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PROPERTIES OF HIGH MANGANESE Fe-Mn-Al-C ALLOYS

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ABSTRACT
Materials characterized as TRIPLEX having decreased density are constituted on the following chemical composition usually: Fe-26/30Al-0.9/1.2C. Alloy microstructure is preferentially based on the FCC arrangement. Further, microstructure consists of nano-size carbides regularly dispersed in the FCC matrix and of low ferritic particle content (8% approximately). The strength level of this material is immediately connected with the solid solution strengthening forming the matrix basis. Besides this effect, it is useful to take into consideration process of its strengthening due to precipitated fine carbides (above mentioned nano-size k-carbides). The preferential effect of this material is connected with its high absorption capacity (double capacity in comparison with the conventional deep drawing steels applied in automotive industry).
The formation of uniformly arranged shear bands (SIP effect) has very important influence on the realized deformation process of discussed material and the achieved beneficial technical response. This process is also influenced due to regular distribution of nano-size k-carbides being coherent to the FCC matrix. Owing to the density decrease up to 10-12%, attained strength level (1000MPa), excellent formability and high resistance to dynamic loading (high absorption and achieved dynamic capacity) the presented high manganese material can be held for perspective type for many applications in automotive industry. Further, this material finds a perspective application in cryogenic technique (transport and storage of liquid gases) and in rotating machine elements, too.
Keywords: high manganese alloy, nano-size k-carbides, shear bands, stacking fault energy

1. INTRODUCTION

The high strength alloy constituted on the Fe-Mn-Al-C basis represents one of high manganese alloy of a new generation known as TRIPLEX commercially having the FCC microstructure type predominantly with 8 % of ferrite and 6-9 % of nano-size k-carbides being dispersed in FCC solid solution matrix [1]. Universally beneficial properties predestine the mentioned alloy for a broad application. The presented paper makes its physical-metallurgy properties more accurate from point of microstructural analysis including elucidations of reduced specific density reasons and mechanism of plastic deformation modification. The aim of paper is to summarize data concerning the TRIPLEX behaviour and to show application possibilities.

2. MICROSTRUCTURAL ANALYSIS

The alloy TRIPLEX consists of the FCC matrix characterized by annealing twins, about 8 % of ferrite and nano-size k-carbides being regularly distributed in the FCC matrix and having regularly arranged FCC structure ($L1_2$). For optimal properties reaching an additional aging application is necessary contributing to the regular k-carbides precipitation demanded for subsequent realization of specific deformation mechanism (SIP effect) [1]. Given alloy is resistant to ε-martensite transformation. Namely, positive free enthalpy austenite decomposition into ε-martensite ($\Delta G^{\gamma\rightarrow\varepsilon} = +1755$ J.mol^{-1}) is a reason of the high FCC matrix stability. Transformation into martensite is also suppressed due to relatively high stacking fault energy (SFE) being about 110 $mJ.m^{-2}$ [2]. The high SFE level is also reason of none mechanical twinning susceptibility of TRIPLEX. Recently has been found, tendency to the ε-marternsite is recorded when the SFE is lower than 15÷20 $mJ.m^{-2}$ [3]. The detected modification of the SFE level and ε-marternsite transformation resistance (HCP crystallographic lattice) is caused of Al addition (to the basic solid solution with Mn) increasing the SFE and so suppressing deformation twinning generally [4, 5].

Reduction of specific density is given due to Al and Mn solubility level in matrix and to their higher atomic radius in comparison with the Fe atomic radius. In analysed alloy at 12 % of Al and 28 % of Mn contents the FCC matrix density corresponds to the 6.5 $g.cm^{-3}$. General weight decreasing of the coexisting FCC and BCC phases in solid solution leads to a reduction of average molar weight of alloy matrix and to decreasing of unite cell molar density. Matrix lattice will be bigger, resulting from Al and Mn atomic radius (r_{Al} = 0,147 nm, r_{Mn} = 0,134 nm) in comparison with the Fe atoms (r_{Fe} = 0,126 nm).

Besides the basic FCC, the TRIPLEX microstructure consists of ferrite (6÷8 %) and nano-size k-carbides precipitating in the FCC matrix and showing regular arrangement ($L1_2$) with central situated C-atom. Unite cell can be expressed as $(FeMn)_3AlC$. Average lattice parameter level a_0 = 0.3857 nm and is mainly depended on Al content in alloy [1]. The k-carbide lattice represents figure 1.

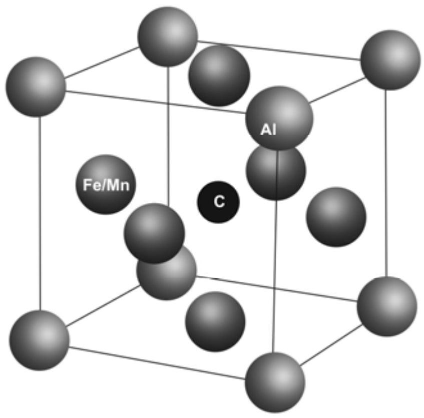

Figure 1. Unit k-carbide cell ($L1_2$ type)

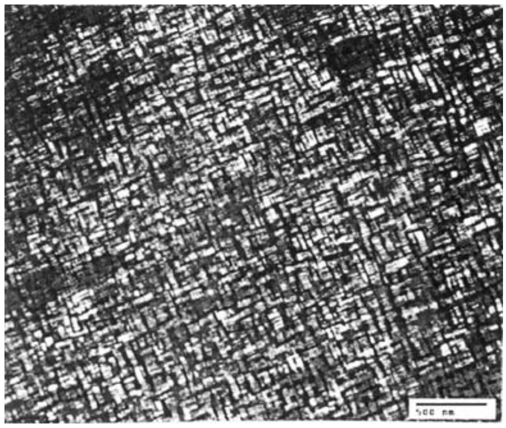

Figure 2. TEM of k-carbide (dark field)

Twinning deformation and martensite phase transformation being realized in high manganese alloys are replaced by uniformly arranged shear bands formation on the {111} planes being of the highest density within the FCC matrix. These features represent a way of important contribution to realization of homogeneous shear deformation to the large plastic elongation known as the SIP-effect (shear band induced plasticity). Due to above given positive free enthalpy value (+1755 $J.mol^{-1}$) for martensite transformation and due to relatively high SFE (around of 110 $mJ.m^{-2}$) TRIPLEX alloys are not prone to martensite transformation or to severe mechanical twinning.

The microstructural analysis of the k-carbide precipitation morphology demonstrates the regular distribution of nano-size particles of this phase coherent to the FCC matrix (presented in figure 2 – dark field – carbides of 20÷30 nm in size) [1]. This finding confirms the important role of the above discussed k-carbides distribution in matrix by the influencing the uniformly arranged shear bands contributing to the strengthening of the TRIPLEX alloy.

3. MICROSTRUCTURE AND THE MODIFIED DEFORAMTION RESPONSE

Engineering stress-strain curves of high Mn-Al TRIPLEX alloy determined at different test temperatures lying between -100 °C ÷ 400 °C reflect a realization of distinct strain hardening behaviour and different deformation mechanism in the investigated temperature interval. The best plastic strain ε_{pl} (of about 53 %) was detected at 20 °C (strength reached 1100 MPa). With the higher temperature the ε_{pl} was increasing together with the strength (at 400 °C for ε_{pl} = 19 % the strength corresponded to 700 MPa). The lower test temperature was chosen, the higher stress level was

reached together with the worst plastic strain (at -100 °C for ε_{pl} = 37 % the achieved strength was equal 1260 MPa). Results are summarized in table 1.
In order to increase the mechanical characteristics in strength level without plastic response degradation, particularly, the investigated alloy is usually subjected to thermal aging at 550 °C for different isothermal aging time being from 2.1 min. to 46 min. The obtained results are summarized in figure 3 in a form of the engineering curves of aged samples. After the prolonged aging time, the R_p (0.2) increase from 700 MPa to 1060 MPa is found (determined at room temperature). The presented stress – strain dependences are almost similar to these of the ideal elastic – plastic solid where virtual no strain hardening occurs. This result demonstrates a specific role of uniform shearing for achieving extended plastic deformation realized by moderate deformation hardening mechanism.

Table 1.Relationship between stress and strain values of TRIPLEX alloys in neck region (by tensile testing)

	Testing temperature [°C]			
	-100	**20**	**200**	**400**
Strength [MPa]	1260	1100	850	700
Plastic strain [%]	37	53	44	19

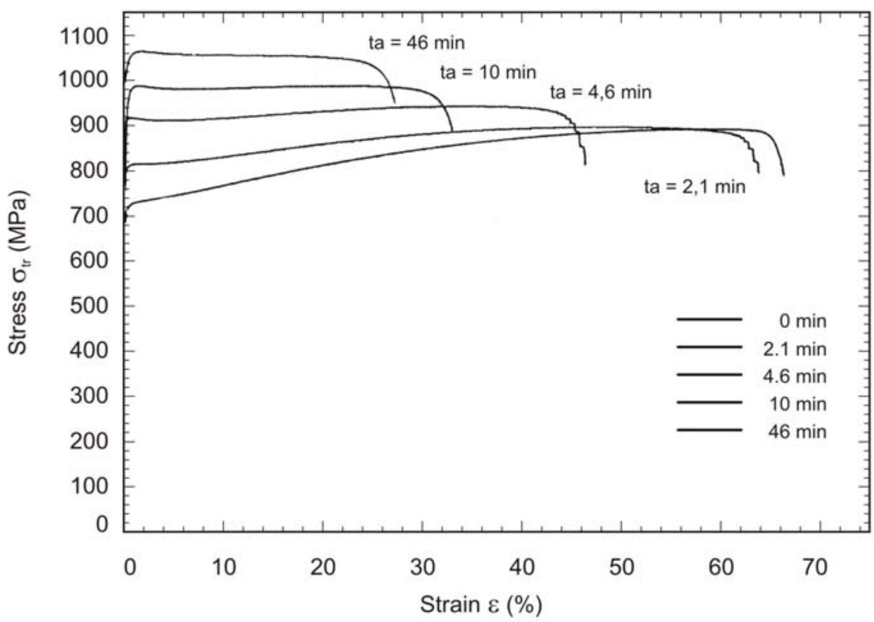

Figure 3. Engineering stress-strain curves of thermally aged TRIPLEX alloy. Aging was realized at 550 °C for different time intervals.

In figure 4, the specific energy absorptions ($E^V_{spec.}$) defined as dissipative energy per unit volume at high strain rate of $10^2 \div 10^3$ s^{-1} (at the conditions relevant to the crash modelling) of the chosen material types are compared. In set of the evaluated steels and alloys two variants of high Mn alloy and 4 steel types applied as deep drawing materials are indicated. The presented comparison shows the absorption energy of the conventional deep drawing steels is lower than the absorption level of TWIP and TRIPLEX of high Mn alloys (figure 4). The absorption capacity of these alloys is more than double in comparison with considered deep drawing steel types. These higher absorption values of the above mentioned alloys reflect a higher flow stress and beneficial plastic elongation level. In case of TRIPLEX alloy a very important role in the absorption capacity can be ascribed to the effect of severe shear band formation at high strain rate [1].

4. CONCLUSIONS

The presented paper summarizes the results achieved up to present time by the study of TRIPLEX alloys. The investigated Fe-26/30Mn-10/12Al-0.9/1.2C alloy in majority consists of the FCC microstructure possessing a dispersion of nano-size k-carbides ($L1_2$) and partially ordered α-ferrite. The chemical composition of k-carbide is $(FeMn)_3AlC$. The achieved superior properties of this alloy can be connected with effective solid solution and precipitation strengthening.

High energy absorption level ($E^V_{spec.}$) of the high Mn alloys represents their very important material parameter. Contribution of deformation mechanism to the achievement of enhanced ductility is connected with the SIP-effect (shear band induced plasticity) realization. The homogeneous shear bands formation is accompanied by dislocation glide. The realization of this mechanism depends on uniform arrangement formation of nano-size k-carbides being coherent to the FCC matrix. The TRIPLEX alloy due to the reduction in specific weight, high strength and beneficial formability inclusive the superior crash resistance has many application domains e.g. in automotive industry, in cryogenic technique, facilities for the storage and transport of liquid gases and/or for weight saving constructions generally.

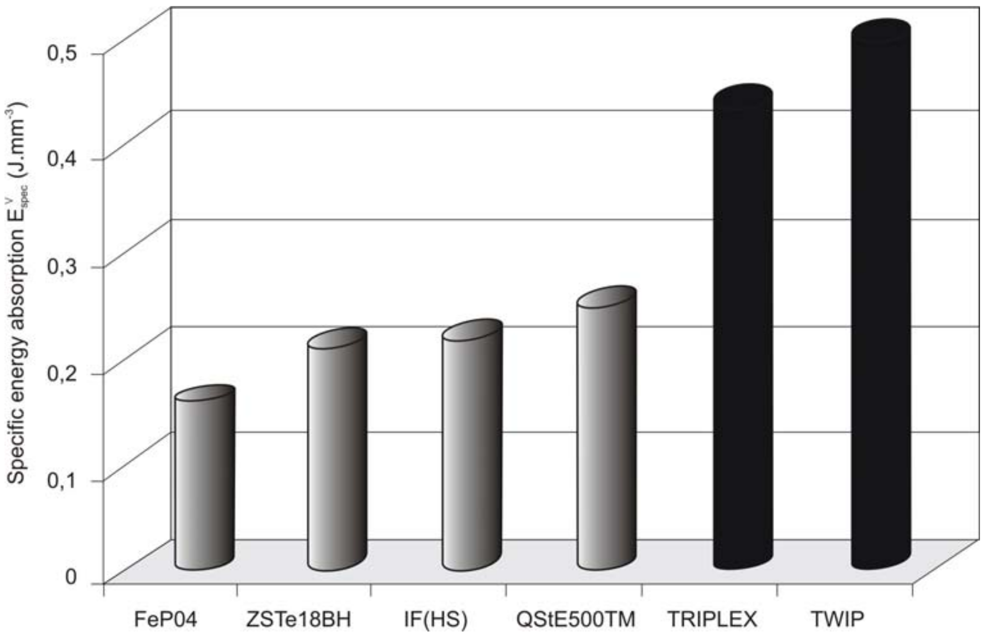

Figure 4. Specific energy absorption ($E^V_{spec.}$) of the high Mn alloys and conventional deep drawing steels (crash modelling).

5. ACKNOWLEDGEMENT

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