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Plastic behaviour and microstructure characterization high manganese aluminium alloyed steel for the automotive industry

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Materials

ABSTRACT

Purpose: Automotive industry constantly demands high-strength steels which are characterized by the energy absorption possibilities during a collision. Such materials may, in the future, replace the currently used conventional steels. The groups of steels which meet these criteria are the austenitic steels and austenitic-ferritic steels with high manganese content (15-30%) and high aluminium content (1-9%).

Design/methodology/approach: Susceptibility of steel to cracking at high temperatures was tested on Gleeble 3800 simulator: zero resistance temperature was determined (TZW), zero plasticity temperature was determined (TZP), plasticity reversal temperature was determined (TNP). Research was completed by determination of steel plasticity and stress applying in next stage the deformation of samples in temperature from 850 to 1175°C. This temperature range corresponding with the field of parameters of plastic processing. For samples after tension the ultimate tensile strength was determined (R_m) together with contraction (Z). Character of fractures of stretched samples was tested with the use of scanning microscope Hitachi S-4200.

Findings: The tests show that the tested steel is characterised by relatively lower temperatures in comparison with low-alloyed steels. Tested steel has high plasticity in temperature wear to temperature of plastic processing 1150-800°C.

Practical implications: The obtained steel is characterised by beneficial properties which outbalance the austenitic steels type TWIP and may be applied in vehicle construction on elements connected with safety.

Originality/value: Conducted simulation will be helpful by elaboration of technology of continuous casting and the choice of the right parameters for plastic processing of high-manganese steel with aluminium.

Keywords: Metallic alloys; Gleeble; Microstructure; Mn-Al steels; Plastic deformation

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1. Introduction

Application of new highly-resistant steel with higher formability in automotive industry leads to a significant decrease of the car weight. At the same time an improvement of safety is observed during a collision due to high energy absorption of elements produced with the use of this type of steel. High-manganese steels which are currently the objects of interest of scientific institutes are characterised by particularly high formability and high resistance [1,2]. Furthermore, the ability to absorb energy is in this case much bigger that in case of conventional steels. Manganese steels are in the class of high-manganese steels elaborated in 1882 by R. Hadfield. Carbon content in those steels is about 0.003 to 0.6% of mass. Optimum content of manganese in those steels is about 20-35% of mass [3,4]. These steels also include aluminium and silicon. The only obstacles on the road to their wider application are the difficulties connected with the process of their manufacturing and processing. Development of this group of steel, implementation in industry manufacturing and application as construction materials is conditioned by the improvement of their plasticity in room temperature and hot-plastic processing. By the right choice of chemical composition, disintegration of crystallites and application of the right thermal-plastic treatment the optimum connection of the strength properties and plastic properties can be achieved [5-8]. Silesian University of Technology has started tests on steels for automotive industry including high-manganese type steels [9-16].

The article presents the results of microstructure tests and mechanical properties of dual phase austenitic-ferritic high-manganese steel with aluminium. Tested steel includes up to 0.6% of carbon, 30% of manganese and 9% of aluminium [15,17,18].

This paper presents tests results of plasticity and liability to brittle cracking at high temperature on Gleeble simulator. The evaluation of the fracture character were conducted with the use of scanning microscopy (SEM).

On the basis of prepared characteristics the range of decreased plasticity in the process of continuous casting was defined. Those tests are important for elaboration of technology of continuous casting and rolling of this group of steels.

2. Materials and experimental method

Experimental melt with mass of about 65 kg was prepared in vacuous induction furnace type VSG-100 (PVA TePla AG company). Technology of melts conduction included: choice and preparation of the charge, process of melting the charge, process of degassing and refining of metal bath, deoxidation, regulation of the composition and temperature, process of casting.

Modifications of non-metallic inclusions were conducted with the use of mishmetal by introducing it in the quantity of 1.0 g per 1 kg of steel (0.1%) as the last addition to metal bath. Process of casting was conducted in argon atmosphere through heated intermediate ladle to a crystalliser, which was properly prepared before and cooled with water with square intersection: 100 ×100 mm and height of 1100 mm (Fig. 1). Applied crystalliser had an isolation insert in its upper part to reduce the scrap of the top of ingot caused by the presence of contraction cavity. The ingots were cooled for about 2 hours in a closed furnace in argon atmosphere in order to minimise the oxidation of steel in crystalliser. After such time air was let into the chamber and the furnace was opened. The ingots were "disarmed" in a „cold" state after a dozen or more hours from the casting process. Assumed and achieved chemical composition of steel X60MnAl30-9 is presented in Table 1.

Initial rolling was conducted on mono-cage reversible rolling stand LPS in Institute for Ferrous Metallurgy in Gliwice. The ingot was heated to the temperature of 1170°C, the rolling process was conducted in temperature range from 1150-950°C. Flat bars with thickness of 12 mm were achieved.

Castings from created melt in initial state have dendritic austenitic-ferritic microstructure (Fig. 2). Samples were etching in 10% of nital solution. In Figure 3 the microstructures of steel X60MnAl30-9 samples after hot rolling was presented, a - longitudinal section, b - transverse section. Ferrite on the longitudinal section of dual phase steels is arranges in characteristic elongated packs and its quantity in microstructure was determined on the level of 15%.

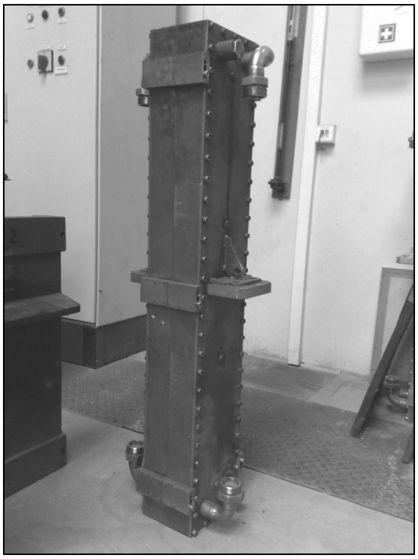

Fig. 1. Copper crystalliser cooled with water, simulating the process of continuous casting of steel

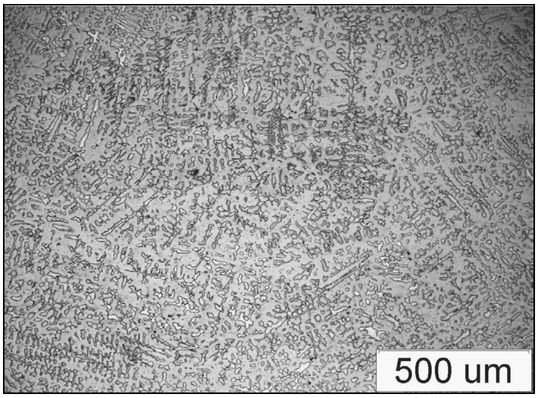

Fig. 2. Microstructure of steel X60MnAl30-9 after casting

Table 1.
Assumed and achieved chemical composition of steel type DUPLEX (X60MnAl30-9), % mas

Chemical composition	C	Mn	Si	Al	P	S	Mo	B	Ce	La	Nd	N ppm
Assumed	0.55 0.65	29.0 31.0	0.30 0.40	8.50 9.50	max. 0.025	max. 0.010	0.10 0.20	0.001 0.003	-	-	-	max. 100
Received	0.62	30.0	0.37	9.0	< 0.010	<0.006	0.15	0.002	0.004	0.002	0.002	14

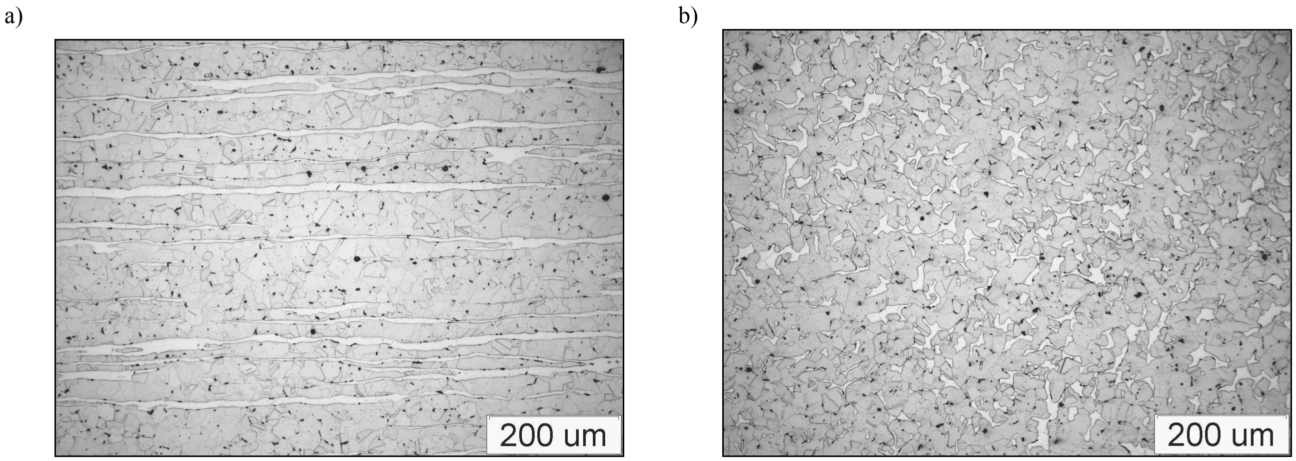

Fig. 3. Microstructure of austenitic - ferritic X60MnAl30-9 steel after hot rolling, a) longitudinal section and b) transverse section

3. High-temperature characteristics of plasticity

Susceptibility of steel to cracking at high temperatures was tested on Gleeble 3800 simulator:
zero resistance temperature was determined (TZW), zero plasticity temperature was determined (TZP), plasticity reversal temperature was determined (TNP).

Research was completed by determination of steel plasticity and stress applying in next stage the deformation of samples in temperature from 850 to 1175°C, which is temperature range corresponding with the field of parameters of plastic processing.

For samples after tensile test the ultimate strength was determined (R_m) together with area reduction (Z). Character of fractures of stretched samples was tested with the use of scanning microscope Hitachi S-4200.

Temperature of zero resistance was marked on the basis of experiment in which, after heating, a cracking of sample appears which is subject to small load after reaching the temperature of zero resistance ZW. This temperature is defined on the level of 1265°C. Next, the temperature of zero plasticity was marked (TZP). The scheme of conducted experiment is shown in Figure 4.

Samples were heated to a temperature of 1200°C with heating rate of 20°C/s, and then to the target temperature with heating rate of 1°C/s, and after a short suspension they were stretched. The highest applied temperature was 1255°C.

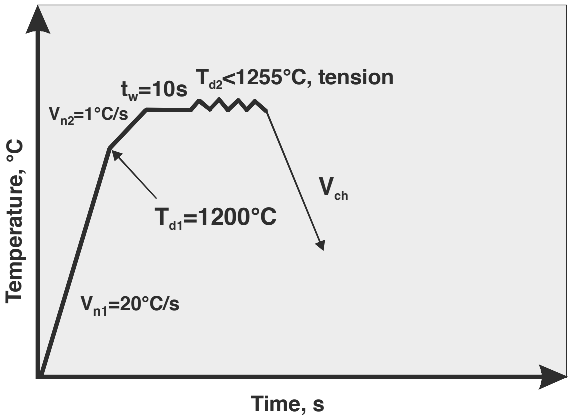

Fig. 4. Scheme of conducted experiment to determine temperature of zero plasticity (TZP)

Next, the temperature of plasticity reversal was marked (TNP). The scheme of conducted experiment is shown in Figure 5. Samples were heated to a temperature of 1200°C with heating rate of 20°C/s and next to temperature of 1255°C with heating rate of 1°C/s, according to guidelines the temperature should be 10°C lower than the zero resistance temperature. After suspension in temperature T_{d2} the temperature was decreased to the target temperature and sample was stretched. The highest applied temperature was 1225°C and was 30°C lower than zero resistance temperature.

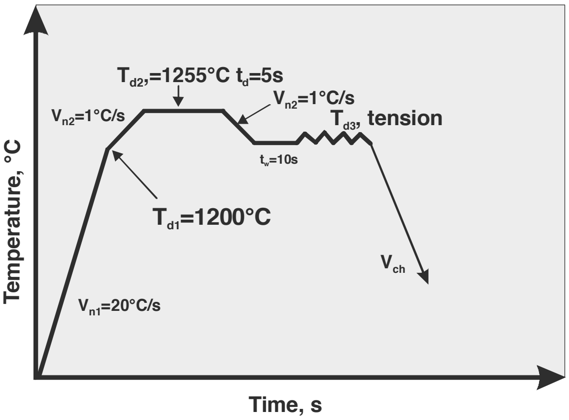

Fig. 5. Scheme of conducted experiment to determine temperature of plasticity reversal (TNP)

The outer appearance of the samples after stretching is shown in Figures 6 and 7. The samples show a differentiated contraction value dependent on the stretching temperature. In Figure 8 the influence of temperature on the area reduction Z is presented with the resistance to stretching R_m of tested steel. On the basis of contraction analysis the temperature of zero plasticity was marked and it was the temperature in which the sample did not show signs of plasticity - 1235°C. For lower temperature the contraction rose, up to over 70% in temperature of 1100°C. The temperature of plasticity reversal is lower, defined for a temperature where the stretched sample shows a contraction of 5%. The sample deformed in temperature of 1215°C was corresponding with the mentioned value of the contraction. Samples stretched in higher temperatures did not show plasticity. Lowering of the temperature of stretching caused the increase of contraction and the maximum value of about 70% was achieved in temperature of 1150°C.

In the whole tested range of variability of parameters from temperature of 800 to 1175°C, the character of fractures is trans-crystalline and ductile which proves the ductility of steel (Fig. 11a-d).

The influence of temperature on ultimate tensile strength R_m and area reduction Z are shown in Figure 9. Together with decrease of deformation temperature the increase of resistance is observed from 5.5 MPa in temperature of 1175°C to 275 MPa in temperature of 800°C. Plasticity of steel increases with decrease of temperature to 1000°C, where the achieved contraction was 84%. Further decrease of temperature causes the decrease of plasticity of tested samples which is proved by gradual decrease of contraction.

Results of fractographic tests are shown in Figure 10. Deformation of samples in 1225°C, in an experiment which aimed at determining the temperature of plasticity reversal, caused formation of inter-dendritic crackings which may signify the presence of liquid phase on crystallite boundaries (Fig. 10a). In lower temperature a cracking was found on the surface of the fracture having brittle trans-crystalline or inter-crystalline character and the samples shows contraction of 5% and plasticity reversal (Fig. 10b). Together with the further decrease of temperature the increase of plasticity is observed but the fracture has inter-crystalline character (Fig. 10 c-f).

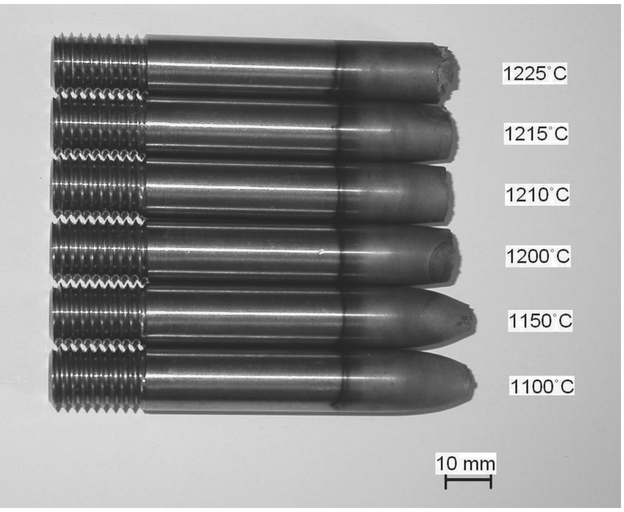

Fig. 6. Fracture of sample after tension in accordance with schematic show in Figure 5 for determining of plasticity return temperature (DRT)

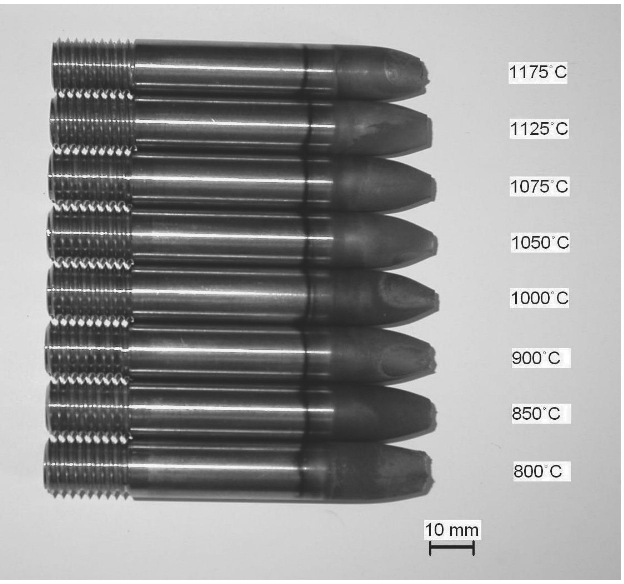

Fig. 7. Fracture of sample after hot temperature tension test in range 800°C to 1175°C

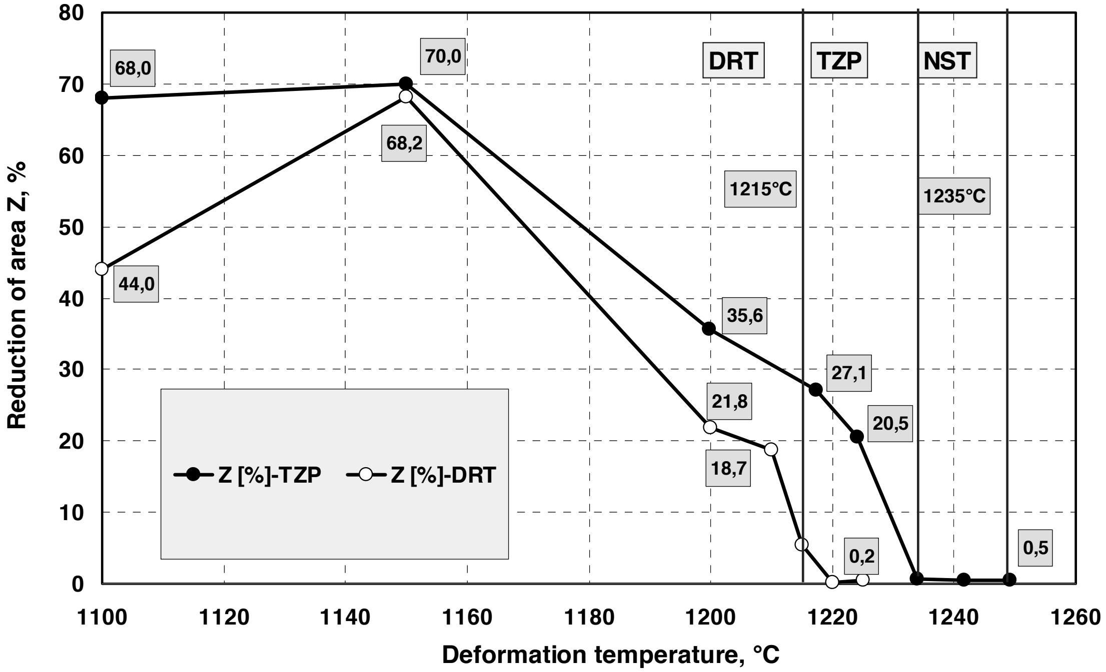

Fig. 8. Influence of temperature on the contraction Z in tested samples of steel according to assumptions presented in Figs. 4, 5

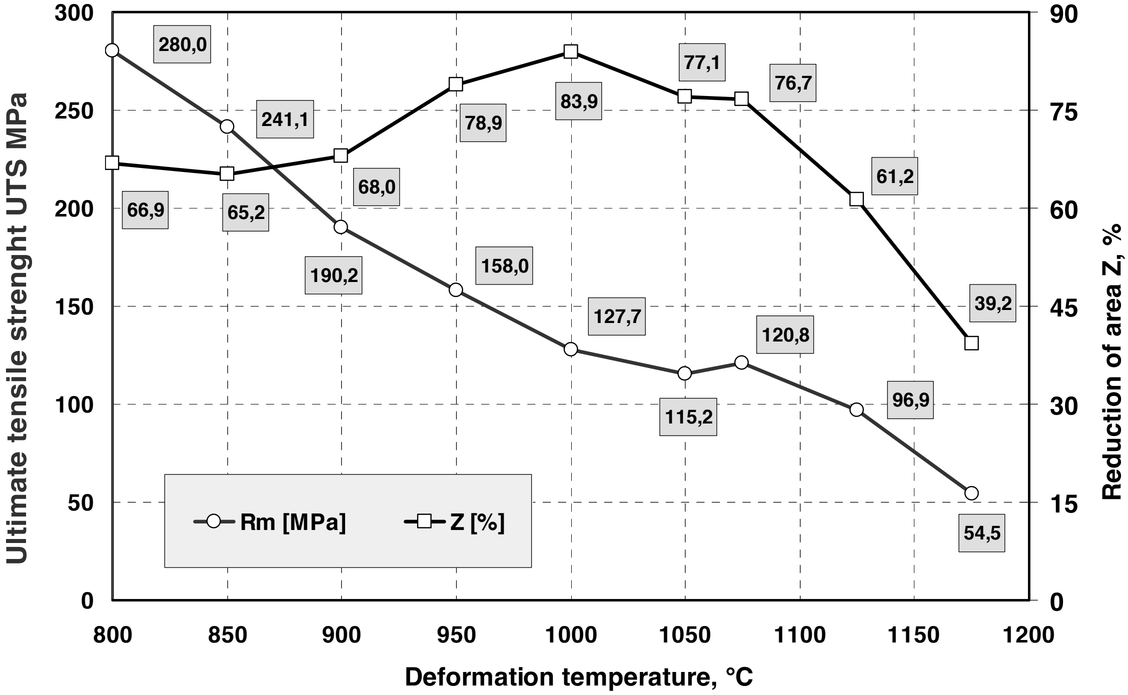

Fig. 9. Influence of temperature on ultimate tensile strength R_m [MPa] and contraction Z [%] of tested steel X60MnAl30-9

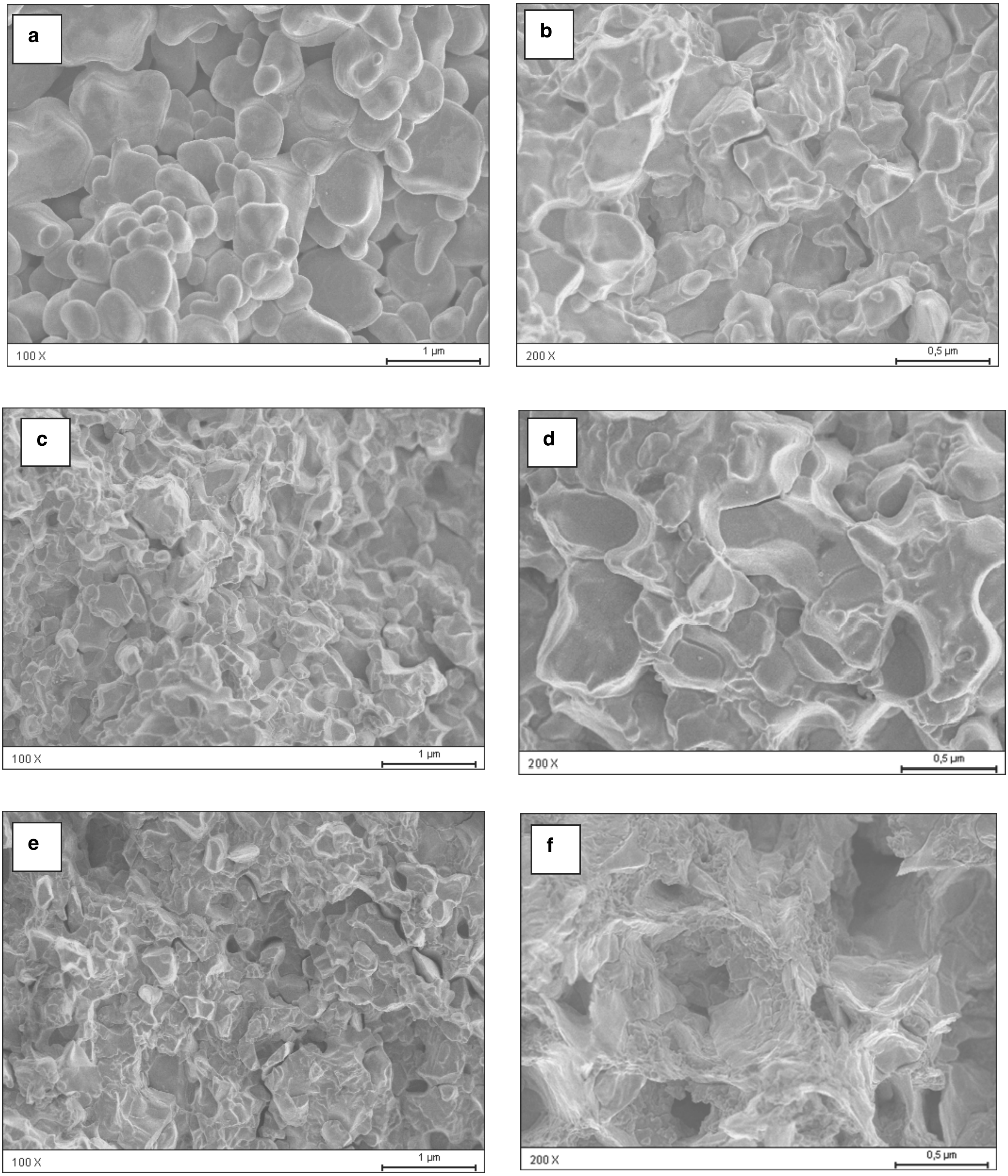

Fig. 10. Fractography of sample fractures after stretching of the samples in order to determine the temperature of plasticity reversal a) 1225°C; b) 1215°C; c, d) 1200°C; e) 1150°C; f) 1100°C

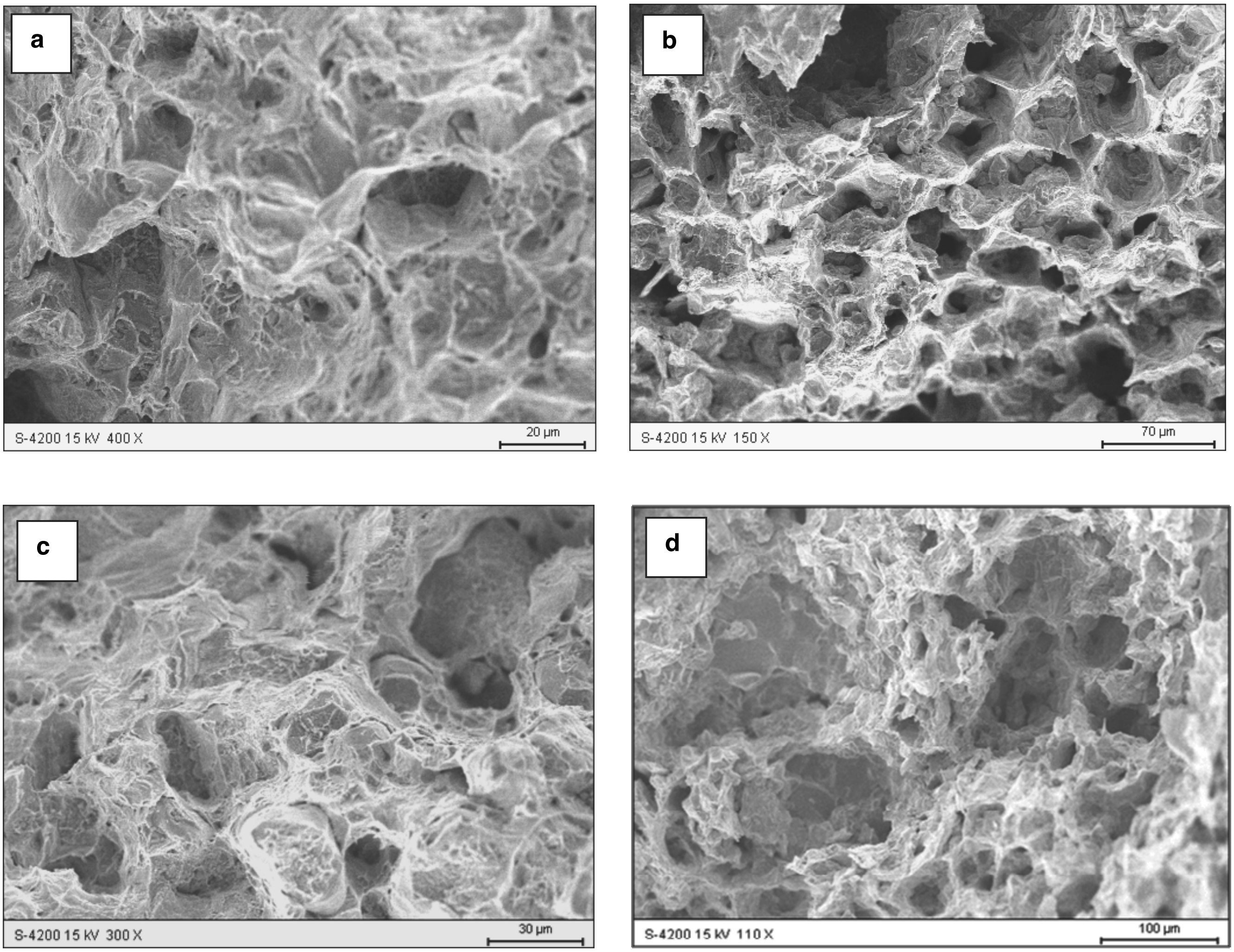

Fig. 11. Fractography of sample fractures after stretching of the samples: a) 800°C; b) 900°C; c) 1000°C; d) 1175°C

4. Conclusions

Conducted tests on high-manganese steels with aluminium, the part of which is presented with test results in this article, show the modern research trend in search for materials, for car industry, with high resistance and big ability to absorb energy.

Tested steel X60MnAl30-9 meets the criteria and after hot-plastic treatment has ultimate tensile strength of about 1000MPa and elongation A reaching 50% [17,18]. In this article the high-temperature characteristics of plasticity were analysed for austenitic-ferritic steel, which is indispensable to improve technology of manufacturing of such steel.

Microstructure of steel after rolling shows the presence of fine-grained austenite whereas the ferrite crystallites there (the amount of which is 15%) have band character. It results from the liability of austenite to recrystallisation and ferrite to recovery during high-temperature processing of heat-plastic type.

Experiments on Gleeble simulator were conducted to determine the liability of steel to cracking during stretching (Figs. 4, 5). Temperature of zero resistance was determined ($T_{(ZW)}$=1255°C), together with zero plasticity ($T_{(ZP)}$=1235°C) and plasticity reversal ($T_{(ZP)}$=1215°C) (Fig. 8). Conducted tests show that tested steel is characterised by relatively low values of marked temperatures in comparison to low-alloyed steels.

Analysis of fractures after stretching in temperature of 1225°C and higher shows the advantage of fissile cracking in dendrite area. In some areas partial melting may appear on crystallite boundaries. Low temperature values of plasticity reversal and zero plasticity show that plastic processing of the ingots should start in temperature lower than 1200°C, because of material's beneficial plasticity at that temperature.

Tested steel is characterised with high plasticity in temperature corresponding the temperature of plastic processing 1150-800°C which is proved by the values of contraction (Fig. 10). Fractures of samples have ductile character in the whole tested temperature range of stretching.

Achieved results of simulation tests will be helpful in preparation of continuous casting technology and the choice of parameters for hot-plastic treatment of high-manganese steel with aluminium.

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