PLASTICITY OF STEEL X50MnAl27-7 WITH NICKEL AND COPPER ADDITION

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Abstract
In temperature interval from 16 °C to 1000 °C, plasticity expressed by reduction of area (RA) of two high manganese steels (HMS) showing 27 wt. % of manganese, 7 wt. % of aluminium with nickel and copper addition in rate 2:1 with aim to increase the anticorrosion resistance of given material is studied. In plastic behaviour important decrease in area of 700 °C was detected. It was explained by AlN presence. Ferrite portion is studied mathematically, by use of dilatometer and differential thermal analysis (DTA). Investigation of strength properties being going down with increasing temperature completes the solution.

Keywords: TRIPLEX steel, reduction of area, strength, differential thermal analysis

1. INTRODUCTION
High manganese steels of TRIPLEX type are very attractive for automotive industry, and cryogenic applications. Thanks the lower density due to manganese and especially aluminium content also for rotating elements. Strength and plasticity expressed by reduction of area (RA) represent important parameters playing role at deformation mechanisms and defect propagation. This can be also influenced by ferrite formation in TRIPLEX steels [1, 2], which should not be higher than 15% and represents sole phase in basic fcc structure after cast and/or hot rolling. It is true the optimised chemical composition is able to ensure above mentioned requirement [3, 4]. However, aluminium content represents possible complications during manufacturing of the high manganese steels in consequence of aluminium high affinity for oxygen and also strong bonding to nitrogen. Balanced aluminium content with other key elements is also necessary [3, 5]. In standard steel materials strain rate represents significant role, because under slower strain rates diffusion processes can get ahead unlike faster strain rates supporting more favourable response of reduction of area [1, 6, 7]. In works [8, 9] hot ductility of high manganese steels showed lower reduction of area approximately at 700 °C owing to AlN formation and according sulphide contents. Kang [8] investigated TWIP high manganese steel, showing fcc matrix only and chose strain rate of 3×10⁻³ s⁻¹.

Plasticity of TRIPLEX steels was practically not investigated and the presented paper is focused on hot ductility of this steel type with nickel and copper addition with aim partially to increase strength and anticorrosion resistance. The aim of work is to show some selected mechanical properties as hot ductility and strength of the steel X50MnAl27-7.

2. EXPERIMENTAL APPROACH
For casting of high manganese materials, the Leybold-Heraeus vacuum induction furnace was used which was equipped with a rotational pump. High pure alloys can be made in it. Ingots for internal use of the research are of 800 g weight and 200x35x20 mm dimensions. Melting was carried out in corundum crucibles made by Capital Refractories at 5-10 Pa pressure and 12 kW output. For complete melting, 120-180 seconds holding time was included and the alloy was cast in vacuum into a cast-iron mould. The aim of the holding time was to secure solubility and homogenization of additions. After two-three hours, the material from mould was pulled out and the ingot was cooled down on the 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, micro-hardness (HV0.3) was determined using the LECO 2000 micro-hardness 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 led in tensile loading of the specimens at 20 °C temperature and then in the range of 600 °C 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. 1000 °C, in consecutive steps, and that first to 800 °C, to 970 °C and heating continued up to 1100 °C. The heating corresponded to 5 °C min⁻¹ and for cooling 10 °C min⁻¹ was used. Feed rate of crossbar movement was 6 mm min⁻¹. 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 of 600 °C to 1000 °C, attention was focused on a micro-fractographic analysis which was performed by use of the eXPLORER electron microscope made by ASPEX which was equipped with the energy-dispersive analyser EDAX (SCIENTIFIC INSTRUMENTS). Mathematical evaluation of ferrite presence was realized in accordance with paper [10] and differential thermal analysis was evaluated using Setaram Setsys-1750 with details presented in paper [11]. For both material types, stacking fault energy (SFE) was calculated according to the concept given in the work [12].

![Fig. 1](image)

**Fig. 1** Microstructure of steel 1 a) under surface, b) central area

3. RESULTS AND ANALYSIS

Microstructures of both steels after cast Fig. 1 and 2 represent. Under surface the both steels show some inhomogeneities in comparison with central areas. Steel 2 is finer up to 800 μm under surface, however the central areas of both steels marked differences are not observed as it from Figs. 1 and 2 follows. Using SEM some complex oxides on manganese, aluminium and eventually silicium basis were detected as a result of imperfect vacuum during cast, even when it was at the maximal level of device being at disposal. The selected chemical compositions led to comparable stacking fault energies (approx. 115 mJ cm⁻²). Defect in a form of porous and/or shrinkage porosity was not revealed. Elementary copper was not observed in matrix, even when both steels show Ni:Cu rate 2:1. It is in accordance with former work dealing with Cu solubility in steels [13]. Slightly higher nickel content in comparison with the level declared in work [9] had none influence on strength of investigated steels.
Micro-hardness of the studied steels showed not important differences between under surface and central area and on average it was at level of 198 HV0.3 (steel 1), respectively 186 HV0.3 (steel 2). It also corresponds to slightly higher carbon content in steel 1 (see Table 1). Results are comparable with steel 1109 [9], where the micro-hardness reached 213 HV0.3 on average and where also carbon contend was 0.64 wt. %. For both steels Figs. 3 and 4 summarize detected tensile strength and reduction of area in dependence on temperature. In both cases with increasing temperature strength level went down as it was also awaited. Maximal tensile strength at ambient temperature for both steels was approx. 729 MPa and the lowest level was 82.9 MPa (steel 1) and 89.6 MPa (steel 2), corresponding to drop of 647 MPa, resp. 640 MPa and to 643 MPa on average. Regarding reduction of area between 600 – 800 °C a drastic fall was detected as a result of formation of hexagonal AlN plates. Figure 5 represents an example of detected AlN particles together with lower portion of MnS particles.
Similar trend was observed in work [8], even when not so intensive, because authors tested high manganese steel of TWIP type with only 1.52 wt. % of aluminium, even when nitrogen was about 80—93 ppm. In our case aluminium was 4.7 times higher and nitrogen 1.8 lower in the worst case. Steel 1 showed the lowest reduction of area which reached 14.5 % and steel 2 demonstrated 12.6 % of RA, while Kang et al [8] reached the minimal value of 30 % with minimally 3.2 times lower sulphur content (20-60 ppm), which can the RA in superposition with nitrogen and lower aluminium content decrease.

It is known aluminium nitrides are stable and from the point of view of thermodynamic should be formed primarily. Crystallographic structure of aluminium nitrides is hexagonal and its precipitation kinetic is slow. Therefore e.g. vanadium addition could be a solution how to eliminate the aluminium nitrides formation, because vanadium nitrides show cubic structure and even when they are not so stable, precipitate much faster than aluminium nitrides particles. A higher deformation rate should be also of a use, because diffusion processes would be not so intensive unlike a small deformation rate and VN precipitates could be preferentially formed. Presented hot ductility experiments were carried out at very low feed rate of crossbeam (6 mm-min\(^{-1}\)).
Hot ductility could be also influenced by ferrite portion resp. the austenite/ferrite interface represents weaker place with different plasticity of both matrixes. The calculated volume fraction of ferrite [14] corresponded to 4.9 % (steel 1) and 4.6 % (steel 2), however using dilatometer and differential thermal analysis (DTA) no ferrite presence was detected as it Fig.6 for steel 2 demonstrates. The heating and cooling rates represented the same conditions being used during cast. It is surprising and explanation can be only sensitivity of used devices, being under detectability of such low ferrite portions and/or low deformation of material being not able under given circumstances to cause partial ferrite transformation. Carbides precipitation was also not registered, what is all right, because ultrafine carbides should only precipitate during aging process followed the deformation operations [15].

![Graph](image)

**Fig. 6** Results of a) dilatometer testing, b) DTA during heating at 5 °C/min, c) DTA during cooling at 10 °C/min

### 4. CONCLUSIONS

Hot ductility and strength of two laboratory X50MnAl27-7 steels type with nickel and copper in rate 2:1 were investigated. After cast microstructures of both steels showed the same character with finer microstructure reaching to 800 µm under surface.

In temperature interval from 16 °C to 1000 °C tensile strength with increasing temperature went down by 643 MPa from the average 729.6 MPa detected at ambient temperature. At temperature of 16 °C hot ductility was...
at level of 60 %, resp. 57 % (58.5 % on average) and the lowest value was approximately detected at 700 °C due to the aluminium nitride precipitation at low deformation (crossbar feed rate was 6 mm-min⁻¹).

In critical temperature range (600-800 °C) faster deformations could be a solution to suppress aluminium nitride precipitation, because at faster deformation rates diffusion processes could be restricted. Addition of vanadium could be of a use. Vanadium nitride does not show high stability as aluminium nitride, however precipitates faster.

Dilatometer measurement and differential thermal analysis were unsuccessful to record ferrite presence unlike mathematical calculation which showed 4.8 % of ferrite on average. Apparatus under detectability level could be elucidation. The k-carbides precipitation was not revealed, being in accord with basic assumption.

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