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Strain induced martensitic transformations in FeMnCr TWIP steel

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Abstract. Martensitic transformations in FeMnCr steel were investigated by the thermomechanical treatments achieved by uniaxial tensile tests with different temperature and strain rate. During thermomechanical treatments, when a well-controlled combination of the temperature and the deformation rate is applied an extraordinary combination of microstructures for a strain induced α' and/or ε martensite and thermally induced ε martensite can be achieved in this steel. The volume fractions of the phases after tested at different temperatures were determined and the phase ratios of individual martensite were observed.

1. Introduction

Austenitic steels are best suited for automobile applications including press-formed parts because of their energy absorption or structural reinforcement. Austenitic FeMnCr steels have high strength, high toughness and formability because of the martensitic transformation. In these steels the temperature as well as 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 austenite 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. The austenite–martensite transformation depends on composition, deformation rate and temperature [3, 4]. 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. Because of the ratio and quality of resulted phases determines the properties of the product an extraordinary mechanical property can be predicted after or during the treatments [5–8].

Although many articles/research papers have been written/published in the past on the Martensitic transformations in the TWIP/TRIP steels, the novelty of this project was to present the complex martensitic behaviour in the High Cr (Chromium) Austenitic FeMnCr TWIP steels, which is quite different from various other martensitic transformations which consists of two phases rather than the three phases system as observed in this work. The presence of Alpha and Epsilon martensites along with Austenite at the same time makes it complicated to determine the mechanical properties of such type of steels. In this work the



main task was to determine the volume fraction (composition) of the martensites when the test temperature and percentage of deformation were varied.

2. Experimental approach

Alloy was produced at TU Bergakademie Freiberg. The composition of examined alloy 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 $\varepsilon \leftrightarrow \gamma$ transformation temperatures of the quenched alloy was determined by DSC (Differential Scanning Calorimetry) can be seen in Table 2.

Table 1. Composition of Steel, [wt %]

	C	Mn	Cr	Si	P	S
Steel 1	0.026	17.7	2.26	0.1	0.0051	0.029

Table 2. Martensite and Austenite start-finish temperatures [°C]

	A _s	A _f	M _s	M _f
Steel 1	194	224	149	121

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, Metal forming and Nanotechnology at the University of Miskolc. The samples in the climate chamber were heated up to 300 °C (in a separate furnace for achieving homogenization) before the tensile tests to reach pure austenitic state of the alloy. Then it was cooled down to the test temperature (Cooling substantially takes place inside the climate chamber). The test temperatures were selected as 200, 180, 160, 140, 125, 110 and 25°C. The samples were loaded up to the fracture, but the strain at 125 °C, 140 °C and 180 °C were also varied, the tests were interrupted at two smaller 0,25 and 0,35 true strain value.

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 (Light Optical Microscopy) and SEM (Scanning Electron Microscopy) investigation. Grinding and mechanical polishing by Nital and Beraha etchants were used for sample preparation for microscopic investigation. The volume fraction of phases was determined on the cross section of sample. Full intensity profile fit XRD (X-Ray Diffractometry) methods was used.

3. Results and discussion

The true stress-true strain curves of fractured samples at different temperatures are shown on figure 1. 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. Whereas, at the lower temperatures i.e. between the room temperature and 125 °C, a slight increase in the elongation (decrease in cross-section area) and increase in the true stress without any change in the tensile strength is seen which also is an unusual manner of this type of steels.

To clarify of this attribute interrupted tensile tests were performed at 125 °C 140 °C and 180 °C. The true stress-true strain curves are shown on figure 2 - 4.

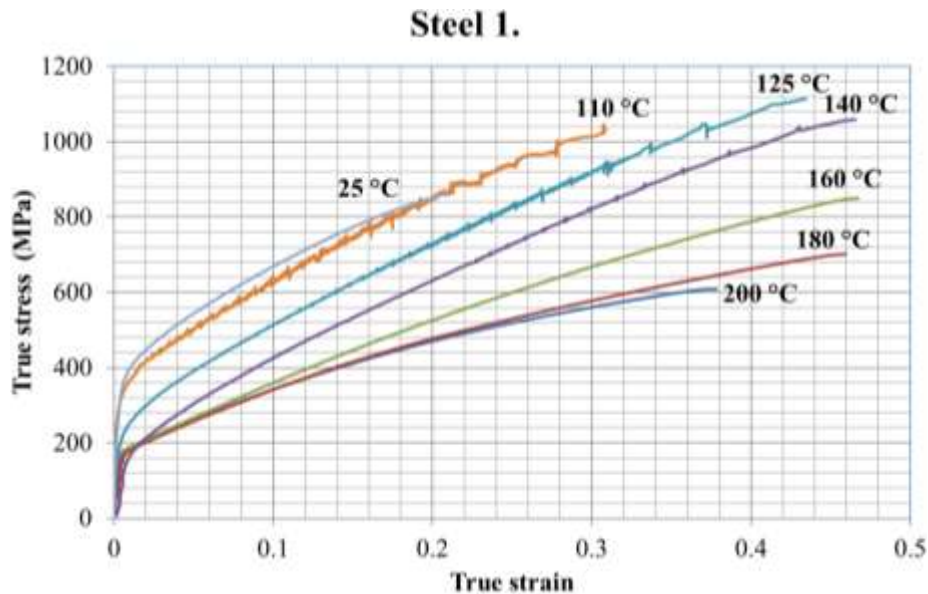


Figure 1 True stress- true strain curves of Steel 1 fractured at different temperature

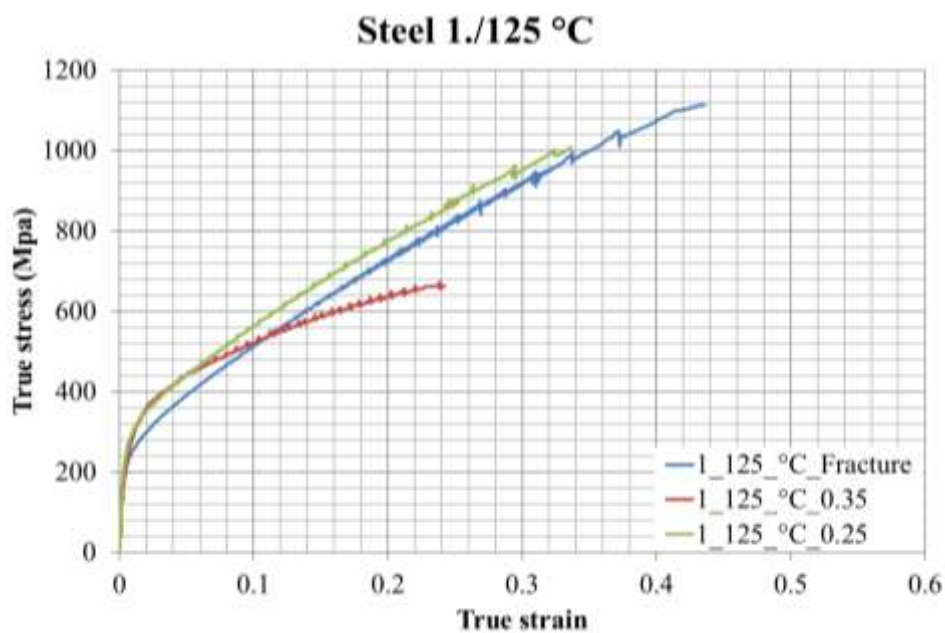


Figure 2. True stress-true strain curves of Steel 1 loaded at 125 °C, two interrupted and one up to fracture

In case of 180 °C the curves are identical. It is a remarkable effect that the fractured sample behaves very different from the two others at 140 °C. 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 take place and interacts with the strain induced transformation. Just some thermal inhomogeneity of the climate chamber can produce such effect. The M_s temperature is much lower than 180 °C, so thermally induced martensite formation before the loading is not predictable in that case. The microscopic examination shows very fine microstructure (figure 5 and 6).

Zig-zag type needles and twins are also 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.

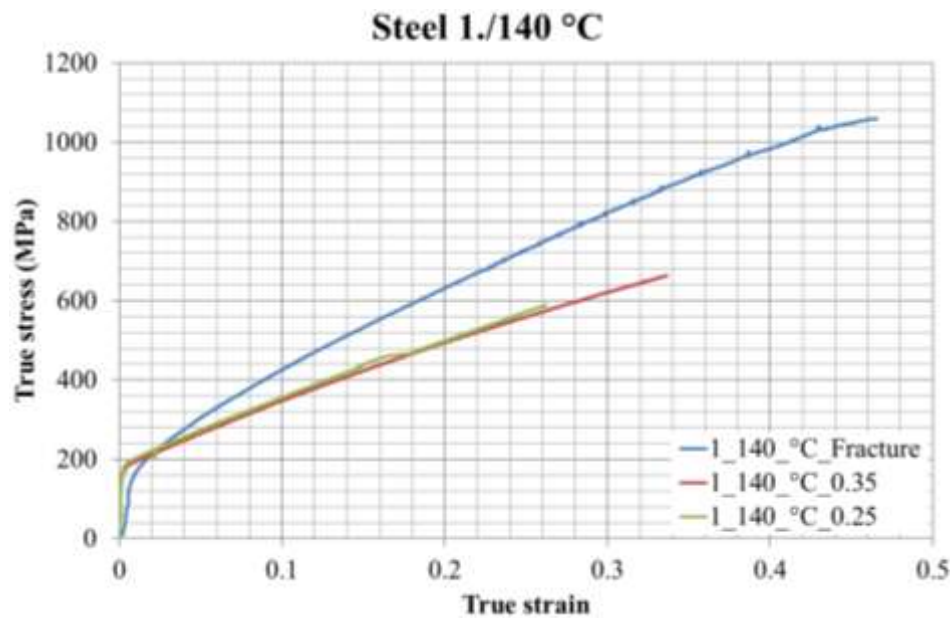


Figure 3. True stress-true strain curves of Steel 1 loaded at 140 °C, two interrupted and up to fracture

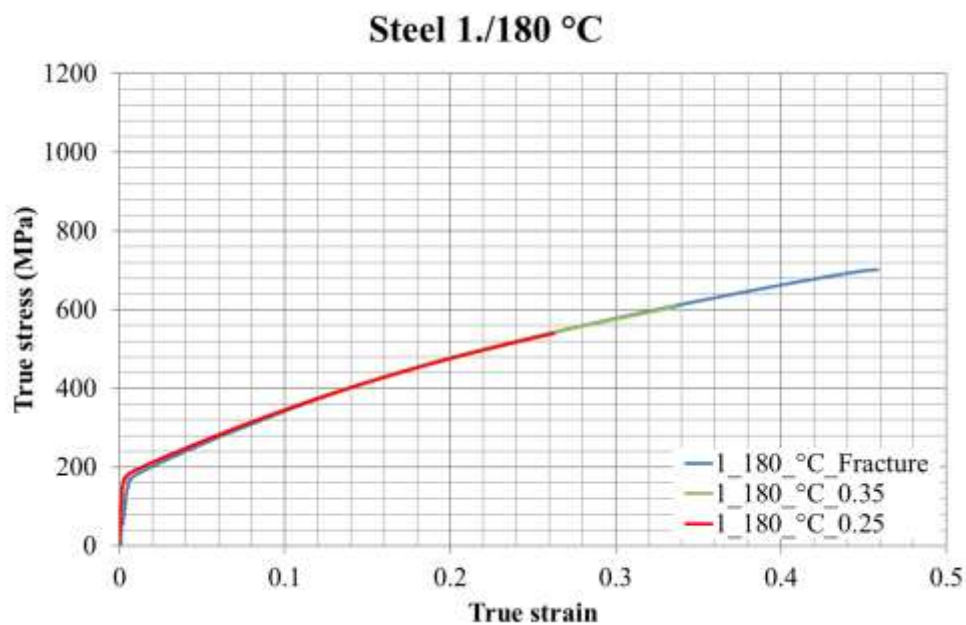


Figure 4. True stress-true strain curves of Steel 1 loaded at 180 °C, two interrupted and up to fracture

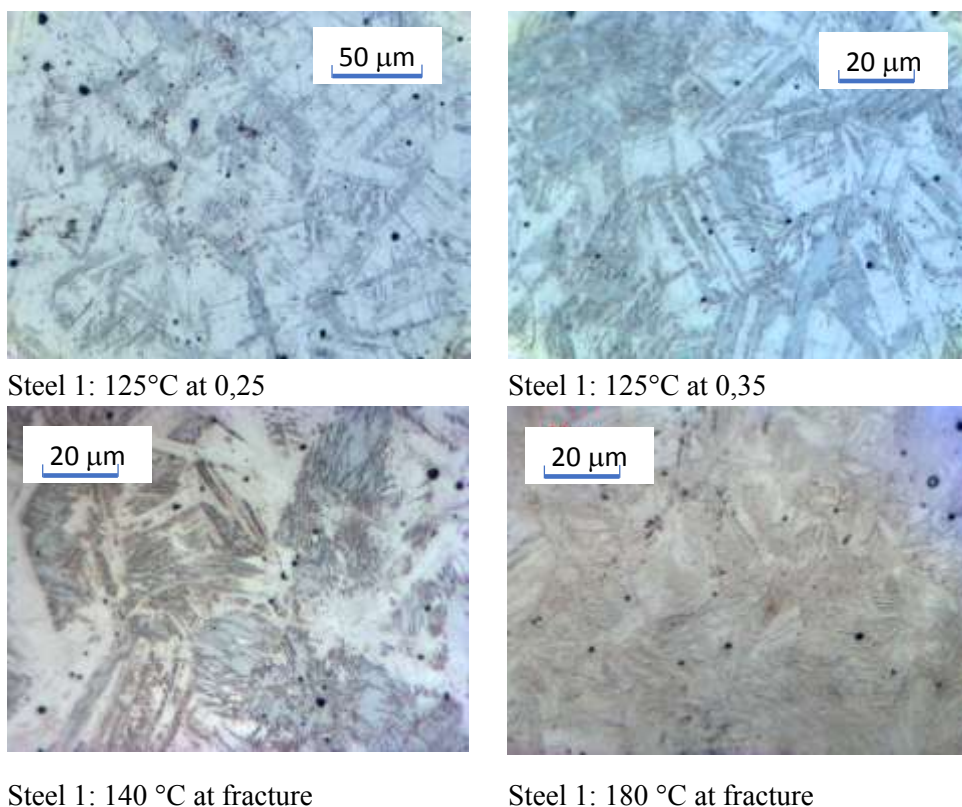


Figure 5. LM (Light optical microscopy) images of Steel loaded at 125 °C, 140 °C and 180 °C

As it was seen the steel tested at different temperature shows different behaviour in strength and strain value. This phenomenon can be related to the presence and the quantity of martensites. To identify the different phases XRD investigation was done. The figure 7 shows the XRD diffractograms of Steel 1 loaded at different temperatures and strain rate. The result of the volume fraction calculations is introduced at figure 8 and 9. It is shown the twining induced plasticity and the strain induced transformation coexists during deformation.

On the three highest temperature the volume fraction of the ϵ phase is lower after thermomechanical treatment than in the “as quenched” sample, so one can conclude in these samples the ϵ martensite forms during the subsequent cooling of tensile test and its volume is less because the plastic deformation stabilizes the austenite. This statement is confirmed by the figure 4 where the curves almost perfectly cover each other, so only the austenite phase suffer the transformation. On the lower isotherms significant differences can be observe on the tendency of curves what refer possible inhomogeneous phase constitutions. The volume fraction of ϵ martensite is higher at lower temperatures, so the formation of strain induced ϵ martensite is obvious. We have already shown in previous investigations the α' martensite can be only strain induced above the room temperature because M_s is below room temperature [9] [10]. It is in harmony with the results of partially loaded samples on the isotherm of 125 °C where the volume fraction is increasing by the strain rate. It can be declared that the volume fraction of the ϵ martensite is unchanged during the deformation and the increasing of the α' phase amount happens for the expense of austenite, what is not evident because α' may form also via ϵ phase.

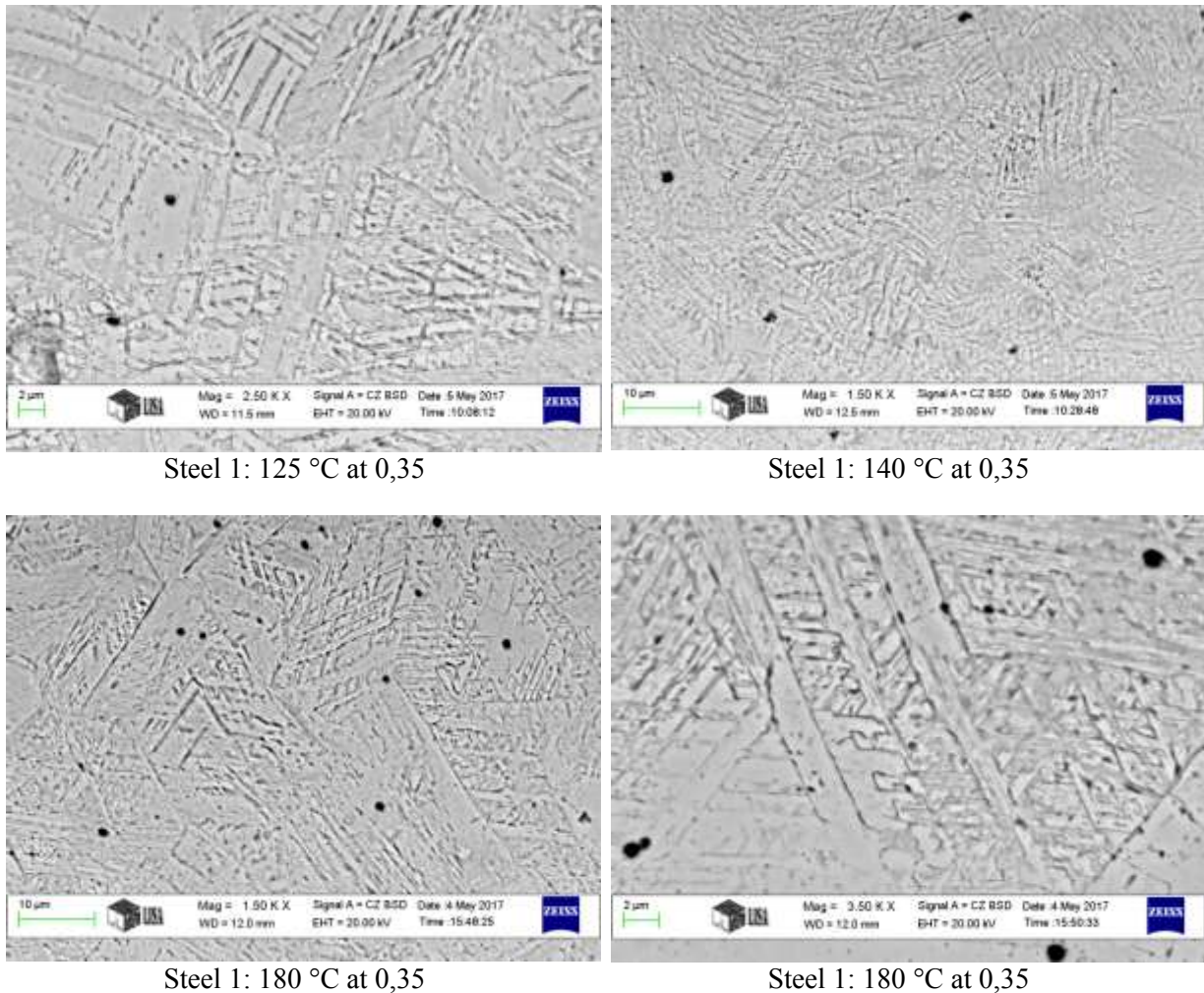


Figure 6. SEM (Scanning Electron Microscopy) images, deformation twins in Steel 1 loaded at: 125 °C, 140 °C and 180 °C

4. Summary

Solid state phase reactions in austenitic FeMnCr TWIP steel was studied induced by thermomechanical treatments. Uniaxial tensile load was performed at different temperatures (25 °C-180 °C) and different strain rate. XRD method was used to calculate the phase constitutions after the test. Based on the results the formation of different martensites (thermally or strain induced ϵ or strain induced α') can be predicted. It was also concluded the deformation stabilizes the austenite.

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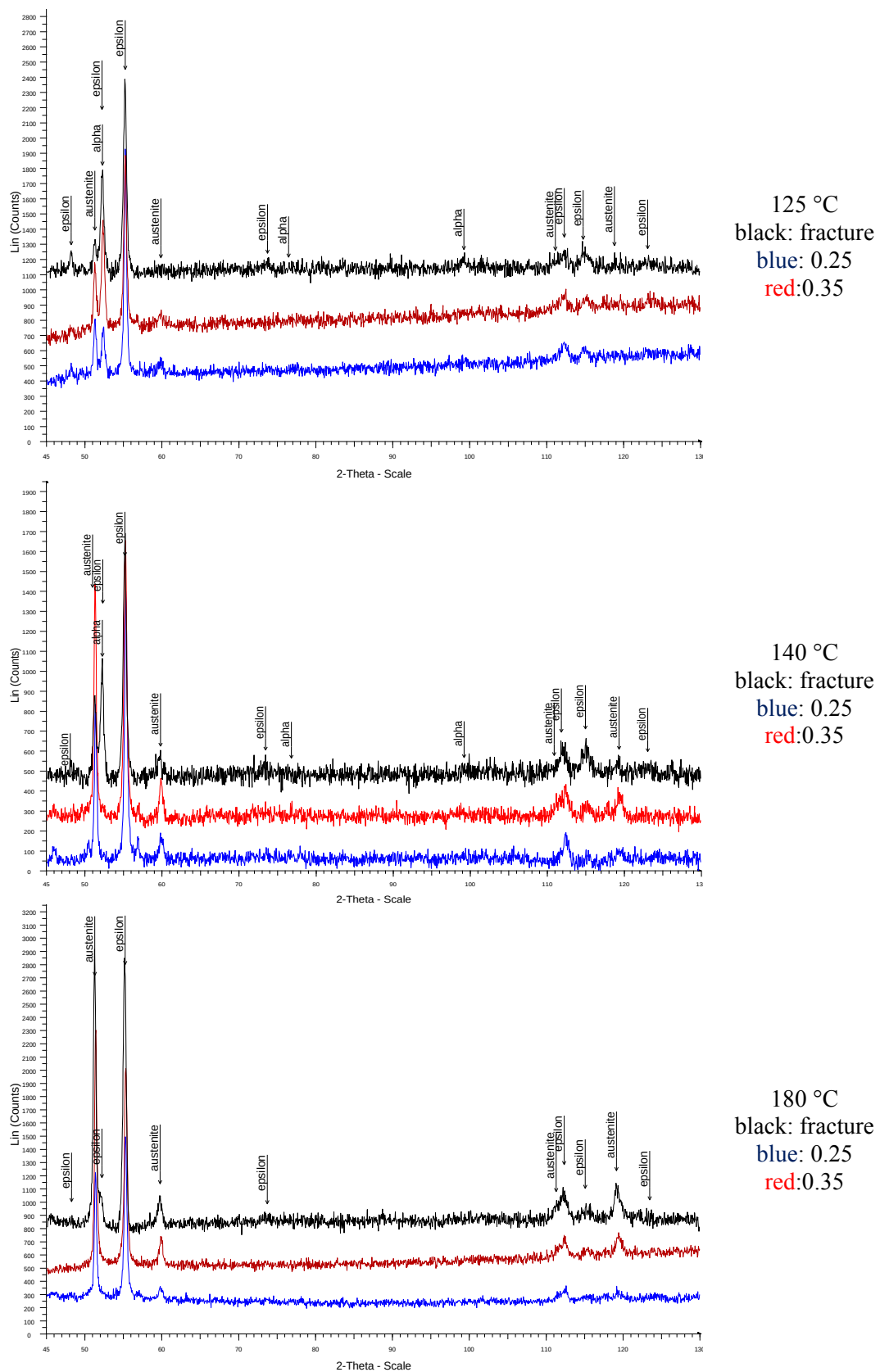


Figure 7. X-Ray diffractograms of Steel 1 loaded at different temperatures and strain rate

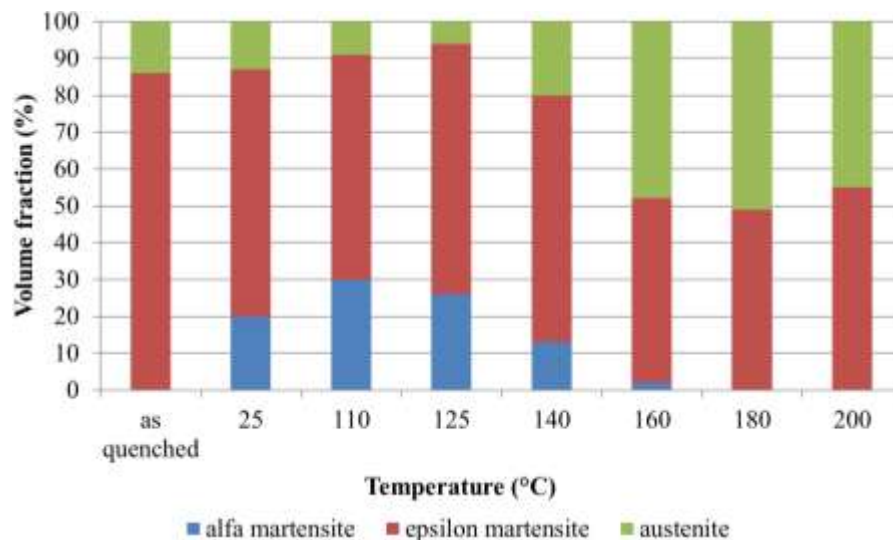


Figure 8. Volume fraction of Steel 1 after loaded at various test temperatures up to fracture

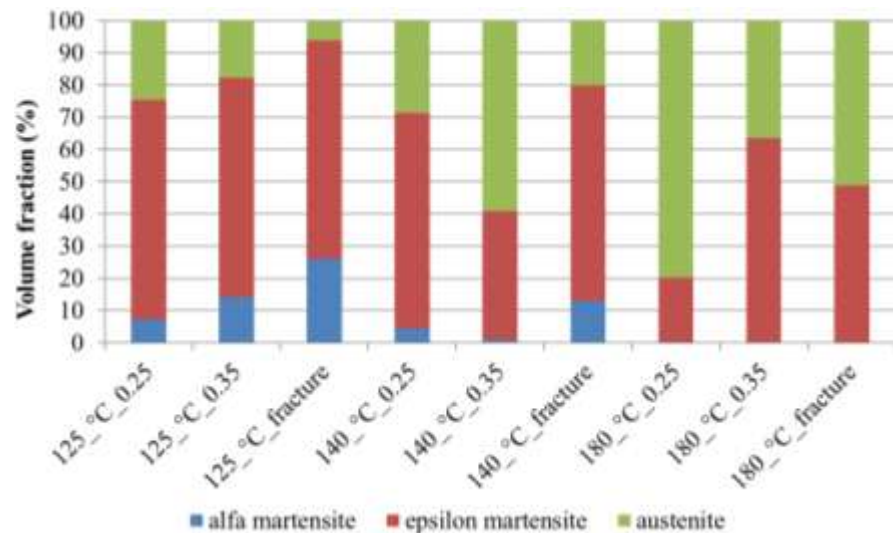


Figure 9. Volume fraction of Steel 1 at 125 °C, 140 °C and 180 °C test temperatures loaded up to different strain rate

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