

MARTENSITES FORMATION DURING THERMOMECHANICAL TREATMENTS OF TWIP STEELS

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Introduction

Austenitic steels are attractive for automobile applications including press-formed parts due to their energy absorption or structural reinforcement. Austenitic FeMnCr steels have high strength, high toughness and formability because of the martensitic transformation. In this steels not only the temperature but also strain-induced non thermoelastic martensitic phase transformation takes place. This is the so-called TRIP (transformation induced plasticity) and TWIP (twinning induced plasticity) effect. TWIP steel can deform by both glide of individual dislocations and mechanical twinning [1,2].

It has been known that during plastic deformation of austenitic steels it can transform into α' martensite. Two transformation mechanisms have been observed. The first one describes the direct formation of α' martensite from austenite, while the second one involves a two-step reaction in which α' phase is formed from ϵ martensite [3, 4]. The austenite–martensite transformation depends on composition, deformation rate and temperature. During thermomechanical treatments, when a well-controlled combination of the temperature and the deformation rate is applied an extraordinary combination of microstructures can be achieved [5-8]. Because of the ratio and quantity of resulted phases determines the properties of the product an extraordinary mechanical property can be predicted after or during the treatments.

Martensite formation in manganese steels with different Cr content were investigated. Uniaxial tensile tests with different temperature and strain rate were performed to achieve thermomechanical treatments. The flow rate the hardening effect and the microstructure were investigated and compare in the different steels.

Experimental

Alloys with different compositions were produced at TU Bergakademie Freiberg. The composition of examined alloys can be seen in Table 1. The cast ingots were hot rolled to rods with diameter of 10 mm. Tensile test specimens and samples for transformation temperature examinations were machined from the rods. The

specimens were solution treated at 1000°C for 30 minutes under argon atmosphere and subsequent water quench was applied. The $\epsilon \leftrightarrow \gamma$ transformation temperatures of the quenched alloys were determined by DSC. The results are summarized in Table 2. The samples contain thermally induced martensite at the room temperature. We have showed in our previous work that it is the hexagonal ϵ martensite.

Table 1.
Composition of examined steels

	C [m%]	Mn [m%]	Cr [m%]	Si [m%]	P [m%]	S [m%]
Steel 1	0,026	17,7	2,26	0,1	0,0051	0,029
Steel 3	0,08	17,7	6,12	0,06	<0,003	0,025

Table 2.
Transformation temperatures of the examined alloys
M_s- martensite start, M_f- martensite finish, A_s- austenite start, A_f- austenite finish

	M _s [°C]	M _f [°C]	A _s [°C]	A _f [°C]
Steel 1	142	112	188	218
Steel 3	118	95	175	204

The thermomechanical treatments were achieved by uniaxial tensile test in climate chamber of the 100 kN maximal load multipurpose Instron 5982 floor installed equipment in the Laboratory of Material Testing of Institute of Physical Metallurgy, Metalforming and Nanotechnology at the University of Miskolc. The sample in the climate chamber was heated up to 300°C before the tensile tests to reach pure austenitic state of the alloys. Then it was cooled down to the test temperature. The test temperatures were selected as 200, 180, 160, 140, 125, 110, 25°C. The samples were loaded up to the fracture, but the strain rates at 140°C were also varied, the tests were interrupted at two or three less value (Table 3.).

Table 3.

	Test temperature [C]	Nominal elongation at the interrupted test [%]		
Steel 1	140	55	40	30
Steel 3	140	55	40	

After the tensile tests, specimens were cooled down to room temperature, and samples machined from the uniformly elongated part (gauge section) of the specimens for LM and SEM investigation. Mechanical parameters as tensile strength (R_m), yield stress (R_{p0.2}) were determined from tensile test. Lademo

function was used to fit the plastic deformed part of true stress-true strain curves and the derivatives of the fitted curves as a hardening curves were calculated. Grinding and mechanical polishing Nital and Beraha etchants were used for sample preparation for microscopic investigation.

Results and Discussion

The true stress and true strain curves of samples were loaded up to fracture of Steel 1 and Steel 3 are shown in Fig 1., and Fig 2. respectively. The Fig 3. shows the maximum elongation and the tensile strength in function of temperature for both alloys. It is evident that the mechanical behaviours are very sensitive to the test temperature.

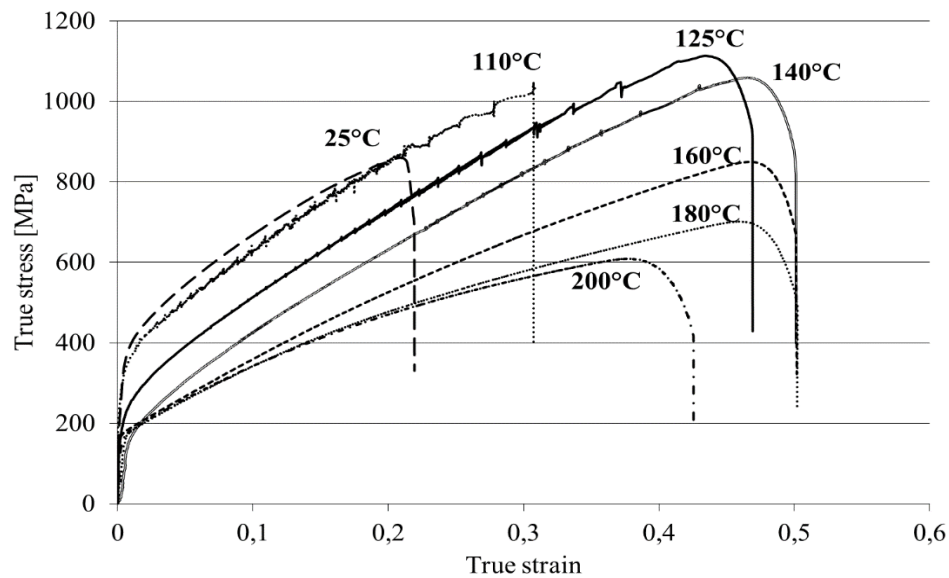


Fig 1. True stress- true strain curves of Steel 1

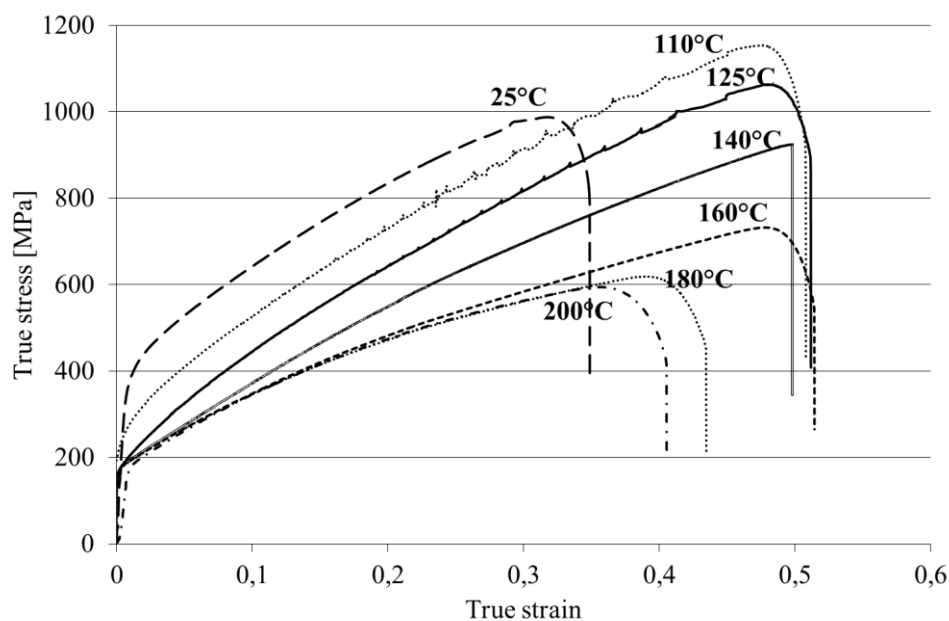


Fig 2. True stress- true strain curves of Steel 3

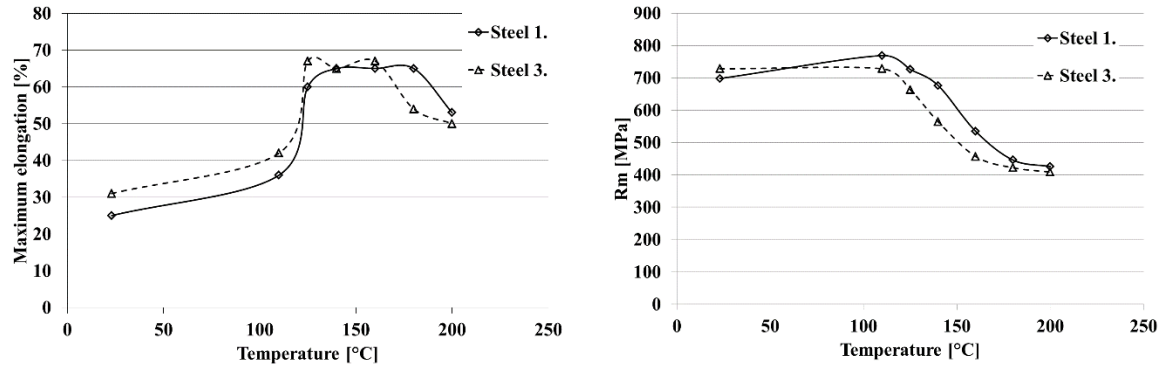


Fig 3. Tensile strength and elongation in function of temperature of steels

A sharp drop on the tensile strengths can be observed as the temperature transcends the 125°C value while the elongation remains till 180°C. Above this temperature a decrease happens in the value of elongation too. Because the slight increase in elongation (decrease in area of cross section) and unchanged value of tensile strength between room temperature and 125°C the true stress increases which also an unusual manner of this type of steels. To clarify of this attribute interrupted tensile tests were performed at 140°C. The true stress- true strain curves are shown on Fig 4. and Fig 5.

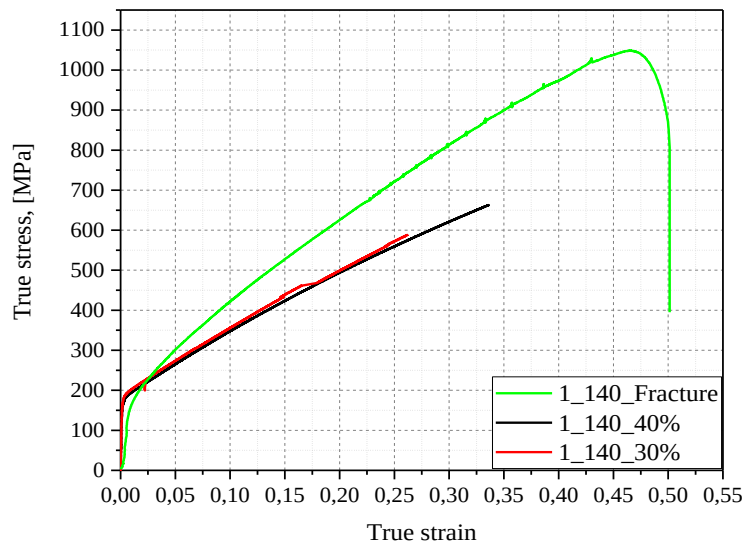


Fig 4. True stress- true strain curves of Steel 1 loaded at 140°C, two interrupted and to fracture loadings

In case of Steel 1 it is a remarkable effect that the fractured sample behaves very different from the two others. A very strong hardening effect can be observed, so a different sequence of the phase transformations can be predicted. If we see the transformation temperatures of this steel (Table 2.) we can conclude that the M_s temperature is very closed to the test temperature, so the thermally induced martensite transformation also can takes place and interacts with the strain induced transformation. Just some inhomogeneity of the climate chamber can produce such

effect. The M_s temperature of Steel 3 is much lower than 140°C , so thermally induced martensite formation before the loading is not predictable.

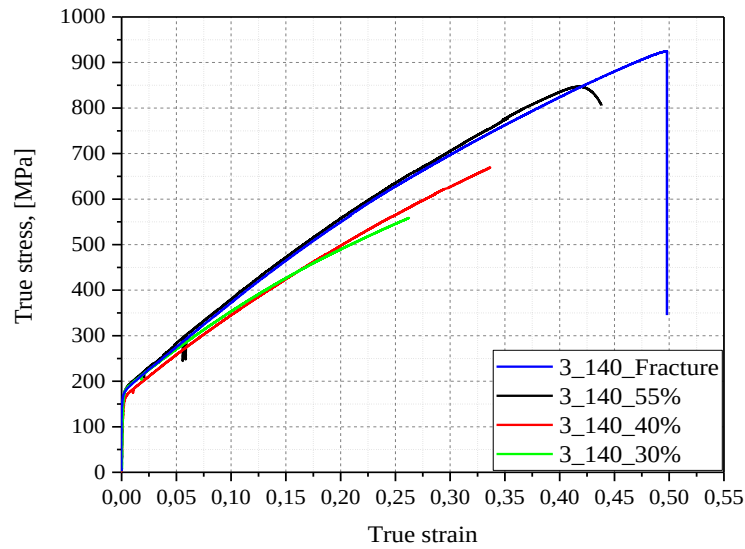


Fig 5. True stress- true strain curves of Steel 3 loaded at 140°C , three interrupted and to fracture loadings

The Fig 6. shows the hardening curves (derivate of true stress curve- $d\sigma'/d\varepsilon$) of all loaded samples at 140°C . The difference in hardening of the fractured Steel 1 sample is evident.

The microscopic examination shows very fine microstructure (Fig 7- 8.). Zig-zag type needles and twins also can observable, the evaluation of the martensite formation is also clear in function of deformation rate, but to distinguish the volume fraction of the different martensites is impossible on based of microscopic examination.

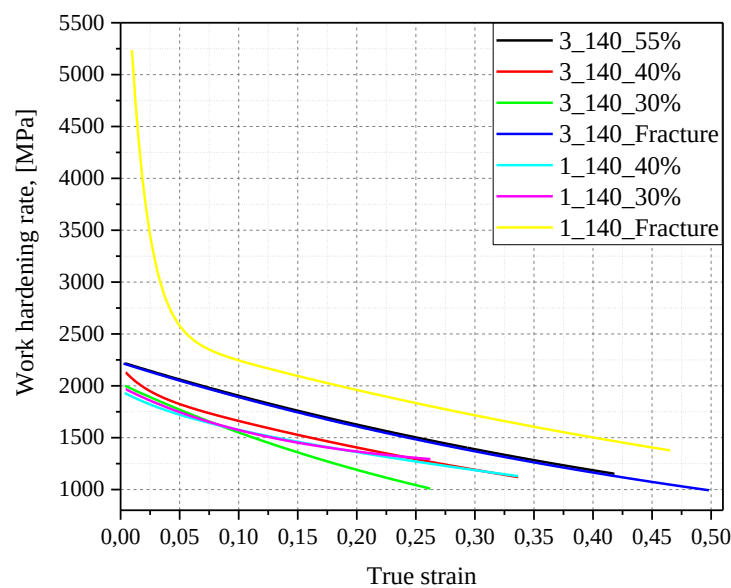
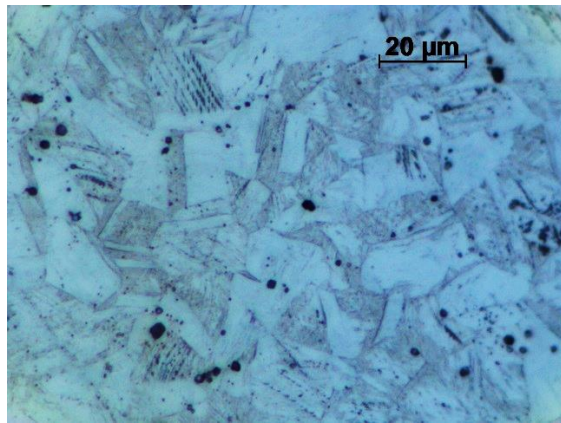
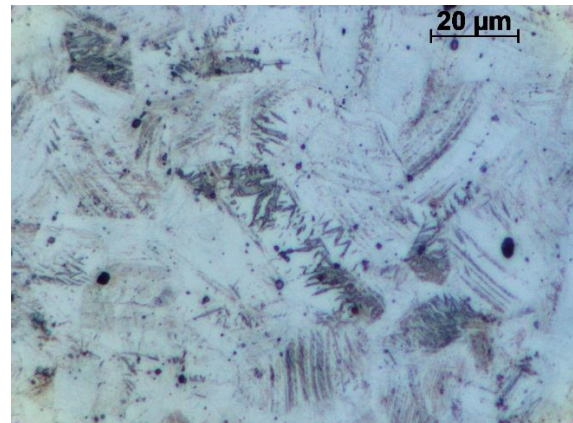


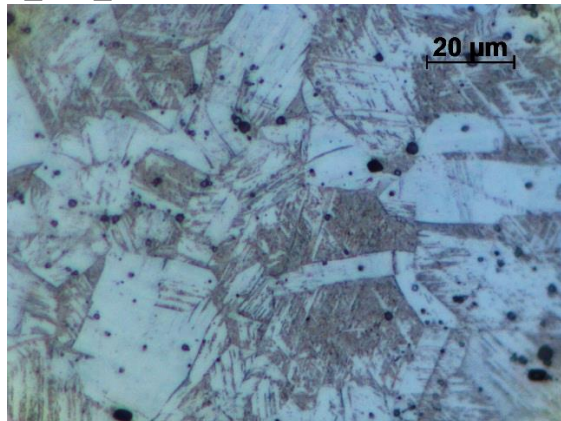
Fig 6. Hardening curves ($d\sigma'/d\varepsilon$)



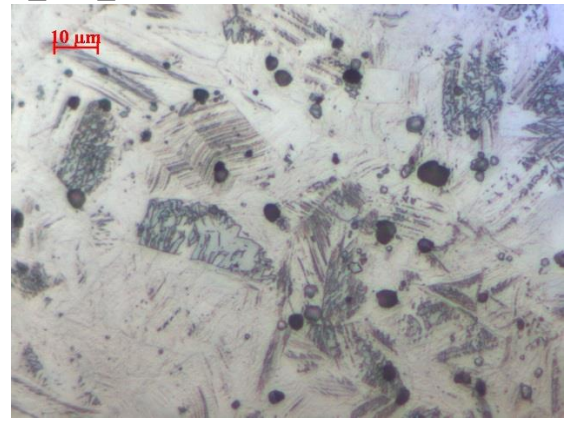
3_140_30%



3_140_40%

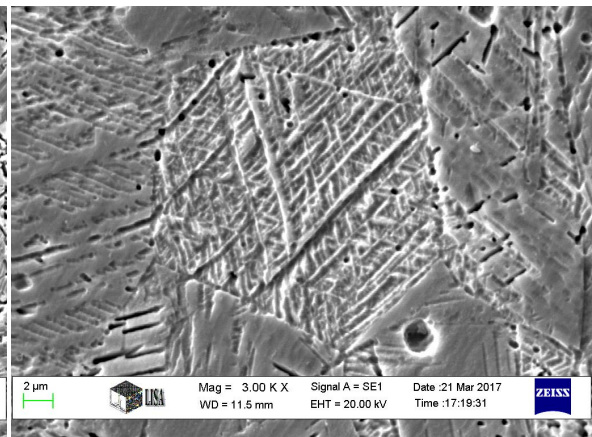
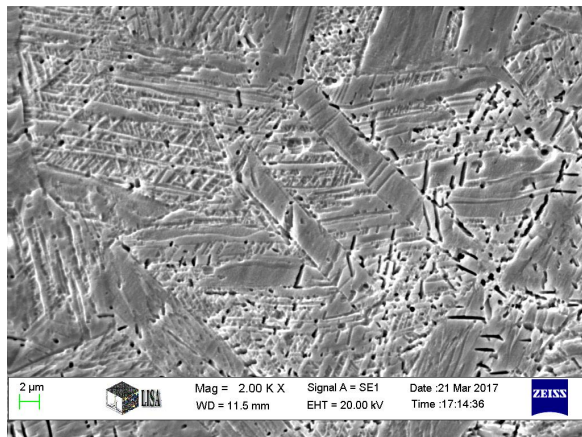


3_140_55%



3_140_fracture

Fig 7. LM images of Steel 3 loaded at 140°C up to different rate



Deformation twins in Steel 3 loaded at 140°C up to 55%

Fig 8. SEM images

Steels with various Cr content shows different behaviour in strength and strain value. The decrease in strain in function of temperature is totally different in the steel with 2% Cr and 6% Cr content. This phenomenon can be related to the presence and the quantity of martensites. It is shown the twinning induced plasticity and the strain induced transformation coexists during deformation.

Acknowledgement

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References

- [1] BHADESHIA H., HONEYCOMBE R.: **Steels, Microstructure and Properties**, Third edition, Butterworth-Heinemann publications, Great Britain, p 229. ISBN 0-7506-8084-9
- [2] PLA-FERRAND R., SÁNCHEZ-CABALLERO S., SELLES M.A., MARTÍNEZ-SANZ A.V.: **TWIP/TRIP steels. Future trends in automotive industries**, Fascicle of Management and Technological Engineering, Volume X (XX) 2011, NR3
- [3] DASH J., OTTE H.M.: **The martensite transformation in stainless steel**, Acta Materialia 11 (1963) 1169-1178
- [4] HAN H.N., LEE G.G., OH C., LEE T., KIM S.: **A model for deformation behaviour and mechanically induced martensitic transformation of metastable austenitic steel**, Acta Materialia 52 (2004) 5203-5214
- [5] Koyama M., Sawaguchi T., Lee T., Soo Lee C., Tsuzaki K.: **Work hardening associated with ϵ -martensitic deformation twinning and dynamic strain aging in Fe-17Mn-0.6C and Fe-17Mn-0.8C TWIP steels**, Materials Science and Engineering A 528 (2011) 7310-7316
- [6] Tang Z.Y., Misra R.D.K., Ma M., Zan N., Wu Z.Q., Ding H.: **Deformation twinning and martensitic transformation and dynamic mechanical properties in Fe-0.07C-23Mn-3.1Si-2.8Al TRIP/TWIP steel**, Materials Science and Engineering A 624 (2015) 186-192
- [7] Xu S., Ruan D., Beynon J.H., Rong Y.: **Dynamic tensile behaviour of TWIP steel under intermediate strain rate loading**, Materials Science and Engineering A 573 (2013) 132-140
- [8] Shterner V., Timokhina I.B., Beladi H.: **On the work-hardening behaviour of a high manganese TWIP steel at different deformation temperatures**, Materials Science and Engineering A 669 (2016) 437-446