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CHEMICAL COMPOSITIONS AND REACHED STACKING FAULT ENERGIES VALUES

CHEMICKÁ SLOŽENÍ A DOSAŽENÉ HODNOTY ENERGIÍ VRSTEVNÝCH CHYB

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Abstract

Stacking fault energy (SFE) is an important parameter influencing deformation mechanism type realized in high manganese alloys marked as TWIP and TRIPLEX. The SFE can be connected with a) dislocation gliding both partial and full ones, further b) with gliding mechanism and deformation induced ε-martensite formation or with c) gliding mechanism in connection with twinning deformation process and/or d) gliding mechanism leading to shear bands realization. The most important chemical composition and temperature influence the SFE. The aim of work is to calculate SFE values for various chemical compositions of TWIP and TRIPLEX alloys. Those are confronted with conclusions of some other papers.

Abstrakt

Energie vrstevné chyby (SFE) je významným parametrem ovlivňujícím typ deformačního mechanismu, který se uskutečňuje ve vysokomanganových slitnách označovaných jako TWIP a TRIPLEX. SFE je spojována a) s dislokačním skluzem jak parciálních, tak i úplných dislokací, b) se skluzovým mechanismem a tvorbou deformačně indukovaného ε-martensitu nebo c) se skluzovým mechnismem ve spojení s procesem deformace dvojčatěním anebo d) se skluzovým mechnismem, který vede k realizaci smykových pásů. Chemické složení a teplota ovlivňují nejvýznamněji úroveň SFE. Cílem práce je výpočet SFE pro různá chemická složení materiálu TWIP a TRIPLEX a tyto konfrontovat se závěry některých dalších prací.

Key words: High manganese alloys, TWIP, TRIPLEX, stacking fault energy

1. Introduction

Material TWIP (twinning induced plasticity) and TRIPLEX (beside iron three elements) are two basic variants of high manganese alloys. The first one is characterized by Fe-Mn-C chemical composition, with low aluminium and silicon contents, respectively. The second material marked as TRIPLEX alloy is constituted on the basis of Fe-Mn-C-Al. The aluminium content is higher than 8 % and silicon is not suitable. Depending on high manganese type and on carbon content manganese reaches higher level than 19 wt. % usually and in this way guarantees the basic austenite microstructure of the FCC type, consequently [1-3]. The TWIP alloy microstructure is monolithic, austenitic and the sole deformation process is twins, whereas the basic FCC TRIPLEX microstructure shows annealing twins. Further, the microstructure consists of 10 ferrite wt. % in average and of the same nano-size k-carbides volume fraction, practically. The sole deformation mechanism is shear induced plasticity (so called SIP-effect) accompanied with dislocation glide. Shear bands have regular arrangement in {111} planes.

High manganese TWIP and TRIPLEX alloys represent new perspective material types, showing not only high strength property, however toughness and ductility in wide temperature interval and high specific energy absorption ($E_{spec.}$) in impact loading, simultaneously. That is reason why those materials are useful for automotive industry not only in bodywork production however for various automotive components as well. The alloys can be also applied as vessels materials for liquid gasses transport advantageously. TRIPLEX variant is also suitable for rotating elements production in consequence of lower matrix density thanks of the increased aluminium and manganese content [3-5].

2. Principles of solution

Properties of mentioned material types are strongly dependent on chemical composition determining SFE. The SFE represents an important quantity characterizing the deformation type being realized in given high manganese alloy. The TWIP alloy shows higher SFE than $18 mJ.m^{-2}$. Given level ensures deformation by mechanical twining preferentially. Movement is conditioned by slip of partial dislocations of a/6<112> leading to the stacking faults in consecutive parallel {111} planes. When the SFE is $18 mJ.m^{-2}$ and lower, ε-martensite is formed when the same dislocation glide in every second {111} plane type occurs. Deformed area shows very fine lamella and/or platelet form being of hexagonal structure (HCP). However that state is not suitable for TWIP material, because leads to its brittleness [6, 7].

With regard to basic chemical composition the TRIPLEX variant shows much higher SFE than the TWIP one. The SFE of the TRIPLEX alloy should lie in interval of $80\text{-}140 mJ.m^{-2}$ [3, 5]. The SFE can be determined using TEM of thin foils. This method is very complicated and time-consuming. In any case, SFE defines realized deformation type in matrix and that is way of its mathematical calculation for concrete chemical composition of high manganese alloys. For ternary system the SFE comes out from molar surface atoms density ρ in close arranged plane of the {111} type, from molar free enthalpy ΔG of the $\gamma \rightarrow \varepsilon$ phase transformation and from interface energy between γ (FCC) and ε (HCP) phases being marked $\sigma^{\gamma/\varepsilon}$ in eqn. (1) [6, 8]:

$$SFE = 2\rho\Delta G^{\gamma \rightarrow \varepsilon} + 2\sigma^{\gamma/\varepsilon} \quad (1)$$

For mathematical calculation further necessary parameters were also presented in some works [6, 8]. In case of quaternary system the situation is much more complicated. Consequently, for the TRIPLEX variant similar SFE calculation was applied as for TWIP materials hence for ternary Mn-C-Fe system.

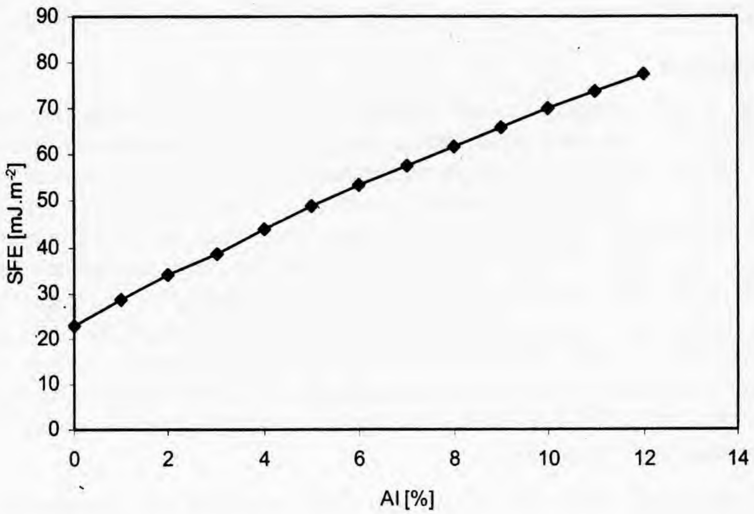

Fig. 1 Plotting of SFE vs aluminium content after approximation

High manganese TRIPLEX alloy contains aluminium whose volume fraction of 12 wt. % was subtracted from iron content. Aluminium content significantly contributes to SFE increase. The SFE values vs aluminium contents were already presented former [1, 8, 9]. In accord with those publications an approximation of mentioned dependence up to 12 wt. % of aluminium was realized and that is presented in Fig. 1. Relevant stacking fault energy values for aluminium and those calculated for the Mn-C-Fe system were added. Into evaluation of stacking fault energies changes of magnetic characteristics connected with $\gamma \rightarrow \varepsilon$ transformation (anti-ferromagnetic⇔paramagnetic process) is not included. The corresponding parameters are very low [8]. That is reason why these values are not taken into account.

3. Experimental material

For TWIP variant (high manganese Fe-Mn-C alloy types) with graded manganese content (10 – 30 wt. % as Tab. 1 demonstrates) at constant carbon level (0.65 and 1.2 wt. %) stacking fault energy evaluation was realized using mathematical calculation. Further, the same was carried out for constant manganese content (20 and 30 wt. %) and varying carbon one (0.65 - 1.2 wt. % as Tab. 2 summarises). Subsequently, stacking fault energies were calculated for constant manganese content (of 20 and 30 wt. %) with lower iron fraction reduced in 12 wt. % of aluminium content following from Fe-30Mn-(0.6–1.2)C-12Al TRIPLEX alloy evaluation. In Tab. 3, chemical compositions of evaluated variants are presented.

Table 1 Chemical composition of Fe-Mn-C alloy (wt %)

a) C=constant = 0.65 b) C=constant = 1.2						
Mn	10	14	20	23	27	30
Fe a)	89.35	85.35	79.35	76.35	72.35	69.35
Fe b)	88.80	84.80	78.80	75.80	71.80	68.80

Table 2 Chemical composition of Fe-Mn-C alloy with constant Mn content

Mn	C	Fe	Mn	C	Fe
20	0.65	79.35	30	0.65	69.35
	0.85	79.15		0.85	69.15
	1.00	79.00		1.0	69.00
	1.20	78.80		1.2	68.80

Table 3 Chemical composition of Fe-Mn-C-(12)Al alloy with constant Mn content

Mn	C	Fe	Mn	C	Fe
20	0.65	67.35	30	0.65	57.35
	0.85	67.15		0.85	57.15
	1.00	67.00		1.0	57.00
	1.20	66.80		1.2	56.80

4. Results and their analysis

Regarding the TWIP alloy (Tab. 1 shows chemical composition) calculated stacking fault energies versus manganese content for two constant carbon levels (0.65 and 1.2 wt. %) are plotted in Fig. 2. Material with 0.65 wt % carbon content and with manganese range of 10 - 30 wt. % (presented in Tab. 1) show stacking fault energies difference corresponding to 27.60mJ.m^{-2}. For the 1.2 wt. % of carbon content the similar stacking fault energies difference represents 24.42mJ.m^{-2}. How Fig. 2

shows differences between stacking fault energies of material having 0.65 and 1.2 wt. % of carbon for one manganese level are always negligible. Further, carbon will not cause any important stacking fault energy changes under given conditions regarding the TWIP variant. However, stacking fault energy will be influenced by manganese content. The higher manganese content the higher fault energy can be detected how Fig. 2 makes evident.

According former information [1] lower stacking fault energy than 18mJ.m^{-2} leads to undesirable $\gamma \rightarrow \varepsilon$-martensite transformation in case of TWIP alloy. Both evaluated TWIP variants show, the threshold level corresponds to 19 wt. % of manganese content. In comparison with Schumann's stability map after tensile testing [1] material containing 0.65 wt. % of carbon is located in possible $\gamma \rightarrow \varepsilon$ transformation area unlike alloy with 1.2 wt. % of carbon being situated on the threshold level as it follows from performed calculation. Stacking fault energy deviation represents 3.75mJ.m^{-2} and could be taken for an insignificant.

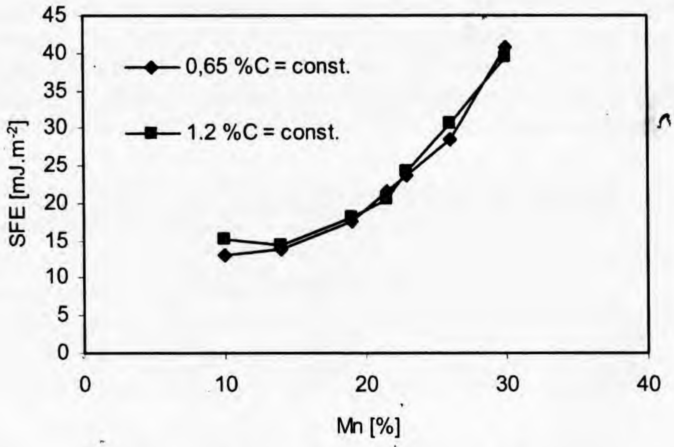

Fig. 2 Relation calculated stacking fault energy values and manganese content (TWIP alloy)

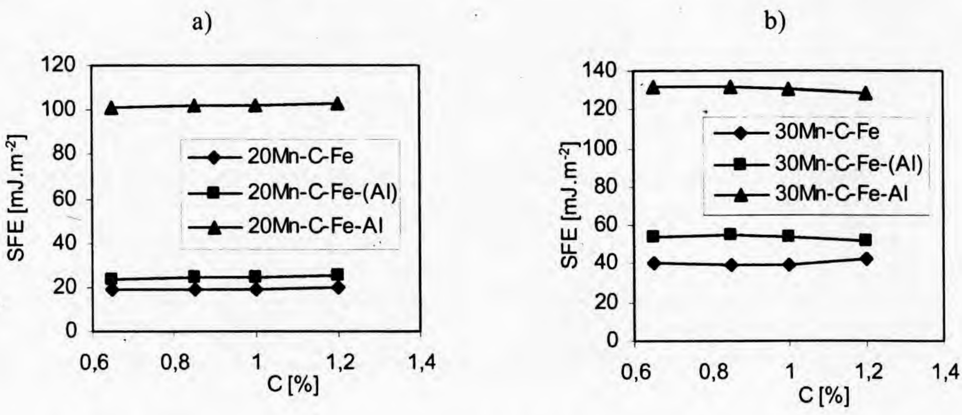

Fig. 3 Stacking fault energy vs carbon content for TWIP and TRIPLEX alloys **a)** Mn = 20 wt. % = const., **b)** Mn = 30 wt. % = const.

Stacking fault energy plotting versus carbon content with constant manganese levels (20 and 30 wt. % both for TWIP and TRIPLEX) are seen in Figs. 3a and 3b. In these pictures rhombus falls to

TWIP variant, triangle belongs TRIPLEX and the square represents TRIPLEX without aluminium influence. The same symbolism has been used in further figures. For TRIPLEX variant total stacking fault energies correspond to calculated values for ternary Fe-Mn-C system having lower iron content (decreasing represents 12 wt. % of aluminium content) being increased in aluminium stacking fault energy corresponding to 77.5mJ.m^{-2} as it follows from Fig. 1 after further trend approximation of known values [6, 7]. In case of TWIP variant increasing carbon content leads to very low stacking fault energy change. Material with 20 wt. % of manganese content and 0.65-1.2 wt. % of carbon content shows 0.6mJ.m^{-2} difference in stacking fault energies only representing 3.1% increase, whereas material having 30 wt. % of manganese content demonstrates 1.6mJ.m^{-2} difference representing 3.9% growth (detected for carbon interval of 0.65-1.2 wt. % again). The both differences are comparable, practically. The TRIPLEX variant shows a distinct dependence in detail, however in given carbon interval (0.65 - 1.2 wt. % C) the maximal stacking fault energy difference corresponds to 1.5mJ.m^{-2}, representing 1.5 % of accrual (for 20 wt % of manganese), how Fig. 3a depicts. In case of TRIPLEX with 30 wt % of manganese the difference represents 2.7mJ.m^{-2} drop corresponding to 2.0%, being seen in Fig. 3b. It is interesting, more than 1 wt % of carbon content in combination with 30 wt % of manganese one leads to slight decrease of stacking fault energy, even when the mentioned carbon content should be kept in solid solution by manganese of about 30 wt % and none carbides should be formed under conditions of ambient temperature and without deformation.

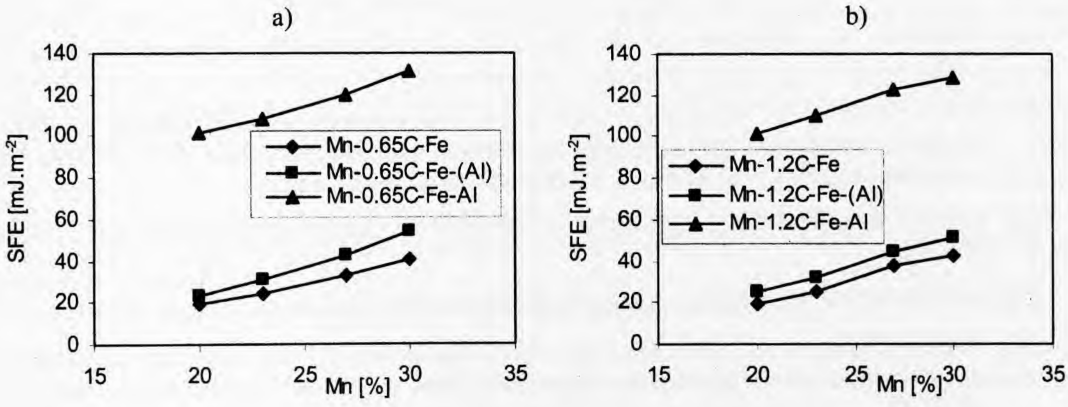

Fig. 4 Stacking fault energy vs manganese content for TWIP and TRIPLEX alloys **a)** C = 0.65 wt. % = const. **b)** C = 1.2 wt. % = const.

Further results demonstrate significant stacking fault energy susceptibility in consequence with manganese content as can be seen in Figs. 4a and 4b. In TWIP variant and for 0.65 wt % of carbon (between 20 – 30 wt % of manganese) the stacking fault energy difference amounts to 21.8mJ.m^{-2} and that equels 115.8%. For 1.2 wt % of carbon the stacking fault energy difference is 22.8mJ.m^{-2} representing 117.4% increase. Regarding the TRIPLEX alloy and the same comparisons the differences correspond to 30.6mJ.m^{-2} what equels 30.3% (lower carbon content) and 26.4mJ.m^{-2} being 25.8% (higher carbon content). Results confirm that higher manganese content and aluminium one make the stacking foult energy higher generally. Results are in good agreement with formerly presented data [9, 10].

5. Conclusion

For 20 and 30 wt % of manganese and varying carbon content of high manganese alloys stacking fault energies were calculated. Comparison of manganese, carbon and iron contents in dependence on stacking fault energy was carried out. In TWIP alloys manganese level influences stacking fault energy significantly whereas carbon and iron contents are without importance, practically. Between manganese interval content of 20 till 30 wt. % the stacking fault energy leads to its 116% increase minimally (in case of TWIP alloys), while under the same conditions the TRIPLEX alloys show the increase of about 30 % for lower carbon content and practically 26% increase for higher carbon level.

Regarding TRIPLEX alloy, minimal SFE level corresponds to 101mJ.m^{-2} (0.65 wt % of carbon and 20 wt % of manganese) and the maximal SFE one equels 132mJ.m^{-2} (0.65 wt % of carbon and 30 wt % of manganese). Aluminium and manganese contents show controlling influence on stacking fault energy level.

Acknowledgement

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References

[1]. SCHUMANN, V.H.: Neue Hütte, 1972, vol. 17, No.10, pp. 605-609.

[2]. GRÄSSER, O., FROMMEYER, G.: Material Sci. and Technology, 1998, vol. 14, pp. 1213-1216.

[3]. MAZANCOVÁ, E.: Nové typy materiálů pro automobilový průmysl-fyzikálně inženýrské vlastnosti vysokopevných materiálů legovaných manganem a slitin hydridů kovů pro uskladnění vodíku.1. vyd. Ostrava : VŠB-TU Ostrava, 2007. 74 p.

[4]. SCOTT, S., ALLAIN, M., FARAL, M., GUELTON, N.: Revue de Métallurgie, 2006, 103, pp. 294-298.

[5]. FROMMEYER, G., BRÜX, U.: Steel Research Int., 2006, vol. 77, No. 10, pp. 627-633.

[6]. MAZANCOVÁ, E., KURSA, M., MAZANEC, K.: Chosen physical metallurgical parameters of high manganese alloys and their influence evaluation. Hutnické listy, 2008, vol. LXI, No. 7, pp. 71-74.

[7]. Bracker, L., Mertens, J., Penning, J., De Cooman, B.C., Liebeherr, M., Adut, N.: Met. Trans. A, 2006, vol. 37A, No. 2, pp. 307-317.

[8]. ALLAIN, S., CHATEAU, J.-P., BOUAZIS, O., MIGOTS, S., GUELTON, N.: Mat. Sci Eng. A, 2004, vol A387-389, pp. 158-162.

[9]. SATO, K., ICHINOSE, M., HIROTSU, Y., INOUE, Y.: ISIJ Int., 1989, vol. 29, No. 10, pp. 868-877.

[10]. MAZANCOVÁ, E., MAZANEC, K.: Stacking fault energy in high manganese alloys. Materials Engineering – will be published.

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