Volume 71 • Issue 1• July 2015

Journal of Achievements in Materials and Manufacturing Engineering

International Scientific Journal published monthly by the World Academy of Materials and Manufacturing Engineering

Laboratory melting, casting and forging of manganese TWIP steel

P. Martinek*, P. Podany, M. Duchek, P. Konopik
COMTES FHT a.s., Prumyslova 995, 334 41 Dobrany, Czech Republic
Corresponding e-mail address: petr.martinek@comtesfht.cz

ABSTRACT

Purpose: The article deals with the possibility of experimental melting, casting and forging of these kinds of steel in laboratory induction melting furnace

Design/methodology/approach: The metallographic tests and Rastegaev compression test were made to describe microstructural properties and flow stress behaviour at different forging temperatures.

Findings: Results of this test show the true stress - true plastic strain diagrams which can be used as a data input to the numerical simulation of forging for example in DEFORM 3D simulation software.

Research limitations/implications: Microstructure analysis proved successful handling during all forging operations - no cracks and similar defects were observed in the microstructure.

Practical implications: Transportation industry demands high strength steels with the possibility to absorb high energy in case of a sudden collision. In recent years, so-called TWIP steels are in the focus of research of materials with high strength suitable for car bodies.

Originality/value: TFeMn TWIP is a high-strength steel concept with superior formability, which may be close to being produced industrially. High manganese TWIP steels are highly ductile, high strength Mn austenitic steels characterized by a high rate of work hardening resulting from the generation of deformation-nucleated twins.

Keywords: TWIP steels; Melting; Microstructure; Flow stress

Reference to this paper should be given in the following way:

P. Martinek, P. Podany, M. Duchek, P. Konopik, Laboratory melting, casting and forging of manganese TWIP steel, Journal of Achievements in Materials and Manufacturing Engineering 71/1 (2015) 39-44.

MANUFACTURING AND PROCESSING

1. Introduction

High-strength steels with high formability in the automotive industry lead to the substantial decrease of vehicle weight. The capability of energy absorption is also much bigger in this case in comparison with conventional steels. Such a set of features can be explained by the presence of alternative deformation mechanisms, such as: the creation of twins (TWIP effect), phase transitions produced by strain (TRIP) and plasticity induced by shear bands. [1 - 2] The dominant deformation mode in TWIP steel is dislocation glide, and the deformation-induced twins gradually reduce the effective glide distance of dislocations which results in the "Dynamical Hall-Petch effect" of delayed fracture behaviour which is connected to hydrogen embrittlement. [2-4] E- martensite is formed during plastic strain only when stacking fault energy SFE of austenite is lower than 20 mJ/m^2. The addition of aluminium into steel increases SFE and austenite stability which leads to suppressed influence on martensitic transformation. While the addition of silicon decreases SFE and allows occurring of γ-ε transformation [5]. Some researchers introduced aluminium up to 9.2 % [1]. Such concepts are beneficial to the decreasing of car body weight.

Various alloying concepts of TWIP steels have been developed in recent years. Usually, they include Al alloying in the range 0.2 – 1.5 wt. %. The importance of the Al additions cannot be underestimated and needs further attention as it results in much-improved TWIP properties. It has been shown by Jung et al. (2008) that even small additions of Al facilitated the TWIP effect and they reported that the suppression of ε-martensite was achieved after addition of 1.5 mass-% Al to a Fe-15%Mn-0.6%C steel. It strongly contributes to suppression

The chemical composition of cast heat is shown in Table 1.

Table 1.
Chemical composition (planed) [wt. %]

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Al	Ti	B	Nb	V	N
Request	0.4	0.3	19.0	Max. 0.020	Max. 0.005	2.2	Max. 0.2	Max. 0.5	Max. 0.1	1.2	Max. 0.005	Max. 0.001	Max. 0.005	Max. 0.005	100 – 200 ppm
Range	0.37 0.42	0.25 0.32	18.5 19.5	Max. 0.020	Max. 0.006	2.0 2.4	Max. 0.2	Max. 0.5	Max. 0.15	1 1.5	Max. 0.05	Max. 0.001	Max. 0.005	Max. 0.010	Max. 200 ppm

Table 2.
Acquired chemical composition [wt. %]

Element	C	Si	Mn	P	S	Cr	Ni	Mo	Cu	Al	Ti	V
wt. %	0.414	0.341	19.02	0.022	0.004	2.256	0.059	0.089	0.061	1.169	-	0.016

2. Experimental melting and casting

Experimental material was melted and cast in vacuum induction furnace. The furnace is capable of melting heat in the crucible with volumes 6 and 60 litres. Minimal operating pressure is 10 Pa, maximal is overpressure 0.2 MPa.

Table 3.
Charge composition [kg]

Item	Weight [kg]	Entry
1	340	Scrap
2	1.5	FeSi
3	20	Mn
4	10	Cr (metal)
5	9	Al
6	7	FeMn+C
7	78	FeMn

The chemical composition of cast heat was measured on optical emission spectrometer BRUKER Q4 TASMAN. The actual chemical composition of heat is shown in Table 2. Charge weight was 460 kg. Its composition is stated in Table 3. Melting temperature was set at 1600°C and operating pressure at 250 mbar of an argon atmosphere.

3. Forging

The bottom and the top part of the ingot were cut off before forging. This semi-product had following dimensions: 272 mm of a radius in the top part, 200 mm in the bottom part and 935 mm in total length. This billet was then forged to the bar with 210 mm radius. Forging took place on Universal Hydraulic Forming Press. The forging temperature was set on 1150°C. Heating to this temperature was made with a dwell for 60 min at 400°C, 45 min at 800°C and final dwell for 45 min at forging temperature. Forging was divided into 14 operations. Basic operations were following (in the order as they are stated here) –

drawing-out, upsetting, straightening, upsetting, straightening, drawing-out, straightening and the last operation was cogging. The finishing temperature of all operations was 900°C at minimum

4. Metalographic analysis

4.1. Macrostructure

The bottom part of the ingot was cut and etched for macrostructure with Aqua regia. Macrostructure is composed of rather a wide columnar zone from ingot surface. There were not visible any defects – cracks, macroinclusions.

Fig. 1. Macrostructure of ingot

4.2. Microstructure

Analysed samples from forged bar underwent standard metallographic preparation, consisted from grinding followed by polishing. Analysed sample was etched in Beraha II solution and metallographic observation was performed on light microscope NIKON EPIPHOT 200. The microscope is equipped with Imaging Software NIS Elements AR 3.2.

The microstructure is identical in the longitudinal direction and in the transversal direction. The microstructure is homogeneous and shows uniform austenitic grains with the presence of inclusions.

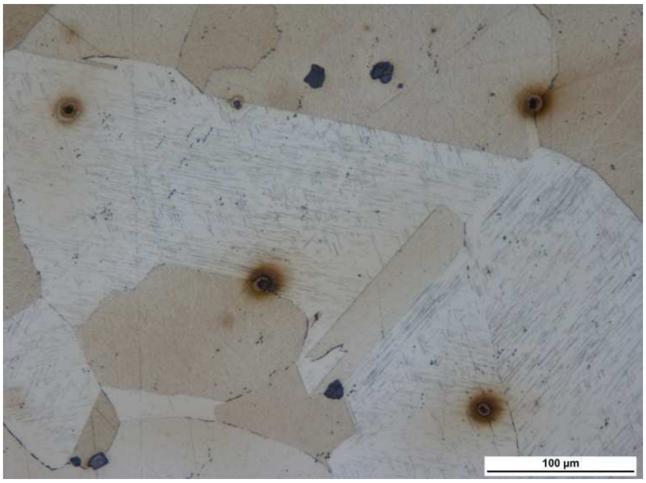


Fig. 2. Longitudinal direction, 200x

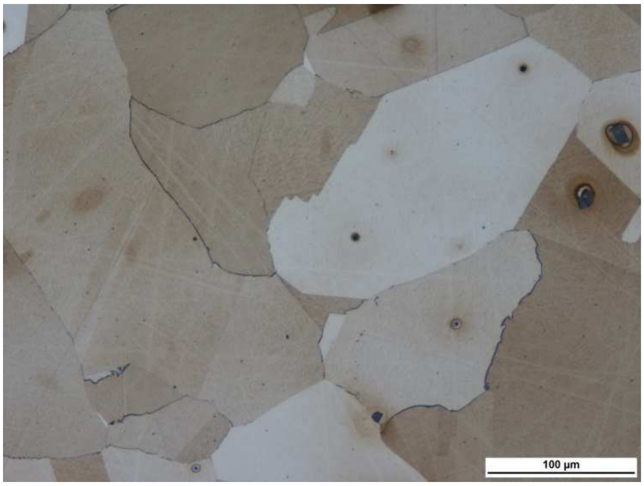


Fig. 3. Transverse direction, 200x

Fig. 4.2 Longitudinal direction, 500x

Fig. 5. Transverse direction, 500x

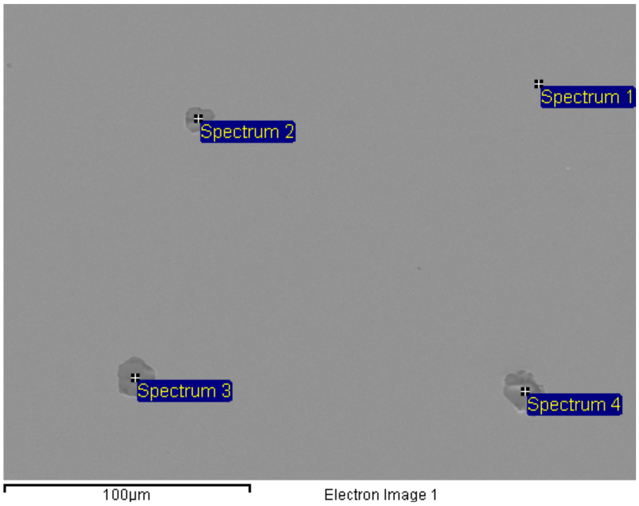


Fig. 6. Measurement locations

Table 4.
Results of EDX analysis

Spectrum	N	Al	Cr	Mn	Fe
Spectrum 1	-	1.12	2.35	20.08	76.45
Spectrum 2	13.94	82.16	-	1.14	2.76
Spectrum 3	34.36	64.45	-	-	1.19
Spectrum 4	33.93	64.72	-	-	1.35

Chemical analysis of inclusions was performed by means of electron microscope JSM 6380, equipped with EDS detector Oxford Instruments Inca x-sight. Results show the presence of aluminium nitride particles (see Fig. 6 and Table 4).

5. Rastegaev compression test

Compression tests were performed at testing temperatures 850°C, 950°C, 1050°C and 1150°C and at strain rates 3 s^{-1} and 30 s^{-1}. Rastegaev cylindrical samples were used and the ratio of height over diameter 1,5 was used, see Fig. 7. A silicon glass powder was used as a lubricant. Samples austenitization was performed in a standard laboratory furnace (these parameters are on Fig. 8). Eq. 1 and Eq. 2 were used for true stress (Kf) and true strain (φ) calculation. Evolution of the properties evaluated in relation to temperature and strain rate are summarized in Fig. 9 - 11.

Test velocities were determined by multiplication of desired strain rate and the specimen height. Compression tests were performed in constant actuator velocity mode. Therefore, in the course of tests the strain rate is not constant but is increasing with decreasing specimen height. Three samples per condition were tested. It was confirmed in previous work, that these results can be used as an input data for numerical simulation software

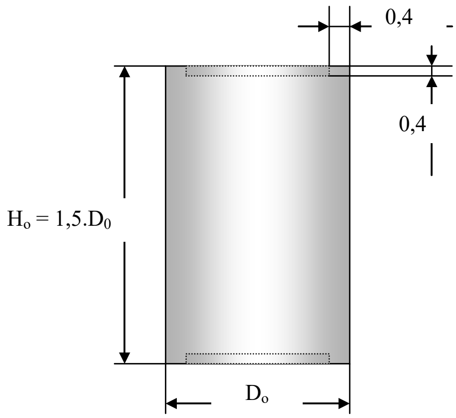


Fig. 7. Rastegaev sample geometry [7]

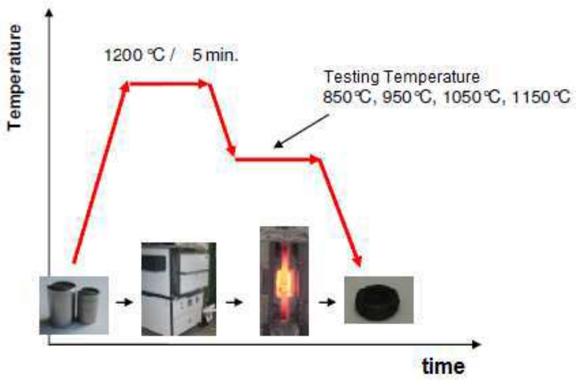
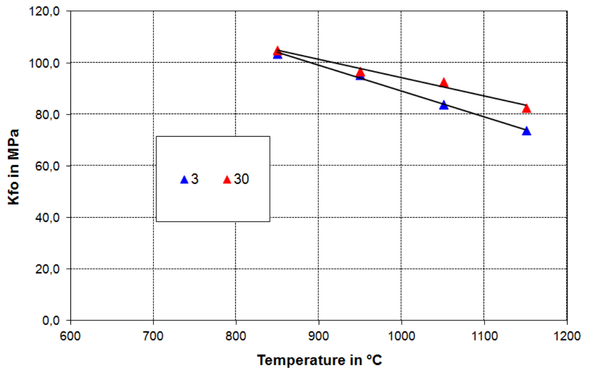


Fig. 8. Process of Rastegaev compression test

$$K_{fi} = \frac{F_i}{S_i} \tag{1}$$



$$\varphi = -\ln\left(\frac{l_i}{l_0}\right) \tag{2}$$

Fig. 9. Results of Rastegaev compression test

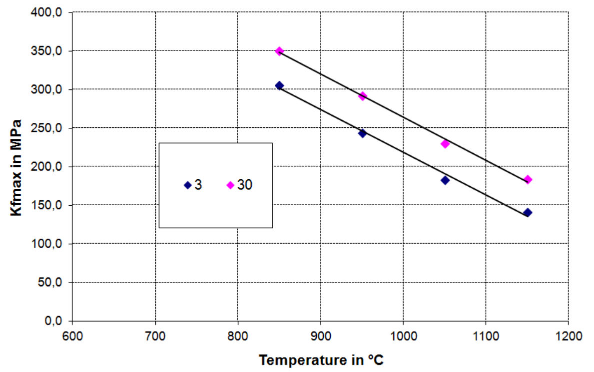


Fig. 10. Results of Rastegaev compression test

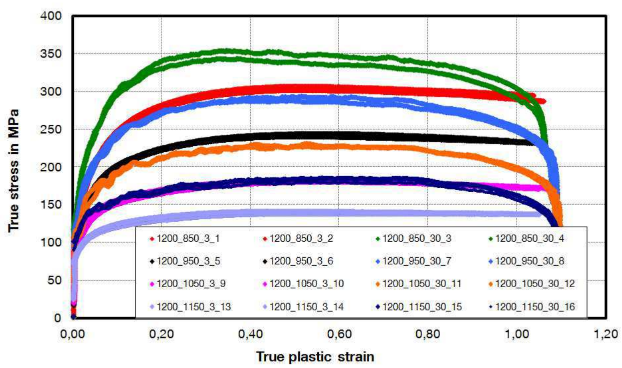


Fig. 11. True stress - true plastic strain diagram

6. Conclusions

The experimental heat was melted and cast in the laboratory furnace. Microstructure analysis proved successful handling during all forging operations - no cracks and similar defects were observed in the microstructure. Microstructure contains numerous aluminium nitrides. Rastegaev compression tests were performed at testing temperatures 850°C, 950°C, 1050°C and 1150°C and at two different strain rates. Results of this test show the true stress - true plastic strain diagrams which can be used as a data input to the numerical simulation of forging for example in DEFORM 3D simulation software.

Acknowledgements

This paper was created by project Development of West-Bohemian Centre of Materials and Metallurgy No.: LO1412, financed by the MEYS of the Czech Republic.

References

[1] G. Niewielski, D. Kuc, J. Cebulski, S. Lalik, Microstructure and selected properties of Mn-Al duplex steels, Archives of Materials Science and Engineering 47/1 (2011) 11-18.

[2] B.C. De Cooman, K.-G. Chin, J. Kim. High Mn TWIP Steels for Automotive Applications, New Trends and Developments in Automotive System Engineering, Prof. Marcello Chiaberge (Ed.), InTech, 2011, Available from: http://www.intechopen.com/-books/new-trends-αnddevelopments-in-automotive-system-engineering/high-mn-twip-steels-for-automotive-applications

[3] J.H. Ryu, S.K. Kim, C.S. Lee, D.-W. Suh, H.K.D.H. Bhadeshia. Effect of aluminium on hydrogen-induced fracture behaviour in austenitic Fe-Mn-C steel. Proceedings of the Royal Society A 469 (2012) 0458.

[4] Y. Kim, N. Kang, Y. Park, I. Choi, G. Kim, S. Kim, K. Cho, Effects of the strain induced martensite transformation on the delayed fracture for Al-added TWIP steel. Journal of the Korean Institute of Metals and Materials 46 (2008) 780–787.

[5] L.A. Dobrzański, W. Borek, Mechanical properties and microstructure of high-manganese TWIP, TRIP and TRIPLEX type steels, Journal of Achievements in

Materials and Manufacturing Engineering 55/2 (2012) 230-238.
[6] J. Džugan, M. Zemko, Input data influence on FEM simulation of steam turbine blades materials hot forming, , Materials Science Forum 773-774 (2013) 79-88.
[7] J. Dẑugan, H. MacGillivray, U. Mayer, V. Mentl, C. Watson, ESIS TC5 European round robin on dynamic compression testing, Proceedings of the 17th European Conference on Fracture 2008: Multilevel Approach to Fracture of Materials, Components and Structures 3, 2008, 2598-2605.