Sakhaei, A.H. et al. They performed finite element analysis in ABAQUS / Explicit program for U-shaped profile. Then, real production trials were performed with the data obtained from the simulation. When the simulation results and actual productions were compared, it was seen that they obtained a high degree of accuracy. It was seen that they applied similar methodology with our study [19].

In the literature investigations, the situation of finite element analysis which is an increasingly popular subject since the beginning of 2000s has been examined. As can be seen from the studies, it has been found that use and accuracy of the programs are increasing day by day. The studies emphasized the benefits of reducing costs, predetermining rolling errors and shortening the commissioning time. In addition to the control of parameters such as motor forces, roller diameters, rolling speed, elongation ratio and rolling temperature are the important benefits. It will be useful to the future studies to estimate the microstructure by computer-aided simulation. In this way, if necessary, additional heat treatments can be performed in the simulation environment and the microstructure phases can be modified without adding alloy to the raw material and high strength steels can be obtained.

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