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Influence of thermo-plastic deformation on grain size of high-manganese austenitic X11MnSiAl17-3-1 steel

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Materials

ABSTRACT

Purpose: The aim of the paper is to compare fragmentation of grains after thermo-mechanical treatment using Gleeble 3800 simulator of high-manganese austenitic X11MnSiAl7-1-3 steel.

Design/methodology/approach: The hot-working behaviour was determined 4- and 8-stage compression tests performed in a temperature range of 850 to 1100°C by the use of the Gleeble 3800 thermo-mechanical simulator. The comparison between two type of thermo-mechanical treatment has been established based on microstructure research and X-ray diffraction analysis.

Findings: It was found that steel X11MnSiAl7-1-3 in initial state and after thermo-mechanical treatment on Gleeble simulator has homogeneous austenite structure. Compression tests were realized in the temperature range from 850 to 1050°C with the true strain 4x0.23 for 4-stage process, and 0.4 in the first deformation, and 0.25 and 0.2 in the following deformations for 8-stage process. The multi-stage compression examination gives the possibility to refine the austenite microstructure. Based on microstructures research were found that this process perfectly led to fragmentation of the material structure which may result in the ideal material properties.

Practical implications: The obtained microstructure after Gleeble simulations can be useful in determination of power-force parameters of hot-rolling for thin sheets to obtain fine-grained austenitic microstructures.

Originality/value: The hot-working behaviour and microstructure evolution in various conditions of plastic deformation for new-developed high-manganese austenitic steels were investigated.

Keywords: High-manganese steel; Thermo-mechanical simulation; Grain size

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1. Introduction

The automotive industry has always developed on several levels: on the one hand there were designed and refined vehicle driving systems, on the other there were carried out investigations on the materials from which they were made, as well as mechanical systems and bodies, reinforcing elements of the car. While at the beginning the most important criterion for the selection of materials was the highest resistance to corrosion and low production cost, so in the last two decades, producers have started to place increasing emphasis on vehicle safety [1-4].

Proper selection of the chemical composition and the manufacturing technologies, which guarantee to provide a proper structure for the insurance of suitable combination of mechanical and plastic properties of steel, in the last forty years there has been developed a new group of steels for application in the automotive industry. Investigations concerning the chemical composition of steel using as the basis for the addition of significant amounts of manganese, and reducing the amount of carbon, led to the development high manganese austenitic steels. The production technology of these steels is based currently on the heat treatment, but a more preferred solution, however, appears to be the use of thermo-plastic treatment [5-8].

Thermo- mechanical treatment is performed at a temperature above the recrystallization temperature, and involves plastic deformation combined with heat treatment, in such a way that the phase transition occurs in the crystal lattice defect density growth conditions, which are strain induced. This allows to increase mechanical properties without losing the plastic properties of steel by controlling the processes occurring in the treated element. Thermo-plastic treatment of austenitic steels used in automotive industry, is carried out under controlled conditions to produce a fine and homogeneous structure [6, 8-12].

The process of thermo-plastic treatment consisting of controlled plastic deformation and cooling with a defined cooling rate from the temperature of the end of this treatment allows the use of the occurring phase transformations in the steel to improve the desired functional properties, in particular for the production of metallic materials with controlled particle size. Influence of temperature and plastic deformation on the grain size during the rolling of a multistage process is presented in Fig. 1. The grain size of the material depends on the temperature and is presented based on the ON curve, where the O point represents the theoretical point of the recrystallization temperature T_r. If the metal with the structure having a grain size corresponding to the point A is heated to a temperature of T_1 and then subjected to plastic deformation, so the grain size is reduced to the value of point A1. In case of the absence of further deformation, the material temperature will slowly decrease, and will cause, that the grain size will again grow according to the curve A_1K. If, however, further deformation occurs at a temperature T_2, when the grain size corresponds to the point B, so the grains will be again refined to the point B_1. After the last passover there are obtained grains with the size presented a point E. Hence the conclusion, that the smallest grain can be obtained, if the last passage takes place at the lowest temperature [12].

Implementation of a too high deformation force deflection, or a too long isothermal heating time after the final deformation results in excessive grain growth, and causes the increase the of strength properties, and in particular cases also the increase of yield stress and tensile strength. In contrast, a too large average grain diameter causes an improvement in the plastic properties, also the elongation ratio can be as high as 80-90%, but there is achieved, however, relatively low tensile strength s [14-18].

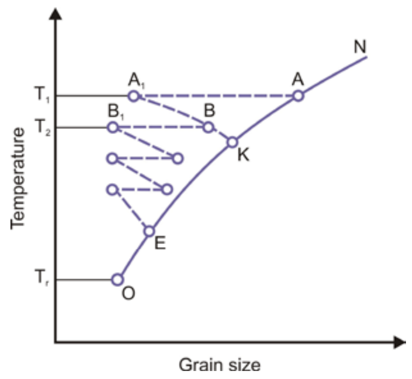


Fig. 1. Influence of temperature and deformation on grain size during multi-stage rolling [12]

Therefore, the main purpose of thermo- mechanical treatment is the selection of process parameters to achieve the optimum values for the mean grain diameter in which the product of tensile strength and elongation reaches the maximum value. In addition, a sufficiently fine-grained structure obtained in the process of thermo-plastic deformation provides an increase of yield improvement will affect the susceptibility of the material to the design of technology as well as cracking resistance. Suitable particle size for austenitic steels is obtained in the process of static, dynamic or metadynamic recrystallization, without allowance to grain growth by controlled cooling immediately following after the last deformation [19-21].

2. Materials and experimental procedure

Investigations were carried out on newly developed austenitic high-manganese stainless steel X11MnSiAl17-3, containing 0.11% carbon, 17.55% manganese, 1.17% silicon and 3.37% aluminum. The exact chemical composition is presented in Table 1. The investigated steel is characterized by a very high metallurgical purity which confirms a very low content of phosphorus and sulfur gases. The melt was modified with rare earth elements like: cerium, lanthanum and neodymium.

Table 1.
Chemical composition of d high-manganese austenitic TRIP steels, mass fraction

steel designation		X11MnSiAl17-1-3
chemical composition, mass fraction	C	0.11
	Mn	17.55
	Si	1.17
	Al	3.37
	P_{max}	0.002
	S_{max}	0.003
	Ce	0.023
	La	0.007
	Nd	0.009
	O	0.0003
	N	0.0036

Plastic pre-hot forming of ingots, on a flat bar of 20x220 mm cross-section, was performed by the open die forging method on a high-speed hydraulic press from Kawazoe capable of generating 300 ton pressure. Ingots were heated for forging in a gas forging furnace in a range between 1200 and 900°C. The ingot body was subjected to forging - its head and feet were cut off at the height of 3 cm to the place which contraction cavity was reached.

Simulation of multi-stage thermo-mechanical deformation was carried out on the Gleeble 3800 simulator. Elastomeric investigations were based on thermo-plastic treatment consisting of 4 or 8 rolling reductions designed to simulate the final rolling passovers. There were prepared two types of samples:

- cylindrical Ø 10x12mm for 4-stage compression,
- axially symmetric 20x35x15mm for 8-stage compression.

Different size and shape of the samples allowed to obtain the proportions on sample width to the width of the anvil in the range of 6:10. The use of axially symmetric samples also allowed to obtain the total deformation equal 2, to provide simulation of thermo-plastic deformation in conditions close to the plane strain condition. The maximum total deformation of the cylindrical sample was approximately 1.8.

Reduction ratios of plastic deformation rates and intervals times between successive plastic deformation stages were selected taking into account conditions of planned hot-rolling on flat sheets with initial thickness of 4.5 mm, rolled down to 3 mm thickness samples. Schematic and parameters of the 4-stage compression test were presented on Fig. 2 (Variants G4W, G4A and G430W), and of the 8-stage compression test were presented on Fig. 3 (Variants G8W, G8A and G830W). In both cases apart from determining force and energy parameters of the hot plastic deformation, the samples were cooling in water, natural cooling in air, and in water after isothermal holding at the temperature of last deformation 850°C.

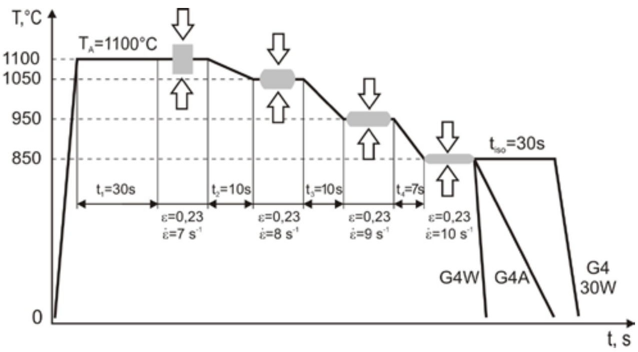


Fig. 2. Schematic and parameters of the 4-stage compression test carried out on Gleeble 3800 thermo-mechanical simulator. T_A - austenitizing temperature, t_{iso} - time of the isothermal holding of specimens at temperature of last deformation - 850°C

Metallographic examination were carried out on samples in researched steel mounted in thermosetting resins. After the sample was mounted, it was grinded on the STRUERS's grinding machine using abrasive papers of 220-4000 μm/mm^2 grain size. Then the samples were subjected to mechanical polishing using diamond suspension of 6 and 1 μm grain coarseness. In order to reveal grain boundaries in the structure of high-manganese austenitic steels a digestion reagent was used, which was a mixture of nitrous acid, hydrochloric acid and water in 4:4:2 proportions respectively. Digestion time for each sample was ranging between 5-10 s.

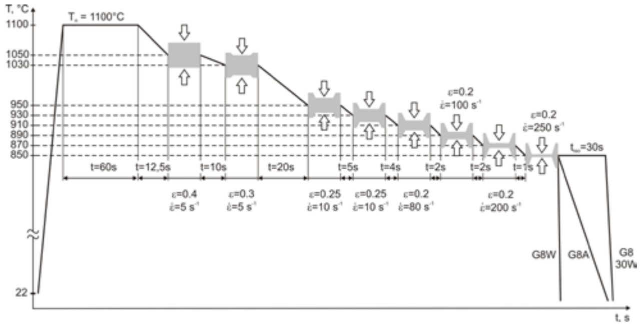


Fig. 3. Schematic and parameters of the 8-stage compression test carried out on Gleeble 3800 thermo-mechanical simulator. T_A - austenitizing temperature, t_{iso} - time of the isothermal holding of specimens at temperature of last deformation - 850°C

Structural observations of probed materials were carried out on the LEICA MEF4A light microscope at magnification from 200 to 1000x.

3. Results and discussion

Application of different variants of thermo-mechanical treatment has no influence on stability of the austenite. Confirmation of that fact is the X-ray diffraction patterns shown in Fig. 4 which presents the comparison of a representative diffraction pattern of the X11MnSiAl17-3-1 steel in initial state and after 4 and 8-stage of compression tests performed on the thermo-mechanical Gleeble 3800 simulator. Based on the results of X-ray diffraction it was found, that the applied thermo-mechanical treatment does not have influence on phase structure changes.

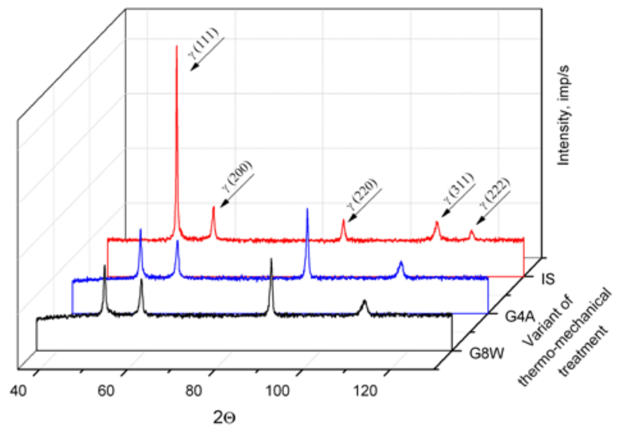


Fig. 4. Comparison of X-ray diffraction pattern after different stages and variants of thermo-mechanical treatment

The output structure of the X11MnSiAl17-1-3 steel in the state after casting and pre-forging on the Kawazoe press consists of austenite grains with a grain size of 150-200 μm (Fig. 5).

Some of the typical optical micrographs of high-manganese austenitic X11MnSiAl17-1-3 steel after hot-working in the thermo-mechanical simulator Gleeble 3800 are shown in Figs 6 and 7.

In all variants of the thermo-plastic deformation of the consisting of 4 rolling reductions there has occurred dynamic recrystallization of austenite grain revealed as uniform structure fragmentation manifested with an uniform structure with a size of 20 μm for the variant G4W to about 30 μm for the variant G4 30W. In the variant, wherein after the treatment there occurs rapid cooling in order to freeze the structure there can be further find fine statically recrystallized or metadynamic grains with the size of about 2-5 μm (Fig. 6a). The initiation of metadynamic and static recrystallization after the last deformation and subsequent air-cooling leads to obtain mean grain size of about 20-25 μm (Fig. 6b). In the G4A variant there is a less amount of the static or metadynamic recrystallized grains, due to their more excessive growth during cooling. As a result of isothermal holding for 30 s G4 30W the structure was reduced to an average particle diameter of 25-30 μm and the mainly statically recrystallized grains have a diameter of about 5 μm.

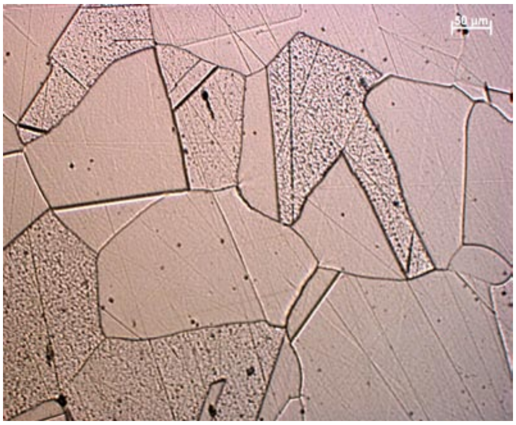
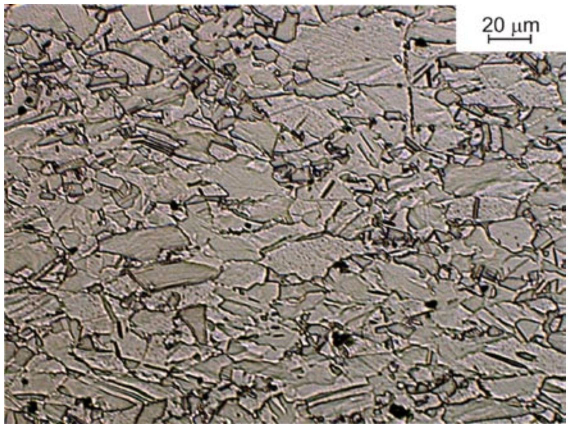


Fig. 5. Steel X11MnSiAl17-1-3 in a initial state

The use of thermo-plastic deformation for the X11MnSiAl17-3- 1 steel consists of 8-fold compression and subsequent rapid cooling in water (G8W) in order to freeze the structure results in dynamic recrystallization with a very large grain refinement. The average grain diameter is in the range of 5-10 μm, and at the grain boundaries there can be seen static or metadynamic recrystallized austenite grains with a size less than 2-3 μm (Fig. 7a).

The appliance of the cooling variant G8A consisting of natural cooling in air after the final deformation at the temperature of 850°C results in fragmentation of the structure to 10-15 μm (Fig. 7b). During plastic deformation, dynamic recrystallization took place, and the use of natural cooling in air results in the occurrence of static recrystallization. After an isothermal annealing at the temperature of the last deformation during 30 causes the occurrence of static recrystallization, and in comparison with variants G8A and G8W a significant grain growth (which were growed during the heating), the average grain diameter is 15-20 μm, and some grains have a diameter in one of the directions even up to 25 μm (Fig. 7c). Thermo-plastic deformation consisting of the four -fold compression of the tested axisymmetric samples in the Gleeble simulator results in about twice less refinement of the structure compared to 8-fold compression, due to lower rolling reduction.

a)



b)

c)

Fig. 6. Structures of high-manganese austenitic X11MnSiAl17-1-3 steel after thermo-mechanical treatment in Gleeble simulator according to schedule shown in Fig. 2 and variant of cooling a) G4W, b) G4A, c) G4 30W

a)

b)

c)

Fig. 7. Structures of high-manganese austenitic X11MnSiAl17-1-3 steel after thermo-mechanical treatment in Gleeble simulator according to schedule shown in Fig. 3 and variant of cooling a) G8W, b) G8A, c) G8 30W

Particle size in the initial state and after heat treatment for all variants of plastic is presented in Fig. 8.

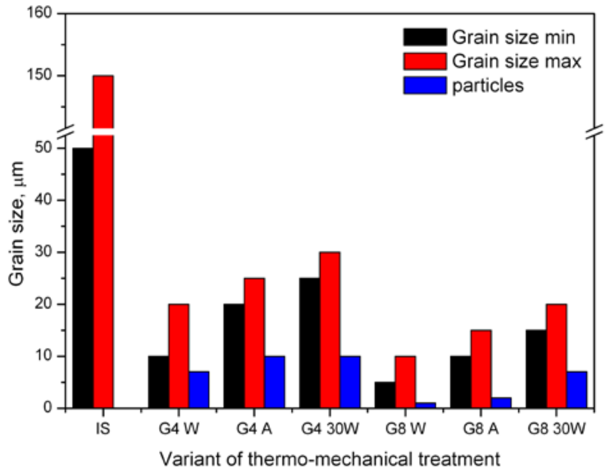


Fig. 8. The grain size of the austenitic steels after different variants of thermo-mechanical deformations carried out on the simulator Gleeble

4. Conclusions

Steel X11MnSiAl17-3-1 in the as cast state and after carried out thermo-mechanical treatment is characterized by a homogeneous austenitic structure, which was confirmed by the X-Rays diffraction investigations. In the initial state the structure of the steel reveals austenite grains with an average diameter of 150-200 µm.

The thermo-plastic treatment carried out on the Gleeble 3800 simulator for the reason to simulate the final hot rolling passovers has resulted in the refinement of the X11MnSiAl17-3-1 steel structure. The use of four-stage compression results in structure refinement with the grain size of up to about 20-25 µm, which in relation to the initial structure constitutes 10% of the original size. The 8-stage compression causes much higher structure refinement, even up to 5-10 µm, which is about 3-5% compared to the grain size of the steel in the as cast state.

Both, during the 4 and 8-stage compression there has occurred dynamic recrystallization of the austenite grains, and in the intervals between the following deformation there has occurred metadynamic recrystallisation. During cooling of the steel after the heat-treatment process there was occurring metadynamic and/or static recrystallization, depending on the variant of the applied cooling.

The carried out simulations of thermo-plastic treatment on the Gleeble 3800 simulator will be the basis for the design of the hot-rolling process in industrial conditions.

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References

[1] L.A. Dobrzański, W. Borek, M. Ondrula, Thermo-mechanical processing and microstructure evolution of high-manganese austenitic TRIP-type steels, Journal of Achievements in Materials and Manufacturing Engineering 53/2 (2012) 59-66.
[2] T. Tański, K. Labisz, Electron microscope investigation of PVD coated aluminium alloy surface layer, Solid State Phenomena 186 (2012) 192-197.
[3] T. Tański, K. Lukaszkowicz, Structure and properties of PVD coatings deposited on the aluminium alloys, Surface Engineering 28/8 (2012) 598-604.
[4] SafetyNet, 2009, Vehicle Safety, retrieved 15.12.2013.
[5] ULSAB-AVC, www.worldautosteel.com.
[6] L.A. Dobrzanski, M. Krupinski, K. Labisz, B. Krupinska, A. Grajcar, Phases and structure characteristics of the near eutectic Al-Si-Cu alloy using derivative thermo analysis (Conference Paper), Materials Science Forum 638-642 (2010) 475-480.
[7] L.A. Dobrzański, W. Borek, Hot-working behaviour of advanced high-manganese C-Mn-Si-Al steels, Materials Science Forum 654-656 (2010) 266-269.
[8] Advanced High Strength Steel (AHSS) Application Guidelines, International Iron and Steel Institute, 2013, www.worldautosteel.org,
[9] L.A. Dobrzański, W. Sitek, M. Krupiński, J. Dobrzański, Computer aided method for evaluation of failure class of materials working in creep conditions, Journal Of Materials Processing Technology 157 (2004) 102-106.
[10] J.A. Jiménez, G. Frommeyer, Analysis of the microstructure evolution during tensile testing at room temperature of high-manganese austenitic steel, Materials Characterization 61 (2010) 221-226.
[11] M. Krupinski, L.A. Dobrzanski, J.H. Sokolowski, W. Kasprzak, G. Byczynski, Methodology for automatic control of automotive Al-Si cast components, Materials Science Forum 539-543 (2007) 339-344.
[12] Z. Jaglarz, W. Leskiewicz, M. Morawiecki, Technology and equipment rolling flat products, Publishing house Silesia, Katowice, 1979 (in Polish).
[13] W. Ozgowicz, K. Labisz, Analysis of the state of the fine-dispersive precipitations in the structure of high strength steel Weldox 1300 by means of electron diffraction, Journal of Iron and Steel Research, International 18 (2011) 135-142.
[14] L.A. Dobrzański, T. Tański, Influence of aluminium content on behaviour of magnesium cast alloys in bentonite sand mould, Solid State Phenomena 147-149 (2009) 764-769.
[15] L.A. Dobrzański, A. Grajcar, W. Borek, Microstructure evolution of C-Mn-Si-Al-Nb high-manganese steel during the thermo-mechanical processing, Materials Science Forum 638 (2010) 3224-3229.
[16] L.A. Dobrzański, W. Borek, Thermo-mechanical treatment of Fe-Mn-(Al, Si) TRIP/TWIP steels, Archives of Civil and Mechanical Engineering 12/3 (2012) 299-304.
[17] A. Grajcar, M. Opiela, G. Fojt-Dymara, The influence of hot-working conditions on a structure of high-manganese steel, Archives of Civil and Mechanical Engineering 9/3 (2009) 49-58.
[18] L.A. Dobrzański, R. Maniara, J. Sokolowski, W. Kasprzak, M. Krupinski, Z. Brytan, Applications of the artificial intelligence methods for modeling of the ACAlSi7Cu alloy crystallization process, Journal of Materials Processing Technology 192 (2007) 582-587.
[19] T. Tański, Characteristics of hard coatings on AZ61 magnesium alloys, Journal of Mechanical Engineering 59/3 (2013) 165-174.
[20] L.A. Dobrzański, W. Borek, Hot-rolling of advanced high-manganese C-Mn-Si-Al steels, Materials Science Forum 706/709 (2012) 2053-2058.
[21] A. Grajcar, W. Borek, The thermo-mechanical processing of high-manganese austenitic TWIP-type steels, Archives of Civil and Mechanical Engineering 8/4 (2008) 29-38.