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ISSN 0543-5846
METABK 54(4) 619-622 (2015)
UDC – UDK 669.74.15:621.771:620.17.18=111

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

Received – Primljeno: 2014-08-30
Accepted – Prihvaćeno: 2015-02-12
Original Scientific Paper – Izvorni znanstveni

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 plasticity (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 5th roll pass / °C | *T* between the 5th and 6th roll pass / °C | *T* after the 6th 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).

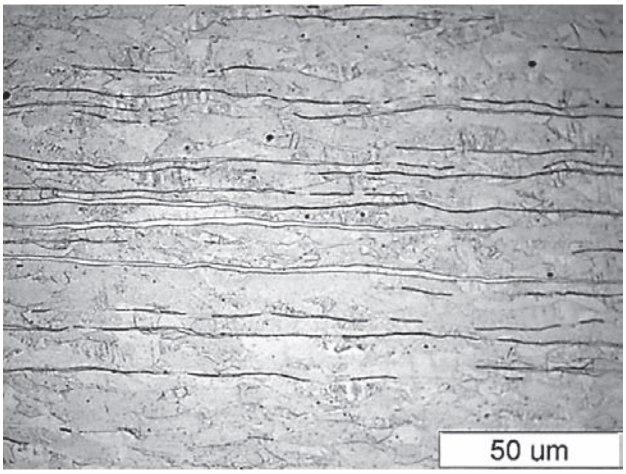

**Figure 1** Structure of the Fe – 15 wt.%, Mn – 4 wt.%, Al – 0,1 wt.% C steel rolled in the temperature range of 1 100 °C - 800 °C cooled in air

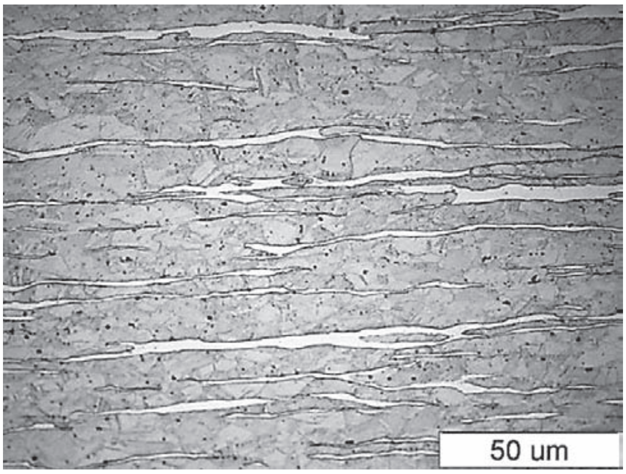

**Figure 2** Structure of the Fe – 30 wt.%, Mn – 9 wt.%, Al – 0,65 wt.% C steel rolled in the temperature range of 1 100 °C - 800 °C cooled in air

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 ºC 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

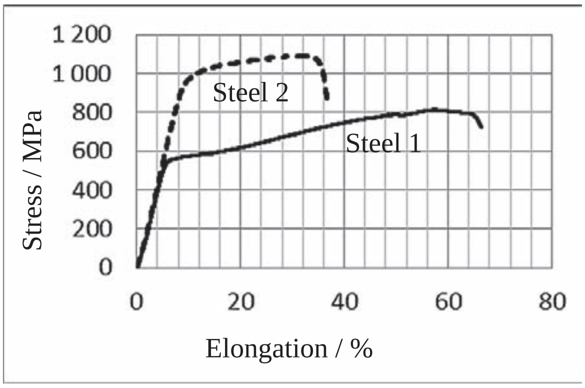

**Figure 3** Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 900 °C, cooled in water

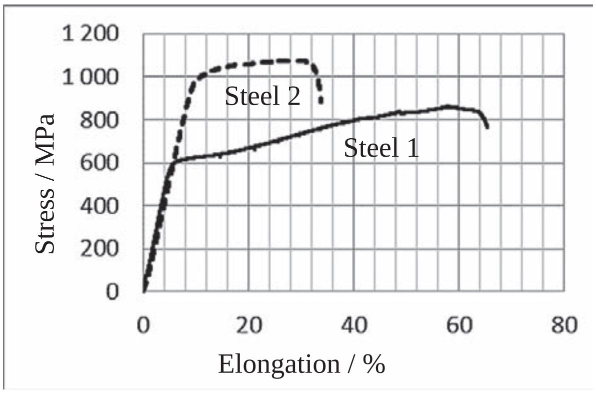

**Figure 4** Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 800 °C cooled in water

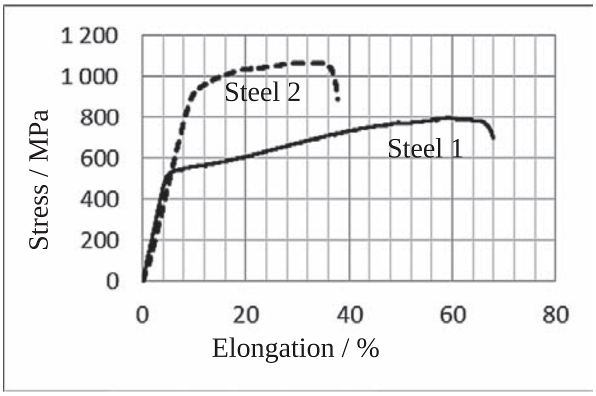

**Figure 5** Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 900 °C cooled in air

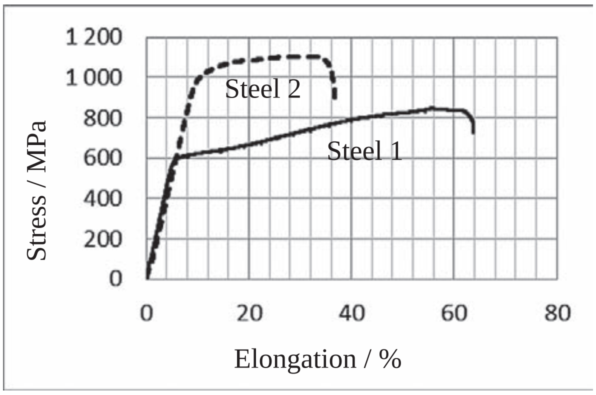

**Figure 6** Stress-strain curve for the samples rolled in the temperature range of 1 100 °C - 800 °C cooled in air

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* rolling finish / ˚C | $R_{0,2}$ / MPa | $R_m$ / MPa | $R_{0,2} \backslash R_m$ | $A_5$ / % | $R_m \times A_5$ / MPa × % |
|---|---|---|---|---|---|---|
| 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 contents in the steel increases the strength properties, while it has no unequivocal influence on the ductility and impact resistance.

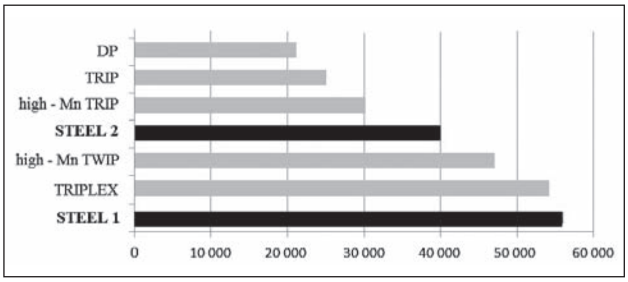

**Figure 7** Classification of steels in respect of $R_m \times A$, MPa × % index, with the studied steels marked in black [prepared based on 17].

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 × %.

## 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 then 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.

## Acknowledgments

Work conducted within the Research and Development Project of National Centre for Research and Development No. 15 0012 06 as well as BK-220/RM3/2015.

## REFERENCES

[1] A. S Hamada, Manufacturing, mechanical properties and corrosion behaviour of High-Mn TWIP steels, Universitatis Ouluensis (2007), 1 - 56.

[2] D. Kuc, E. Hadasik, G. Niewielski, I. Schindler, E. Mazancová, S. Rusz, P. Kawulok, Structural and mechanical properties of laboratory rolled steels high-alloyed with manganese and aluminum, Archives of Civil and Mechanical Engineering 12 (2012), 312 - 317.

[3] S. Lasek, E. Mazancova, Influence of thermal treatment on structure and corrosion properties of high manganese triplex steels, Metalurgija 52 (2013) 4, 441 - 444.

[4] E. Mazancova, I. Ruziak, I. Schindler, Influence of rolling conditions and aging process on mechanical properties of high manganese steels, Archives of Civil and Mechanical Engineering 12 (2012), 142 - 147.

[5] S. Wiewiórowska, Analysis of the Influence of Drawing Process Parameters on the Mechanical Properties of TRIP-Structure Steel Wires Arch. of Metal. And Mater. 58 (2013) 2, 573 - 578.

[6] M. Jabłońska, A. Śmiglewicz, Analysis of substructure of high - Mn steels in the context of dominant stress mechanism, Defect and Diffusion Forum 334-335 (2013), 177 - 181

[7] W. Bleck, K. Phiuon: Effects of Microalloying in Multi Phase Steels for Car Body Manufacture, 14. Säsiche Fachtagung Umformtechnik, Werkstoffe und Komponenten für Fahrzeugen, Freiberg (2007), 38 - 55.

[8] M. Jabłońska, A. Śmiglewicz, G. Niewielski, M. Hetmańczyk, Heat treatment of high manganese type X57MnAl27-5 austenitic steel, Technologies and Properties of Modern Utilised Materials, Book Series: IOP Conference Series - Materials Science and Engineering 22 (2011), 1 - 5.

[9] A. I. Z. Farahata, O. Hamedb, A. El-Sisi, M. Hawash, Effect of hot forging and Mn content on austenitic stainless steel containing high carbon, Materials Science and Engineering A 530 (2011) 98 - 106.

[10] M.B. Jabłońska, Mechanical properties and fractographic analysis of high manganese steels after dynamic deformation tests, Arch. of Metal. And Mater. 59 (2014) 3, 1193 - 1197.

[11] A. Kokosza, J. Pacyna, Formation of medium carbon trip steel microstructure during annealing in the intercritical temperature range, Arch. of Metal. And Mater. 59 (2014) 3, 1017 - 1022.

[12] A. Grajcar, M. Różanski, M. Kaminska, B. Grzegorczyk, Study on non - metallic inclusions in laser - welded TRIP - aided Nb-microalloyed steel, Arch. of Metal. And Mater. 59 (2014) 3, 1164 - 1169.

[13] W. S. Yang, C. M. Wan, The influence of aluminum content to the stacking fault energy in Fe –Mn - AI -C alloy system, Journal of Materials Science 25, (1990), 1 - 3.

[14] S. Wiewiórowska, Z. Muskalski, The influence of the partial single reduction on mechanical properties wires made from trip steel with 0,43 % C, Metalurgija 54 (2014), 184 - 186.

[15] R. Kuziak, R. Kawalla, S. Waengler, Advanced high strength steels for automotive industry, Archives of Civil and Mechanical Engineering 2 (2008), 103 - 118.

[16] L. Chen, Y. Zhao, X. Qin, Some aspects of high manganese twinning - induced plasticity (TWIP) steel, Acta Metall. Sin. 26 (2013), 1 - 15.

[17] G. Frommeyer, U. Brüx. Microstructure and mechanical properties of High-Strength Fe - Mn - Al -C Light - Weight TRIPLEX Steels, Steel Research 77, (2006) 9-10, 627 - 633.

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