

A STUDY OF MECHANICAL PROPERTIES OF HIGH MANGANESE STEELS AFTER DIFFERENT ROLLING CONDITIONS

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In the paper, two grades of high-manganese steels with aluminum after a thermos - mechanical treatment were studied. Steel grades with an austenitic - ferritic structure with various contents of carbon, manganese and aluminum were selected for the studies. The main goal of the work was to define the most preferable parameters of heat treatment, rolling finish temperature and cooling rate in order to obtain the most favorable strength - ductility relation for the examined steels. The structural analysis was carried out using optical microscopy techniques. The evaluation of strength properties was carried out based on the results of static tensile test of steel sheets.

Key words: high manganese steels, rolling, mechanical properties, microstructure

INTRODUCTION

High-strength manganese-aluminum austenitic and austenitic-ferritic steels have a significant application potential as structural elements in automotive and railway industries because of their perfect combination of high mechanical properties and good plasticity. Their development and commercialization, as well as application as construction materials depend on improvement of their casting properties and deformability under conditions of plastic working. This may be obtained by a proper selection of chemical composition, modification of the initial microstructure, grain refining, and application of proper parameters of the thermo-mechanical treatment (TMT), ensuring an optimal combination of strength and plastic properties [1 - 9].

In conventional steel grades, as well as in alloys for automotive industry, high strength properties may be obtained, however at the cost of significantly decreased plastic properties. The new high - manganese-aluminum steels included into AHSS (advanced high strength) and UHSS (ultra high strength) groups are an exempt from this rule, allowing for a reduction in the vehicle weight, and thereby a reduction in fuel consumption. In consequence, many national and international research centers are working strenuously on application of these materials in automotive industry and railway engineering [4 - 10]. Integration of high strength properties and a good formability, ensuring high absorption of energy by structural components, enables application of these new high - manganese steels in elements critical for the safety, and replacement of dual phase (DP) steels. The newest high-manganese steels, such as transformation induced plastic-

ity (TRIP), twinning induced plasticity (TWIP), or micro bands induced plasticity (MBIP), are different than conventional steels by their contents of alloying elements deciding about the microstructure stability, stacking fault energy (SFE) value and strength properties [10 - 16]. Especially beneficial combination of properties in this group of AHSS steels have consistently two - phase, on which work has not been carried out.

TEST MATERIALS AND METHODS

High-manganese steels were the material for studies. Steel 1: Fe – 15 wt.%, Mn – 4 wt.%, Al – 0.1 wt.% C; Steel 2: Fe – 30 wt.%, Mn – 9 wt.%, Al – 0.65 wt.% C. The steels were prepared in Institute for Ferrous Metallurgy, Gliwice, Poland, in a vacuum induction furnace from Balzers. The casting process was carried out under an argon atmosphere, via a hot tundish, to a water-cooled copper concast mould properly prepared earlier. The concast mould feedstock was rolled into square section with a dimension of 45 mm, then into flat bars with a thickness of 11 mm and flat bars with a thickness of 3 mm. The flat bars with a thickness of 11 mm were rolled in the Institute of Modelling and Control of Forming Processes in Ostrava's VSB-TU, using a laboratory rolling line with a furnace and roller system simulating. The line includes two duo- type reversible rolling stands allowing for a change in the rolling direction in 0,1 sec. The flat bars were rolled at a varied rolling finish temperature, using water and air - cooling. The data including the temperatures between the finishing roll passes and cooling variants may be found in Table 1.

Mechanical properties of the studied steels were determined using a static tensile test on a Zwic/Roell Z100 testing machine. The structural analysis was carried out using optical microscopy techniques.

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Table 1 Temperature and cooling rate variants for flat bars with a thickness of 3 mm

	T Rated /°C	T before the 5 th roll pass /°C	T between the 5 th and 6 th roll pass /°C	T after the 6 th roll pass /°C	cooling
Steel 1	900	893	866	845	water
	800	798	790	768	water
	900	911	887	868	air
	800	816	788	773	air
Steel 2	900	911	885	872	water
	800	809	792	783	water
	900	913	886	872	air
	800	816	796	788	air

RESULTS AND DISCUSSION

The studies was carried out on two grades of high-manganese steels with an austenitic-ferritic structure with various contents of carbon, manganese and aluminum. The structural analysis was carried out on samples cut out according to the rolling direction. Elongated ferrite grains were a characteristic feature of the observed austenitic-ferritic structures, resulting from low recrystallization propensity of the ferrite (Figures 1, 2).

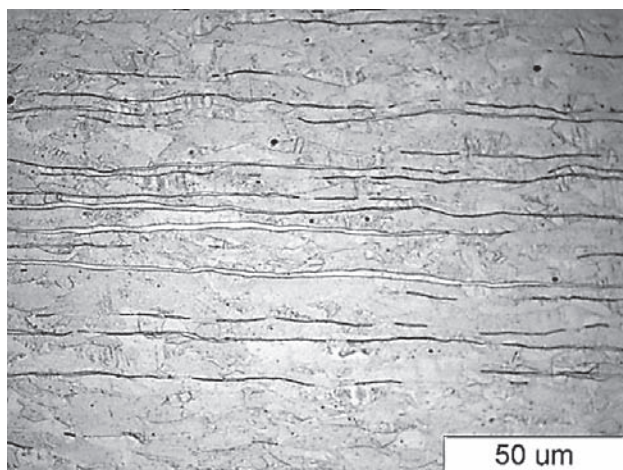


Figure 1 Structure of the Fe – 15 wt.%, Mn – 4 wt.%, Al – 0,1 wt.% C steel rolled in the temperature range of 1 100 °C – 800 °C cooled in air

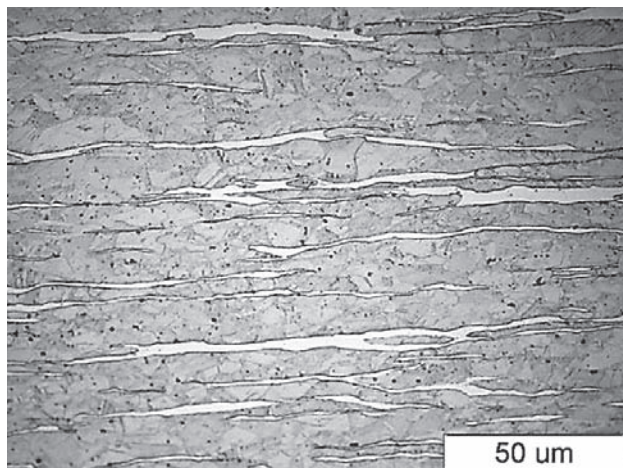


Figure 2 Structure of the Fe – 30 wt.%, Mn – 9 wt.%, Al – 0,65 wt.% C steel rolled in the temperature range of 1 100 °C – 800 °C cooled in air

The results of the static tensile test were shown in the form of stress - strain curves for the samples having the same rolling finish temperature and cooled with the same rate. Based on Figures 3 - 6, the highest strength properties were obtained for the steel 2 - 1 100 MPa with the rolling finish temperature of 800 °C while cooled in air, however ductility of the steel amounted to 35 %. The highest ductility, irrespective of the rolling finish temperature and cooling medium, was exhibited by the steel 1 - ca. 65 %, with the tensile strength in the range of 800 - 850 MPa.

Based on the curves obtained while the static tensile test, proof stress $R_{0,2}$, tensile strength R_m , as well as

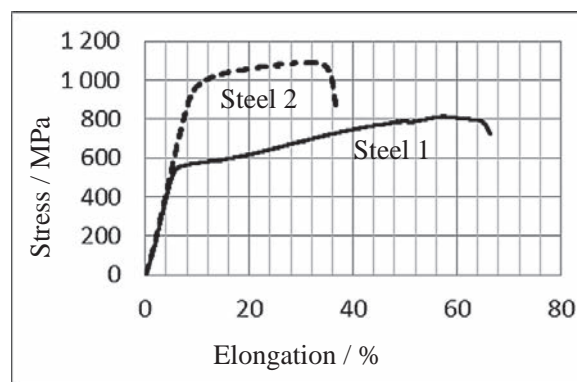


Figure 3 Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 900 °C, cooled in water

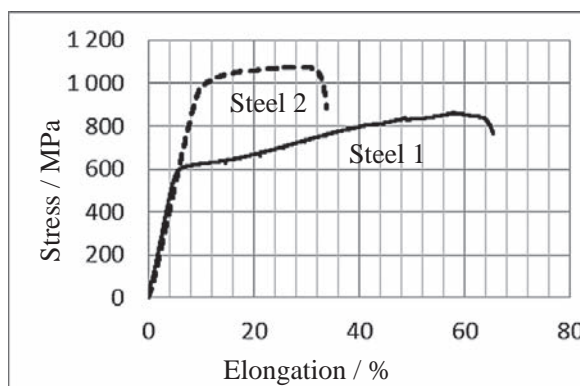


Figure 4 Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 800 °C cooled in water

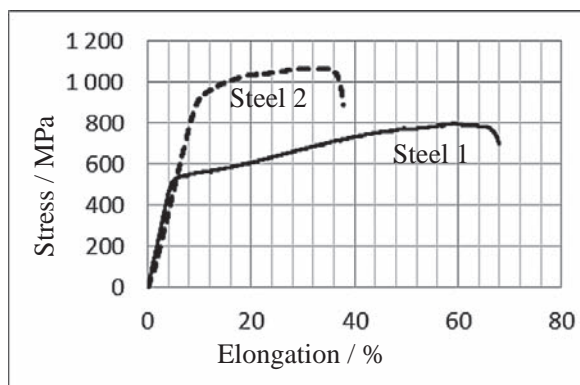


Figure 5 Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 900 °C cooled in air

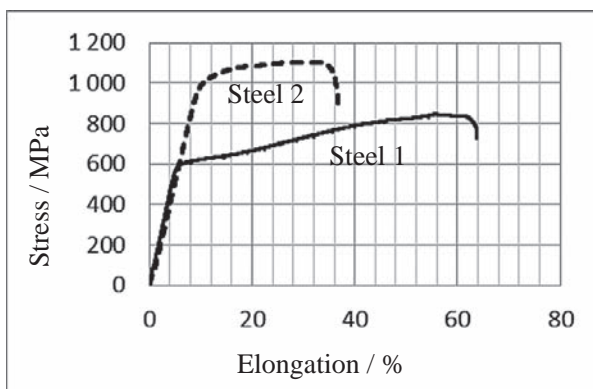


Figure 6 Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 800 °C cooled in air

elongation A_5 were determined. The results are gathered in Table 2.

Table 2 Mechanical properties obtained after different conditions of rolling for flat bars with a thickness of 3 mm

	$T_{\text{rolling finish}} / ^\circ\text{C}$	$R_{0,2} / \text{MPa}$	R_m / MPa	$R_{0,2} / R_m$	$A_5 / \%$	$R_m \times A_5 / \text{MPa} \times \%$
Steel 1	900 water	551	817	0,67	66	53 922
	800 water	604	860	0,70	65	55 900
	900 air	529	799	0,66	67	53 533
	800 air	599	845	0,71	63	53 235
Steel 2	900 water	964	1 087	0,89	36	39 132
	800 water	990	1 075	0,92	33	35 475
	900 air	929	1 063	0,87	37	39 331
	800 air	999	1 106	0,90	36	39 816

The Fe – 15 wt.%, Mn – 4 wt.%, Al – 0,1 wt.% C steel obtains higher mechanical properties after cooling in water; reduction of the rolling finish temperature has a similar effect. The $R_{0,2}/R_m$ ratio is significantly lower for samples cooled in air. Ductility of this steel is higher in case of samples cooled in water, while the influence of the band temperature after the last rolling pass on ductility cannot be ascertained unequivocally. The reduction in the rolling finish temperature is accompanied by an increase in the strength properties.

A high $R_{0,2}/R_m$ ratio after TMT allows for using the element for car body parts requiring a high rigidity. Elements with a lower $R_{0,2}/R_m$ may be used in the zones enhancing the safety and absorbing energy during a collision. The lowest ratio of the stress proof and the tensile strength $R_{0,2}/R_m$ is exhibited by the Fe – 15 wt.%, Mn – 4 wt.%, Al – 0,1 wt.% C steel, while the highest, amounting to 0,92 – by the Fe – 30 wt.%, Mn – 9 wt.%, Al – 0,65 wt.% C steel. Based on the determined strength properties and ductility, one may ascertain that an increase in carbon, manganese and aluminum con-

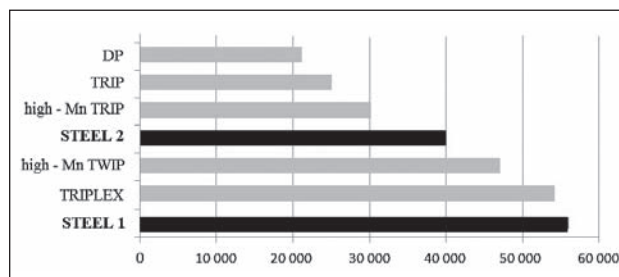


Figure 7 Classification of steels in respect of $R_m \times A$, MPa \times % index, with the studied steels marked in black [prepared based on 17].

tents in the steel increases the strength properties, while it has no unequivocal influence on the ductility and impact resistance.

Comparing the $R_m \times A$ indices for the examined steels and with the literature data [2, 17], it may be ascertained that the steel 1 achieves the highest $R_m \times A$ relation (Figure 7) thanks to its high ductility at the tensile strength of ca. 800 MPa. The steel 2 exhibited a $R_m \times A$ relation on the level of 40 000 MPa \times %.

CONCLUSIONS

In the paper, samples of high-manganese steels with aluminum after a thermo-mechanical treatment were studied. Steel grades with an austenitic-ferritic structure with various contents of carbon, manganese and aluminum were selected for the studies. The main goal of the work was to evaluate quality of the studied steels and to determine the most preferable parameters of heat treatment, rolling finish temperature and cooling rate in order to obtain the most favorable strength-ductility relation for the examined steels. Structural elements made of MnAl steel may achieve a higher quality than the elements made of conventional steels of DP, TRIP, IF types, thanks an enhanced strengthening effect during TMT. In order to achieve this goal, post - TMT treatment with varied cooling conditions were used (Table 1).

Based on the investigations carried out, an influence of chemical composition on strength-plasticity relations for the studied high-manganese steels was ascertained.

It was shown that the final properties of an MnAl steel may be fashioned using TMT. A decrease in the rolling finish temperature improves mechanical properties, however it decreases plasticity of the steel.

No significant influence of changes in cooling rate on the strength properties and plasticity of steel sheets made of the studied steels was ascertained. Thus, a good quality of the products may be achieved by cooling the sheets in air. Simplification of the technology leads to a reduction in costs of the manufactured component parts.

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Note: The responsible translator for English language is Dr. Janusz Mrzigod, Katowice, Poland