Deformation behaviour of cold-formed 32Mn2.3Si3Al TWIP steel in tension at different temperatures

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Abstract

The dependence of the mechanical behaviour of cold-formed 32Mn2.3Si3Al TWIP steels on temperature is still not completely explained. This steel has been specially developed. Therefore, the mechanical properties of a cold-formed 32Mn2.3Si3Al TWIP steel was characterized by tensile tests over a temperature range of up to 800 °C. This study was undertaken to investigate the elevated temperature mechanical properties of TWIP steel. Tensile tests were undertaken using a steady state test method for temperatures in the range 20 – 800 °C. Test results were compared with inside.

Key words: 32Mn2.3Si3Al TWIP steel, TWIP steel, mechanical properties, elevated temperature

1. Introduction

Steels combining these two traditionally contradictory properties exhibit reasonably low yield strength (YS) but relatively high uniform elongation (A) and ultimate tensile strength (Rm), i.e., their work hardening capability are very good and extend to relatively high strains. TWIP (Twinning-Induced Plasticity) steels are typical representatives of the group of advanced high strength steels (AHSS) that have been developed to meet the demands put forward mostly by the automotive industry. Increased automotive safety standards, reduced automotive body weight, and manufacturing processes requiring a superior formability, have led to a strong interest in advanced high strength steel and “super tough”, high manganese steel characterized by Twinning-Induced Plasticity (TWIP). The high-manganese austenitic TWIP steels present excellent properties, combining very large strain-hardening rate and ductility. The TWIP effect is shown to cause the observed high maximum stress (600 MPa – 1500 MPa) and good elongation (50 % – 95 %) [1-6]. Actually it is believed that these steels are currently the widespread steel options to improve weight reduction and safety performance at the same time. Austenitic steels can exhibit both high strength and ductility due to a particularly high work hardening rate. Among all the possible deformation modes for austenitic steels, Twinning Induced Plasticity (TWIP) has the most beneficial effect on the work-hardening. It is claimed that deformation twins increase the work-hardening rate by acting as obstacles to gliding dislocations. Therefore, TWIP steels can deform under low stresses, but they do not break until strain reaches higher percentage values. As it can be seen from Figure 1, they have extraordinary ductility–strength combinations for automotive applications [1-2]. Advantages of TWIP steels include their ability to be produced

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using proven manufacturing procedures for other steel grades and compatibility with processing methods, such as continuous casting, rolling, pressing and welding.

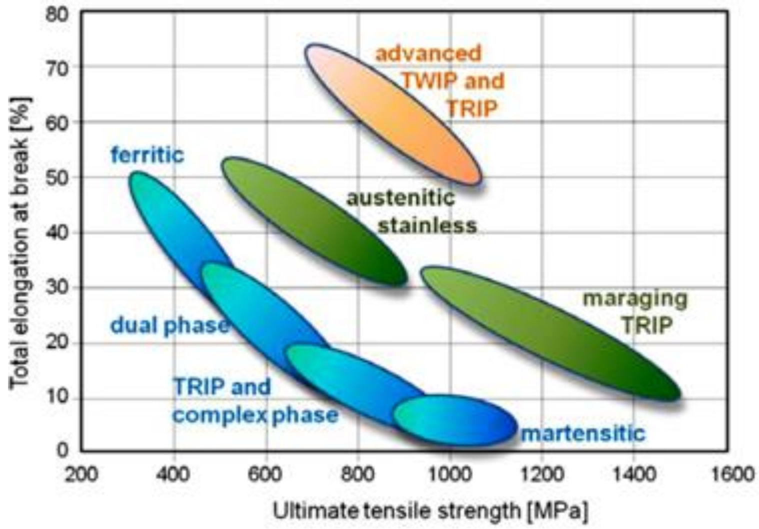

Figure 1. Overview of typical strength–ductility profiles of automotive steels [1-2]

Adding, it is important that thermal characteristics for automobile and other producers, such as continuous casting, rolling, pressing and welding. With increasing temperatures, the mechanical properties of advanced high strength steel (AHSS) change rapidly, resulting in the loss of load bearing capacity of AHSS [5]. Hence a good knowledge and understanding of the thermal characteristics of the mechanical properties with increasing temperatures is essential for the design of TWIP cold-formed steel structures. As a result, there is a need to fully understand the thermal characteristics of yield strength and elastic modulus of TWIP steels at elevated temperatures.

In this study, mechanical properties of 32Mn2.3Si3Al TWIP steel at elevated temperature were investigated. Tensile tests were undertaken using EN ISO 6892-2 standard test method for temperatures in the range 20 – 800 ^{o}C. Test results were compared with the currently available reduction factors for strength and elastic modulus and stress–strain curves.

2. Experimental Investigation

In this study, Fe-32Mn2.3Si3Al TWIP Steel is investigated and its chemical composition given in Table 1.

Table 1. Chemical composition of the TWIP steel, mass percent, %

C	Mn	Si	Al
0.027	32	2.30	3

The most commonly used method to assess the mechanical properties of steels is to perform tensile specimen tests based on either the steady state or the transient state test method. Although the transient state test method is considered to be more realistic in simulating the behaviour of a real fire including the creep effect, the steady state test method is commonly used as it is easier to conduct than the transient state test method and provides the stress–strain curves directly [5-7]. The creep effect is also considered negligible since both steady state and transient state tests are usually completed within an hour. Hence in this research the steady state test method was used. In this method, the specimen is heated up to the required temperature and then a tensile load is applied at a constant rate either as strain controlled or load controlled until failure while maintaining a constant temperature [5]. In this study the tensile specimen tests were conducted under strain control. Tensile specimen tests were conducted to determine the mechanical properties of 1 mm thickness TWIP steels at pre-selected uniform temperatures from ambient temperature to 800 ^{o}C.

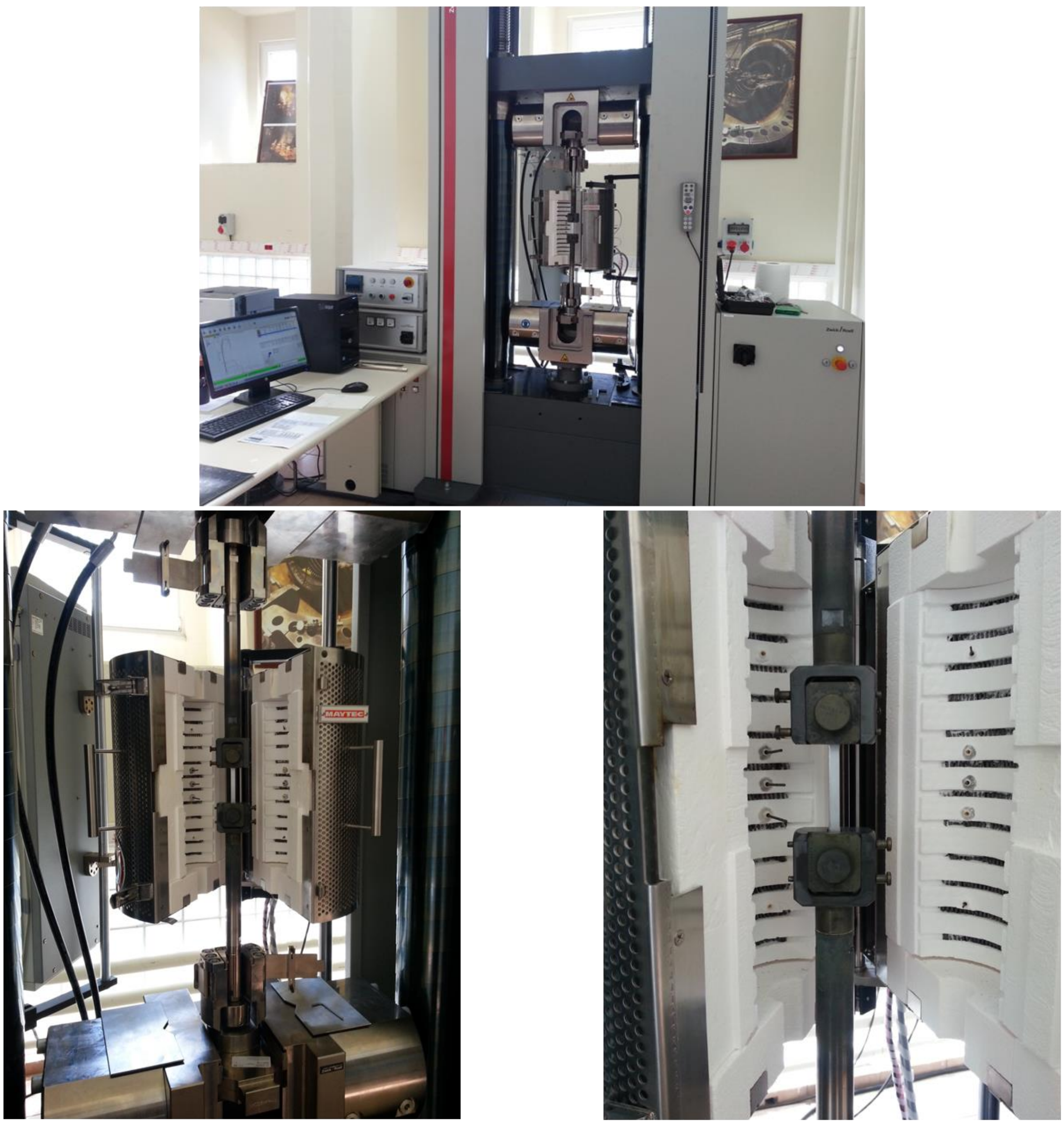

Fig. 2. Tensile test machine and its connections of the specimen

Tensile test specimens were cut in the longitudinal direction of cold-formed steel sheets according to EN ISO 6892-2 standard [8]. All tensile tests were performed with Zwick Z600 material testing machine in Materials Institute of TÜBİTAK MAM. Force accuracy class of the machine is 0.5 with respect to EN ISO 7500-1 [9] standard. Tensile tests were conducted using a fully computerized tensile testing machine. The tensile test results at different temperatures of TWIP specimens were given in Table 2.

Six temperatures were selected in this study: 20, 200, 400, 600, 700 and 800 ^{o}C. Initially, the temperature inside the furnace was increased to a pre-selected value with the specimen inside the furnace using a heating rate of 20 ^{o}C/min. It was observed that the specimen temperature measured by the three thermocouples from up, middle, bottom on the specimen. After reaching the pre-selected temperature, it was allowed to satisfy for ± 3 ^{o}C according to EN ISO 6892-2 before applying the loading in order to ensure to a uniform temperature within the specimen.
Fig. 2 shows the details of the tensile test set-up. The specimen was connected to two vertical end rods, which were accurately aligned with each other. The tensile load was applied by using a electrical motor connected to the top end rod. The machine was used test software for all parameters.

3. Results and Discussions

Fig. 3 shows the comparison of stress–strain curves for TWIP cold-formed steels at elevated temperatures. Generally, the results indicate that the strength of the specimens is decreased at increased temperatures. The total strain and ductility of the specimens are increased also at elevated temperature [5-7,10-12]. The results of the test are shown below in the table and graphics (Table 2, Fig.3). Temperatures show similar kind of stress–strain curves but do not exhibit a smooth yield plateau.

Figure 3 and Table 2 display the tensile behaviour of the TWIP steel at 20 ^{o}C showing an yield strength (YS) of 1444 MPa, ultimate tensile strength (Rm) equaling 1592 MPa and an total strain (A) of 7,8 %. In the tensile behaviour of the TWIP steel at 800 ^{o}C, there was a change decreasing approximately 88 % in YS, 87 % in Rm. Total strain was increased about 13 times according to 20 ^{o}C.

Table 2. Mechanical properties for different temperatures of the TWIP steel

Temperature	***E Modulus***	***Yield strength***	***Ultimate strength***	***Total Strain***
	E	***$Rp_{0.2}$***	***Rm***	***A***
^{o}C	***GPa***	***MPa***	***MPa***	***%***
20	200,82	1444	1592	7,8
200	181,66	1348	1418	5,7
400	175,39	1129	1282	6,4
600	113,25	462	764	18,0
700	51,57	265	352	50,2
800	35,00	168	201	100,0

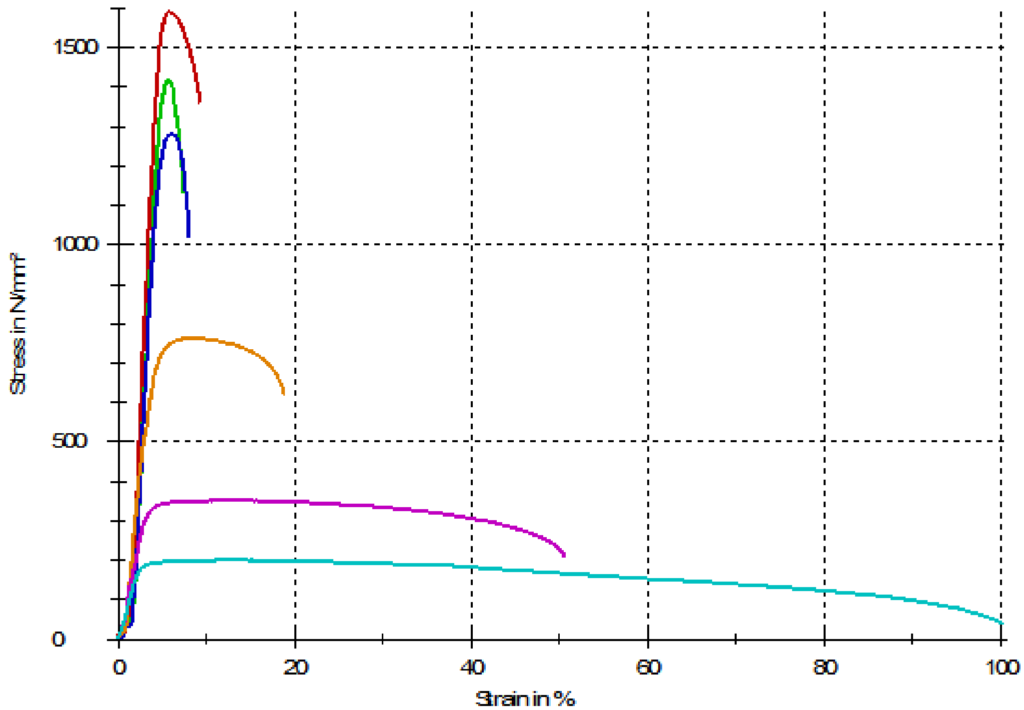

Fig. 3. Stress–strain curves at different temperatures of the TWIP steel

Table 3. Elastic modulus reduction factors, yield strength reduction factors and ultimate strength reduction factors for elevated temperatures of the TWIP steel

Temperature (°C)	***E_T / E_{20}***	***$(Rp_{0.2\,T}) / (Rp_{0.2\,20})$***	***$(Rm_T) / (Rm_{20})$***
20	1,000	1,000	1,000
200	0,905	0,934	0,891
400	0,873	0,782	0,805
600	0,564	0,320	0,480
700	0,257	0,184	0,221
800	0,174	0,116	0,126

The reduction factors of yield strength at elevated temperatures were calculated as the ratio of yield strength at elevated temperatures $Rp_{0.2\ T}$ to that at ambient temperature $Rp_{0.2\ 20}$ given in Table 3. It shows that the yield strength reduction characteristics of low and high temperatures are different. It appears that the yield strengths of TWIP steels do not decrease much up to 400 ^{o}C and then decrease at a rapid rate. Similar observation was also made by ref. [5,11-12].

Elastic modulus was calculated from the initial slope of the stress–strain curve. There reduction factor was then calculated as the ratio of the elastic modulus at elevated temperature (E_T) to that at ambient temperature (E_{20}) given in Table 3. Similar to ultimate strength reduction factor was calculated at different temperatures. These factors show the same characteristic of yield strength reduction factor (Fig. 4).

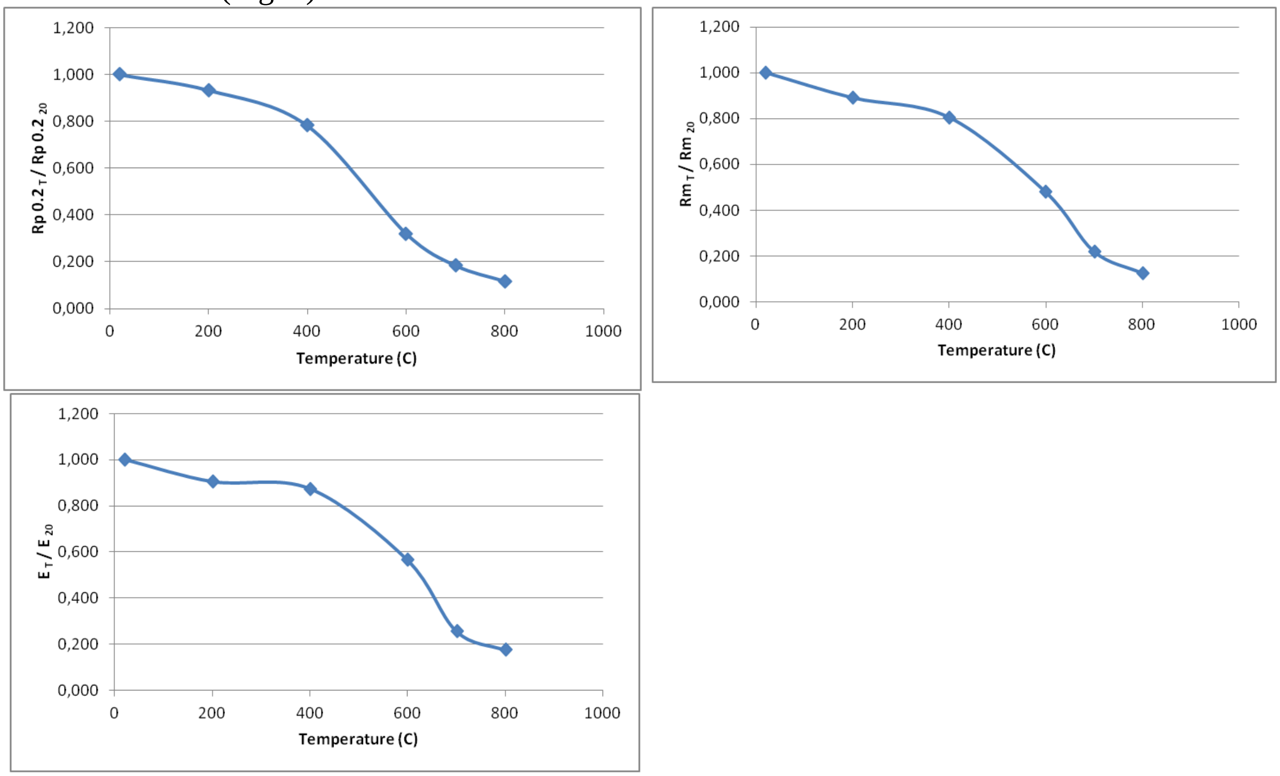

Fig. 4. The reduction factors (ratio) of Elastic modulus, Yield strength and Ultimate strength versus temperatures

Typical failure modes for TWIP cold-formed steel at different temperatures are shown in Fig. 5, respectively. TWIP steels showed less ductile failures at 200, 400 and 600 ^{o}C and their failures became more ductile at higher temperatures.

Fig. 5. Failure modes of tensile specimens at elevated temperatures (20 to 800 ^{o}C)

4. Conclusions

This paper has presented a detailed experimental study of the mechanical properties of cold-formed 32Mn2.3Si3Al TWIP steel at elevated temperatures range 20 – 800 ^oC.
Conclusions can be outlined as follows:

a. The ultimate tensile strength at 600 ^oC of TWIP specimen showed decreasing about 52 % and 800 ^oC decreased about 87 % according to 20 ^oC test.
b. The reduction factors do not decrease much up to 400 ^oC and then decrease approximately 50 % rate.
c. Total strain at 700 ^oC increased about 6 and 800 ^oC increased about 13 times according to 20 ^oC.

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