RESEARCH OF H-SECTION BEAMS STRAIGHTENING PROCESS

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Abstract

One of the most important causes of steel sections failures are the residual stresses. They are those stresses that are locked in the profiles without of application of any service or internal loads. They influence the material properties of rolled materials and as a consequence the propagation of cracks. Based on the received results, three dimensional finite element analysis of the roller straightening process of chosen H-section was found to be promising for the designing of optimal setting of each roll.

Three dimensional finite element modelling of the roller straightening process of H-section beams is presented in the paper. An explicit-dynamic method by using ABAQUS solver was adopted to realize the feeding of H-sections into the intermeshed rolls by rotating the upper rolls and to accomplish the calculation under condition of frequent contact between H-section and roll interface. Realistic kinematic boundary conditions are implemented in the research; the longitudinal movement of the product through straightening machine achieved by the rollers and the friction. For the constitutive equation of the material, elastic-plastic hardening low was used. The effect of the roll gap on the straightness of the chosen H-section after straightening process was examined. Equivalent stresses, strains, forces and torques parameters were calculated as well. Well known global effects eg. increasing of the web height, flapping of the H-section towards rollers occurs in the research as well. The residual stress can be reduced by reasonable straightening process and it contributes to improving the quality and secure life of H-sections.

Keywords: Roller straightening, residual stresses, H-sections, elastic-plastic material, numerical simulations

1. INTRODUCTION

The adequate straightness of long products (e.g. H-sections, I-sections) is one of the most important factors for the quality and value as merchandise [4]. It is also important parameter determining service life of sections. Long products are distorted after hot rolling and cooling on the cooling bed [5]. The curvature of the sections is caused by the residual stresses, which are induced by inhomogeneous cooling, TRIP effect, repeated bending and frictional effects. To meet the demand of straightness of sections and to reduce the residual stresses in the sections, straightening process is added to the production chain. During straightening the section moves through series of driven and non driven rollers, which are located alternately above and below the section. While the section is passing through the rollers in the longitudinal direction it is loaded by a fluctuating bending moment beyond his elastic limit. Combination of bending, shear and roll contact stresses lead to redistribution of residual stresses and decrease the initial distortion. This operation is very important because it is the final deformation process of the production chain and has been commonly used to acquire the adequate straightness. However, settings of design variables such as rotating speed, roll gap, roll intermesh and so on are still prepared empirically. Many researchers have studied the fundamental mechanics of rolling straightening process using simplified numerical analysis [1-4]. In the present paper, three dimensional finite element research of the roller straightening process of chosen HE beams were performed to validate this analysis to the actual settings of the design variables on rolling straightening process. Moreover, the effect of roll gap on the rolling straightening process is discussed. Finally, it obtained the regulation in which the residual stresses are smaller, so it makes the important theoretical and actual sense to formulate the rational straightening process and improves the straightening quality of H sections.

2. STRAIGHTENING PROCESS OF H-SECTION BEAMS

Compound straightening way consist of horizontal roller unit that is made of ten rollers and a guided roller and can straighten up to HE160 sections. In straightening process of H-sections, deformation process can be divided into eight triangular deformation zones when H-beam is straightened by 9+1 straightening rollers, as shown in the **Figure 1**. The geometry of H-section analyzed in the paper is the standard wide flange beam HE160B. The intermeshes are given by offsetting the rolls 2, 4, 6, 8 and 10. The original intermesh (version A) was given according to that of Celsa Huta Ostrowiec steel company, as shown in **Table 1**.

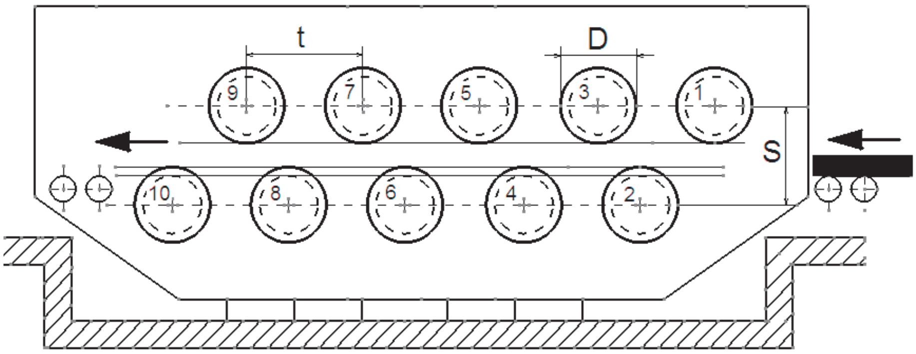

Figure 1 The roller layout of 10-rollers straightener

Table 1 Set of straightening parameters, version A

Roller No.		1	2	3	4	5	6	7	8	9	10
D, mm		590									
t, mm		650	650	650	650	650	650	650	650	650	650
S, mm		598.1	598.1	598.1	598.1	598.1	598.1	598.1	598.1	598.1	598.1
Deflection, mm	V	-	5.5	-	7.2	-	5.4	-	4.0	-	4.0
	H	-	0	-	0	-	0	-	0	-	0

3. THE DESIGN OF SIMULATION OF STRAIGHTENING PROCESS

The finite element simulation modelling was performed with the aid of commercial code ABAQUS ver. 6.17. Dynamic explicit method was adopted for all calculations. Mass scaling factor was taken as unity and was not adopted in the calculations. The models are three dimensional, but the XY symmetry plane is used, so only half of H-beam is modelled. The rollers are non-deformable rigid bodies, all have a diameter of approx. 600 mm and a constant circumferential speed 3 m/s. The rollers are placed in theirs adjusted positions. Then, the H - sections were fed into the intermesh by the bottom rotating rolls. Finally, the roll gap is defined as a distance between flange and rolls at the initial setting, which is another design variable. The roller adjustments of version B simulated process is experimental and confidential (in comparison to version A - change of setting in the V-H directions). The friction coefficient between the H-section and rolls was set at 0.15. At the current project stage, the material model is simplified. The cyclic tension-compression loading is not yet taken into account. Elastic-plastic material behaviour is used; the yield stress, tensile stress and elongation for both versions of the simulations are presented in the **table 2** [6]. For the sake of simplicity, the unstraightened H-beams in the FE models are straight, curvature due to primary processes are not taken into account here, and free of any residual stresses. The H-beams, rolls and guide are meshed with reduced integrated hexagonal elements (type C3D8R) for the discretization. **Figure 2** shows the geometry and discretization of H-section (HE160). The H-section, rolls and guide are meshed with around 3,500,000 elements and 4,000,000 nodes.

Table 2 Material parameter of rollers and H-beams used for FEM calculations (20 °C)

Material parameter	Density (kg/m³)	Young modulus (MPa)	Poisson's ratio	Yield stress (MPa)	Tensile stress (MPa)	Elongation A_5 (%)
H-beam	7,800	210,000	0.3	314	432	36.2
roller	7,800	280,000	0.3	-	-	-

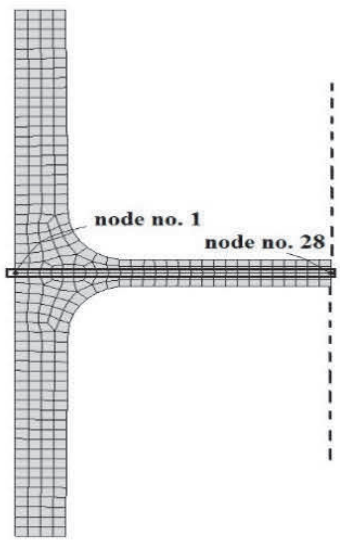

Figure 2 Discrete model of H-section analyzed.

To avoid excessive upwards movement of the profile's end at the entrance to the RDM straightening machine, a guide is implemented in the model. The H-section runs through this guide, the guide restrains the upward (vertical) movement of the product. **Figure 3** presents the model of H-section straightening in the state, where the guide as well as all the rollers are in contact with the H-section.

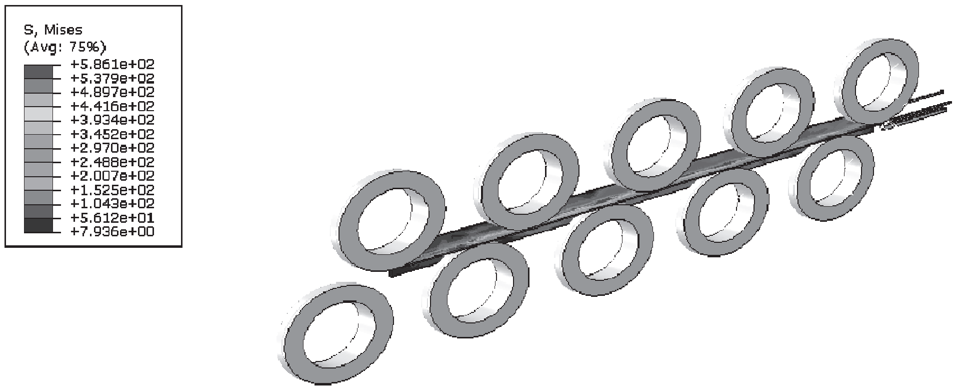

Figure 3 The state where the guide as well as the rollers are in contact with the H-section

4. RESULTS AND DISCUSSION

4.1. Straightening forces

The vertical straightening forces were registered in the calculation at the all rollers and torques on the driven rollers. Based on the research received from the simulation it can be noticed that change of the straightening strategy from setting A to setting B caused significant decreasing parameters during straightening on each roller. The highest drop of the force (around 200 kN) was observed on rollers 3 - 6 and 9 (see **Figure 4**).

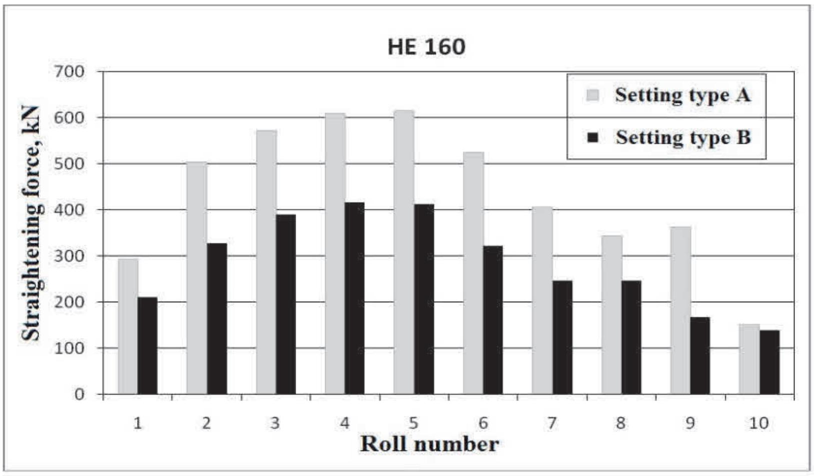

Figure 4 Comparison of the vertical straightening forces for setting type A and B

4.2. Equivalent strains and residual stress

The calculated distribution of the equivalent strains for both straightening scheme (version A and B) are shown in the **Figure 5**. In case of straightening of the HE160 section according to version A it can be shown, that the level of equivalent plastic strain is exceeded on the whole section of the web thickness, **Figure 5a**.

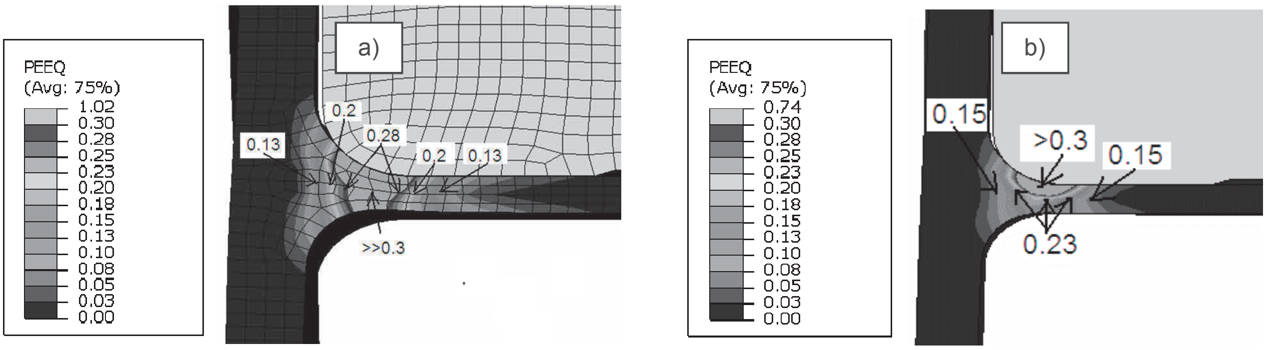

Figure 5 Equivalent plastic strain during bending by the roll No. 3: a) according to schedule A b) according to schedule B

Change of the straightening setting for settings B helped on decreasing of the equivalent plastic strain level, what gave possibility for safe straightening of the section in the rest straightening rollers (see **Figure 5b**). The calculated distribution of the equivalent von Misses stress and longitudinal mean normal stress after straightening the HE 160 section according to version B are shown in the **Figure 6a** and **Figure 6b**. The longitudinal stresses (S_{11}) are the dominant stresses in this process if we compare them to the rest of the three axial stress components (S_{22} and S_{33}). These variables can be analyzed during straightening as well, but as discussed in the introduction, the stresses remaining in the section after straightening are of major importance. FE simulation results show that stress concentration is located in the root area at the web end, (see **Figure 6a**). Additionally, local web necking in the plastic hinge occurs. The finite element calculates a decrease of web thickness in the plastic hinge of approximately 8 % (see **Figure 6b**). It can be concluded that the area of the plastic hinge is the most critical area concerning residual stresses. Analysis of the residual stresses in the symmetry axis of the section show that (for straightening with the settings B) the level of longitudinal stress is transition from tension to compression and tension stress and do not exceed 50 MPa in the web core (see **Figure 7**). In case of straightening with the setting type A, the level of registered compression stress is much higher and reach max value 125 MPa.

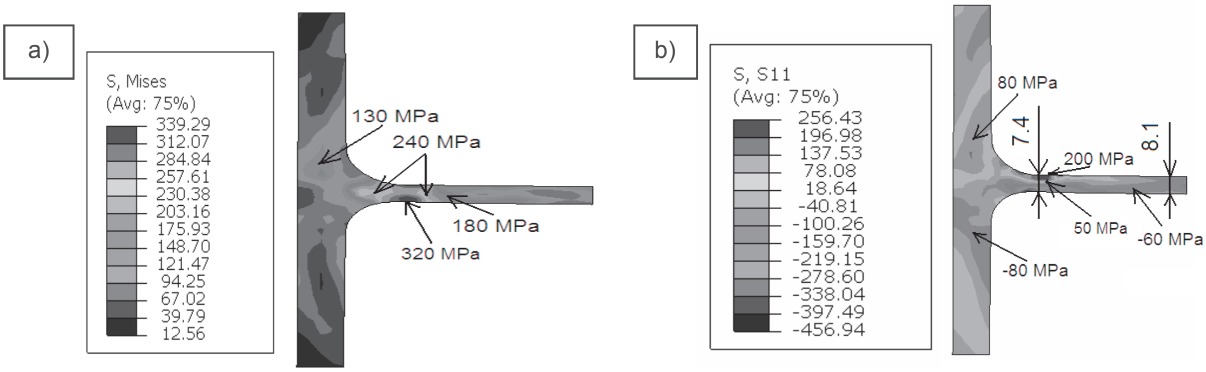

Figure 6 Results of calculation - H-beam after straightening (schedule B): a) distribution of von Misses stress, b) distribution of the longitudinal normal stress S_{11}

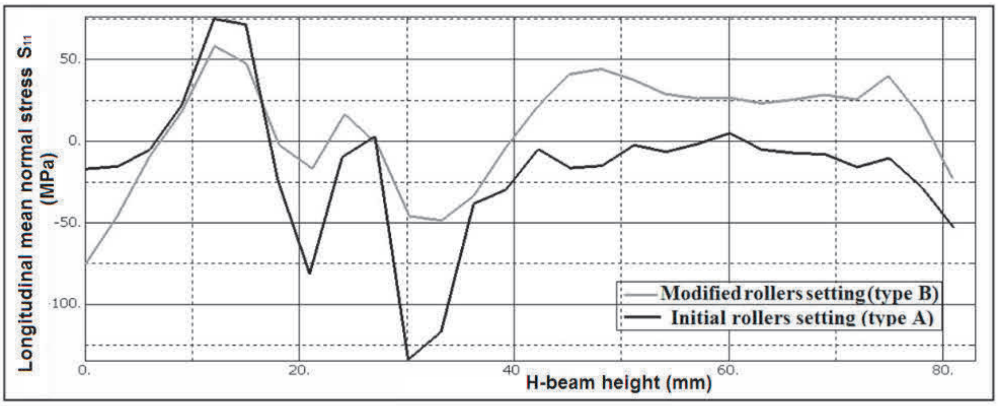

Figure 7 Distribution of the longitudinal normal stresses S_{11} in the H-beam along web symmetry (schedule B)

4.3. Product geometry

From practice, it is well known that the flange of an H-section flaps towards the roller during straightening. This effect is observed in the research as well. **Figure 8** exemplarily shows the shape of the sectional geometry of the H-section straightened for the settings type B at for different rollers. The flange moves towards the upper rollers 1 and 3 and moves towards bottom rollers 4 and 6. The movement of the flange is restricted by the working rollers and the maximum displacement is reached when the tip of the flange touches the face of the roller. Presented simulation results prove as well increasing of the web high of the H-section during straightening. The measurement of the distance on the mesh nodes show insignificant increasing length of the web (approx. 2 %) caused by the straightening process.

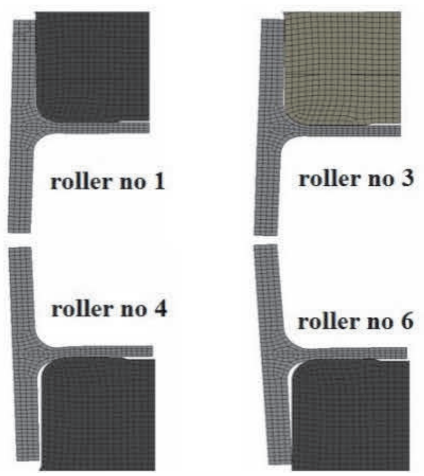

Figure 8 Calculated cross sectional geometries in HE160B beam during straightening at different rollers

5. CONCLUSIONS

Analysis of the phenomena intervening during sections straightening in the industrial conditions are very difficult, and frequently impossible. Essential role plays then possibility of conducting of numerical simulation, which for straightening of heavy and medium sections comprises essential tool for comprehensive analysis of the process. Three dimensional finite element analyses on a straightening process of H-sections by roller straightener were performed for validation of usefulness of research to the actual settings. The obtained conclusions can be summarized as follows:

1) Calculation results show essential influence of intermesh setting of the rollers on the level of residual stresses in the web section after straightening.
2) Proposed in the research changes of the roll gap and bending angles from schedule A to schedule B helped on improvement of the straightening quality of straightened H-section in the industrial conditions.
3) Prepared analysis of H-section helped on evaluation of the extent of plastic deformation accumulation between a flange and a web, which is very important to behave soundness and straightness of the H-section in the corner region.
4) Calculation results estimated the change of cross sectional shape of straightened H-beam.
5) The optimum combination of process parameters was determined from numerical analysis results and applied in the industry during straightening technology of HE 160 sections.

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REFERENCES

[1] LIN Chen, XIAOTING Wang, WEI Tong, ZEYUAN Li, GUO Chang. Numerical Analysis and Simulation of Stress Evolution in the Straightening Process of Different Heavy Rails. *Journal of Metalurgical Engineering.* 2014. vol. 3, no. 1, pp. 43-37.

[2] PETRUSKA Jindrich, NAVRAT Tomas. Numerical modelling of straightening process. *Obróbka plastyczna metali.* 2014. vol. 25, no. 1, pp. 39-50.

[3] HUTO Song, PEILON Wang, LIHUA Fu, MING Chen, ZHONGGIANG Wang, HUIYUAN Sun. Straightening regulation optimization on the residual stress induced by the compound roll straightening in heavy rail. *Shock and Vibration*. 2011. vol. 18, pp. 171-180.

[4] HAYAKAWA Kunio, NAKAMURA Tamotsu, TANAKA Shigekazu. Finite Element Modelling of Roller Straightening of H-Section Beams. In *Metal Forming Conference*. Kraków. 2008. vol. 1, pp. 506-512.

[5] WEISER J. *Analyse der Eigenspannungsentstehung beim Rollenrichten von Schienen*. Otto von Guericke Universität PhD-thesis. Magdeburg. 1997.

[6] DZIEDZIC Michał, TURCZYN Stanisław. 2012. *Analysis of H-beams straightening process by using FEM in the conditions of Medium Rolling Mill Celsa Huta Ostrowiec*. Kraków. 2012. (work not published).