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Mechanical Properties of Two Manganese Steels

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Abstract

The article is focused on thermomechanical and plastic properties of two high-manganese TRIPLEX type steels with an internal marking 1043 and 1045. Tensile tests at ambient temperature and at a temperature interval 600°C to 1100°C were performed for these heats with a different chemical composition. After the samples having been ruptured, ductility was observed which was expressed by reduction of material after the tensile test. Then the stacking fault energy was calculated and dilatation of both high-manganese steels was measured. At ambient temperature (20°C), 1043 heat featured higher tensile strength by 66MPa than 1045 heat. Microhardness was higher by 8HV0,2 for 1045 steel than for 1043 steel (203HV0,2). At 20°C, ductility only differed by 3% for the both heats. Decrease of tensile properties occurred at higher temperatures of 600 up to 1100°C. This tensile properties decrease at high temperatures is evident for most of metals. The strength level difference of the both heats in the temperature range 20°C up to 1100°C corresponded to 83 MPa, while between 600°C and 1100°C the difference was only 18 MPa. In the temperature range 600°C to 800°C, a decrease in ductility values down to 14 % (1045 heat), or 22 % (1043 heat), was noticed. This decrease was accompanied with occurrence of complex Aluminium oxides in a superposition with detected AlN particles. Further ductility decrease was only noted for 1043 heat where higher occurrence of shrinkage porosity was observed which might have contributed to a slight decrease in reduction of area values in the temperature range 900°C to 1100°C, in contrast to 1045 heat matrix.

Keywords: Theory of crystallization, Mechanical properties, High manganese steel, Reduction of area, Precipitates

1. Introduction

High manganese materials of TWIP and TRIPLEX type have proved to be highly attractive for automotive industry field. Any aluminium addition over 1 wt. % not only supports an appreciable increase in stacking fault energy, but also corrosion resistance and in the case of TRIPLEX material, where its content can be up to 12 wt. % level, it reduces matrix density significantly as well, together with manganese present [1-3]. On the other hand, higher aluminium addition means always more complications during manufacturing of the given alloy types in consequence of its high affinity for oxygen and also strong bonding to nitrogen. The basic matrix of TRIPLEX alloys is the austenitic one. During the processing process, aluminium addition supports partial transformation to ferrite. Ferrite should not exceed 15 % limit and manganese content, generally higher than in TWIP type alloys, should keep higher carbon level in the solid solution. Phase stability of both elements has also to be in accordance with Schumann [4, 5].

The same way as in the case of steels, specific characteristics of high manganese steels need to be respected during technological processing [6]. The generally known fact is that C-Mn steels feature two critical areas of plasticity characteristics and that in the low-temperature area in the range c. 600 to 800°C and at high temperatures about 900 up to 1100°C, which are expressed as reduction of area. Both of the critical zones are connected with ferritic areas along boundaries of primary austenitic grain and exclusive of precipitates, respectively inclusions, along the boundary-line of primary austenitic grains, as presented before e.g. by Mintz and Chimani [7, 8]. The above mentioned conclusions cannot be applied in full for high manganese alloys with the basic FCC structure [6].

Plasticity characteristics of high manganese alloys, TRIPLEX type in particular, have not been focused on enough yet, which is the goal of the presented work.

2. Materials and methods

For casting of high manganese materials, the Leybold-Heraeus vacuum induction furnace was used which was equipped with a rotational and Roots pump. High pure alloys can be made in it. Ingots used for internal needs of the research are of 800 g weight and 200x35x20 mm dimensions. Melting was carried out in Al88I corundum crucibles made by Capital Refractories at 5-10 Pa pressure and 12 kW output. For complete melting, 2-3 min holding time was included-in and the alloy was cast in vacuum into a cast-iron mould. The aim of the holding time was all additions to be dissolved and homogenization of the alloy. After two – three hours, the mould was pulled out and the ingot was cooling down in the ambient air. After casting, a transversal specimen was cut-off from each ingot for a control chemical analysis, results given in Table 1, and for a control metallographic analysis which was performed with the help of the OLYMPUS X70 light microscope. In the central and subsurface areas of ingots, microhardness (HV0.2) was determined using the LECO 2000 microhardness tester. After cutting-up and mechanical working of the ingots, 3 tensile tests were carried out with 4 mm diameter specimens of each heat type and for the given temperature. The follow-up measurement lied in tensile loading of the specimens at 20°C temperature and then in the range 600 to 1100°C on the INOVA electromechanical load machine with 20 kN loading force range. Heating was realized in a graphite furnace to the chosen temperature, e.g. 1100°C, in consecutive steps, and that first to 800°C with 200°C/min speed, to 970°C with 50°C/min speed and heating continued up to 1100°C with 10°C/min speed. After the required temperature being reached and 5-minute holding time, the test was started. The crossbar movement was set to 6 mm/min feed speed. The test rod temperature was measured by a Pt/PtRh thermocouple placed in a hole of the furnace casing. In order to avoid decarburization and oxidation of a specimen, the measurement was performed in the inert argon atmosphere.

After tensile tests had been carried out at room temperature and in the temperature range 600 to 1100°C, attention was focused on a microfractographic analysis which was performed with the aid of the eXEPLORER electron microscope made by ASPEX which was fitted with the energy-dispersive analyzer EDAX (SCIENTIFIC INSTRUMENTS). For both material types, stacking fault energy (SFE) was calculated according to the concept given in the work [9].

3. Experimental results and discussion

At standard temperature, the stacking fault energy corresponded to 83 $mJ.m^{-2}$ for 1043 heat and to 95 $mJ.m^{-2}$ for 1045 heat. The difference in SFE values is given by lower ferrum content in 1043 heat where manganese content could establish itself more, as observed in the work [9]. In both of the cases, there are materials in which carbon addition is, in relation to aluminium content, entirely soluble in the manganese solid solution. Microstructures of the central areas of the cast ingots from the both heats are presented in Fig.1 and 2. In 1043 heat, a porous area - shrinkage porosity – was observed, as Fig.1 shows. However, we need to point out that the specimens were taken from the ingot head where occurrence of these inhomogeneities is generally higher. Microhardness in the ingot subsurface areas and in the central part did not differ much and it ranged from 191 up to 218 HV0.2 for 1043 steel, 203 HV0.2 in average. For 1045 steel, the average value was 211 HV0.2 and limit values ranged from 198 up to 223 HV0.2. Then, 1045 material featured higher microhardness by 8 HV0.2 in average which also corresponded to the trend of strength properties determined at 20°C, as obvious from the dependence of the measured strength values at the performed testing temperatures for both types of the investigated materials shown in Fig.3. With increasing temperature, the strength decrease has been practically the same for both steel types. Only at 20°C temperature, the strength values difference of the both steels has been more evident and 1045 heat material has featured higher strength by 66 MPa than 1045 heat material. For 1043 steel, the strength decrease has corresponded to 604 MPa in the temperature range 20°C to 1100°C, while in the case of 1045 steel it has been 687 MPa. Then, the difference between the two heats has been 83 MPa, and that mainly thanks to differences at 20°C temperature.

The difference of the assessed ductility values of the both investigated heats at 20°C was 3 % and absolute values corresponded to 57 % for 1045 heat and 60 % for 1043 material. Ductility level in the range 600°C to 800°C featured a significant decrease.

Table 1.
Chemical composition of studied high manganese alloys (∗ includes Cr+Ni+V)

heat	C	Mn	Al	Si	S	P	N	Fe	∗
	[wt. %]								
1043	0.44	25.78	6.29	0.34	0.018	0.0079	0.00157	67.0	balanc.
1045	0.48	21.58	6.31	0.37	0.019	0.0083	0.00165	71.1	balanc.

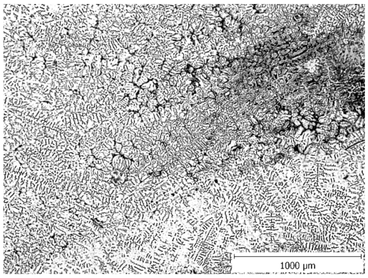

Fig. 1. Micrographs of the cast materials heat 1043

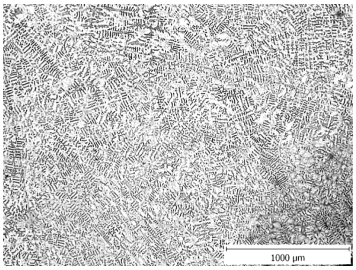

Fig. 2. Micrographs of the cast materials heat 1045

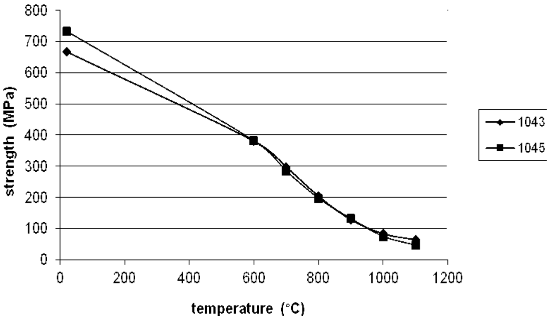

Fig. 3. Temperature dependence of strength for both investigated heats

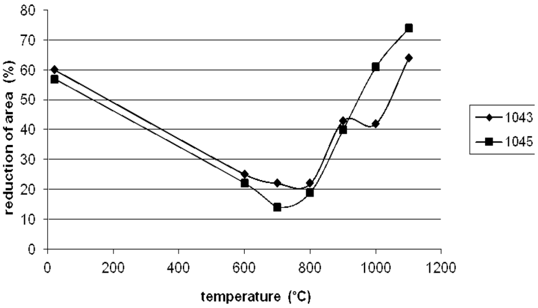

Fig. 4. Temperature dependence of reduction of area for both investigated heats

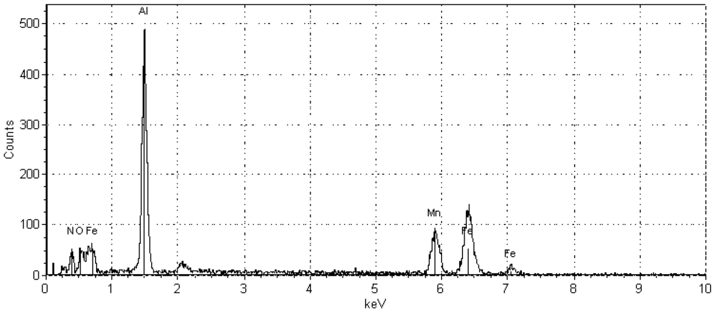

Fig. 5. RTG analysis of oxides and nitrides – steel 1043 at 700°C

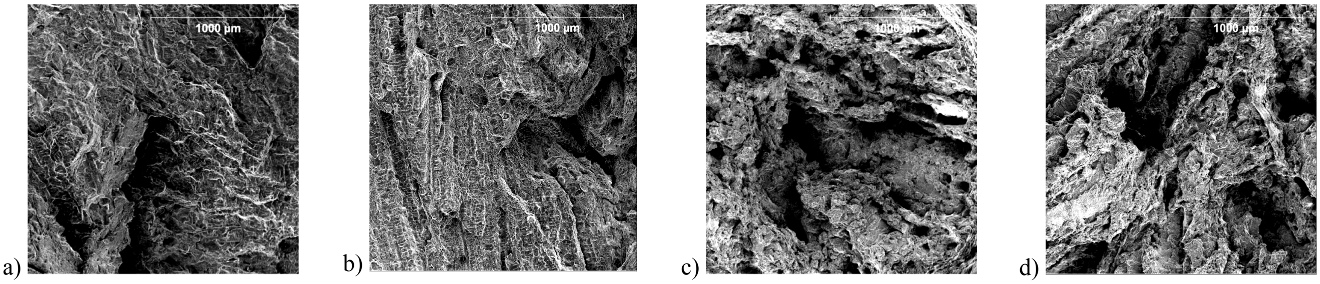

Fig. 6. Micrograph of fracture surface at 700°C a) heat 1043, b) heat 1045 and micrograph of fracture surface at 1100°C, c) heat 1043, d) 1045

For 1045 heat, ductility reached the lowest value 14 % at 700°C, while for 1043 heat, the lowest ductility decrease 22 % was moved to 800°C temperature, as shown in Fig.3. In the case of 1045 heat, from the lowest detected ductility area only its growth up to 74 % followed. However, for 1043 heat, further ductility decrease, though slight, was noted in the temperature range 900 to 1100°C and that from 43 % to 42 %, as given in Fig.4.

The investigated ductility decrease, expressed by reduction of area, cannot be related to ferrite presence in lower temperature areas, as it is for standard steel types [7, 10]. In all cases, complex particles of aluminium oxides with manganese, eventually oxide sulphides, were detected in matrixes of 1043 and 1045 heats on fracture surfaces from the tensile tests performed. Moreover, in the lower temperature range of the noticed decrease of reduction of area, aluminium nitrides were observed, though rarely, which could occur just in the given temperature range, as shown in Fig.5 [11]. Nitrogen presence was proved by the chemical analysis, as evident in Table 1. In the superposition with observed complex oxides, it could be the cause for the decreased cohesive strength of the matrix. Since for 1045 heat, where a greater decrease in reduction of area was noticed, shrinkage porosity was not found out in such an extent as for 1043 heat (see Figs.1, 2), it is not presumable that they could have influenced a more significant decrease of the detected plasticity. On the contrary, in the case of 1043 heat, where shrinkage porosity was observed in a larger extent, particularly in the central area, the decrease in reduction of area values between 900°C and 1000°C could have been caused just by this inhomogeneity because there were not found out any other marks on the fracture surfaces. The fracture surfaces of the both heats at 700°C and 1000°C temperatures are presented in Fig. 6.

4. Conclusion

Ductility (expressed as reduction of area) of two TRIPLEX type steels was investigated; at standard temperature, the calculated SFE values were 83 $mJ.m^{-2}$ (1043 heat) and 95 $mJ.m^{-2}$ (1045 heat). 1043 heat microstructure, in contrast to 1045 heat, featured higher inhomogeneity degree in the form of shrinkage porosity in the central area. Plasticity characteristics were investigated both at standard temperature, and, follow-up, in the temperature range 600°C to 1100°C.

- At standard temperature, 1043 heat (25.8 wt. % of Mn) featured higher strength values by 66 MPa than 1045 heat (21.6 wt. % of Mn). At higher temperatures, i.e. 600 up to 1100°C, a decrease in tensile properties which were practically coincident for both of the heats occurred. The strength level difference of the both heats in the temperature range 20°C to 1100°C corresponded to 83 MPa, while between 600°C and 1100°C it was only 18 MPa.

- In the temperature range 600°C to 800°C, the found-out ductility values featured a decrease in reduction of area values down to 14 % for 1045 heat, or 22 % in the case of 1043 heat. This decrease was accompanied with occurrence of complex aluminium oxides in a superposition with detected AlN particles. Further ductility decrease was detected only for 1043 heat where higher occurrence of shrinkage porosity was observed which might have contributed to a slight decrease in reduction of area values in the temperature range 900°C to 1100°C, in contrast to 1045 heat matrix. Ductility values of the both heats at 20°C differed only by 3 % for the benefit of 1043 heat.

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