Investigation of mechanical properties of DP 600 steels at elevated temperatures

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Abstract

Mechanical properties have an important role in the thermal characteristics of DP 600 steel structures due to the rapid reduction in mechanical properties such as yield strength and elastic modulus under elevated temperature conditions and associated reduction to the load carrying capacities. Hence there is a need to fully understand the thermal characteristics of yield strength and elastic modulus of DP 600 steels at elevated temperatures. Therefore, an experimental study was undertaken to investigate the elevated temperature mechanical properties of DP 600 steels. Tensile tests were undertaken using a steady state 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.

Key words: DP 600, elevated temperature, mechanical properties

1. Introduction

New materials are being considered among other strategies, with increasing demands for higher fuel efficiency in automobiles [1]. The new materials evaluated for their light-weight or higher strength, with the ultimate goal reducing the weight of vehicle, that will result in lower fuel consumption. In this situation, Dual Phase (DP) steel alloys are being developed for substituting currently used low carbon steels in the automotive industry. DP steel consists of martensite and ferrite, and the volume fraction of martensite and ferrite grain size. There are different types DP steel as DP 600, DP 1000 according to ultimate tensile strength. The steels have tensile strength over 600 MPa for DP 600 and 1000 MPa for DP 1000, compared to conventional high strength steels in the range of 400 – 440 MPa, though they have similar yield strengths and are good candidates for making light-weight vehicles [2-3]. As a result, thinner DP sheets, that decrease the weight of automobile, can be used without losing any strength, and having a similar or higher level of crash energy absorption. Most industry experts agree that, as illustrated in figure 1, steel based parts designs using advanced high strength steels (AHSS) offer both the potential for vehicle mass containment and lower production cost. DP and TRIP steels are now well established as AHSS. Weight reductions of about 30-40 % are typically reported for 1300-1500 MPa steels [4]. DP 600 steel has these features and is nowadays widely preferred.

Adding, it is important that thermal characteristics for automobile and other producers such as welding, forming etc. With increasing temperatures, the mechanical properties of DP cold-formed steels change rapidly, resulting in the loss of load bearing capacity of DP cold-formed

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steels [3]. Hence a good knowledge and understanding of the thermal characteristics of the mechanical properties with increasing temperatures is essential for the design of DP cold-formed steel structures. As a result, there is a need to fully understand the thermal characteristics of yield strength and elastic modulus of DP 600 steels at elevated temperatures. Therefore, an experimental study was undertaken to investigate the elevated temperature mechanical properties of DP 600 steel. Tensile tests were undertaken using a steady state 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.

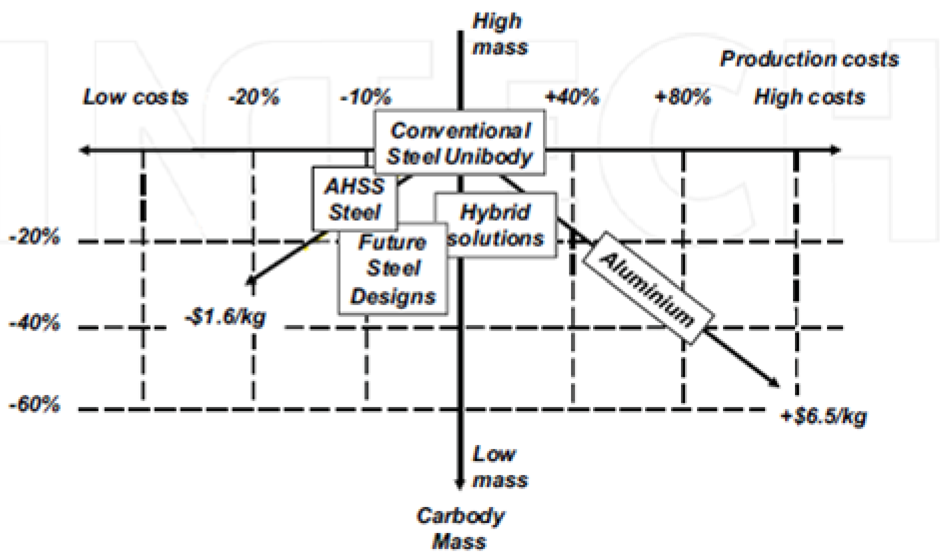

Fig. 1. Comparison of the production cost and vehicle mass containment for designs based on different material selections

2. Experimental Investigation

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 [3-7]. 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 [3]. In this study the tensile specimen tests were conducted under strain control. Tensile specimen tests were conducted to determine the mechanical properties of 1,8 mm thickness DP 600 steels at pre-selected uniform temperatures from ambient temperature to 800 ^{o}C.

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 temperature of DP 600 sheet were given in Table 1.

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.

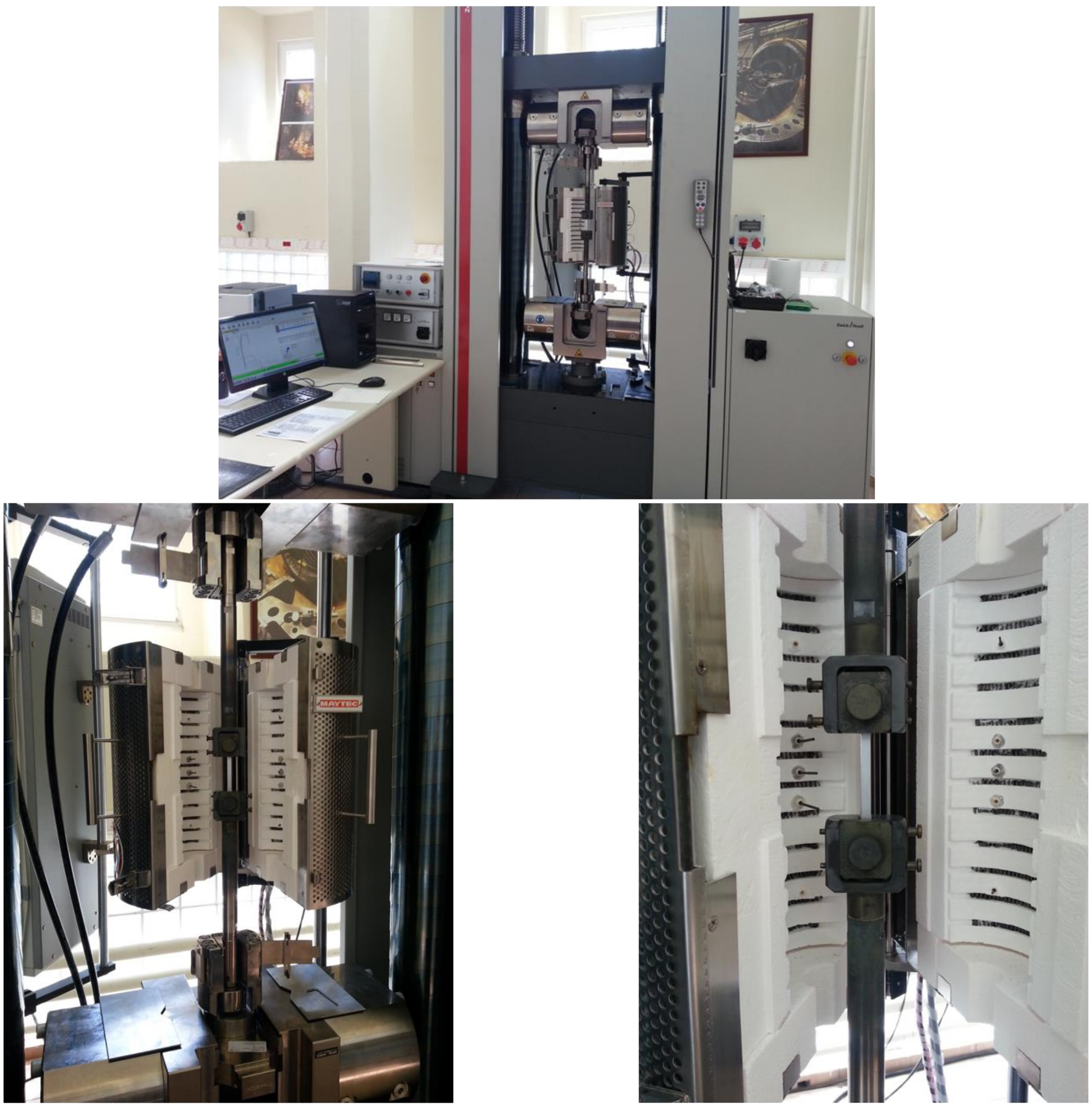

Fig. 2. Tensile test machine and its connections of the specimen

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 DP 600 cold-formed steels at elevated temperatures. Generally, the results indicate that the strength of the specimens is decreased at increased temperatures. The total strain of the specimens is increased also at elevated temperature [3-7]. The results of the test are shown below in the table and graphics (Table 1, Fig.3). The stress–strain curves of DP 600 steel show a linear elastic region followed by a well defined yield plateau at 600 and 700 ^{o}C temperatures. Temperatures at 200 and 400 ^{o}C show similar kind of stress–strain curves but do not exhibit a smooth yield plateau as for ambient temperature.

Table 1 display the tensile behaviour of the DP 600 steel at 20 ^{o}C showing an yield strength (YS) of 431 MPa, ultimate tensile strength (Rm) equaling 671 MPa and an total strain (A) of 22,9 %. In the tensile behaviour of the DP 600 steel at 800 ^{o}C, there was a change decreasing approximately 91 % in YS, 93 % in Rm. Total strain was increased 3,5 times according to 20 ^{o}C.

Table 1. Mechanical properties for different temperatures of the DP 600 steel (*do not break)

Temperature	***E Modulus***	***Yield strength***	***Ultimate strength***	***Total Strain***
	E	***$Rp_{0.2}$***	***Rm***	***A***
^{o}C	***GPa***	***MPa***	***MPa***	***%***
20	201,40	431	671	22,9
200	200,94	413	630	18,3
400	198,80	378	619	22,9
600	97,38	168	224	28,8
700	54,38	84	110	41,1
800	26,63	38	46	80,8*

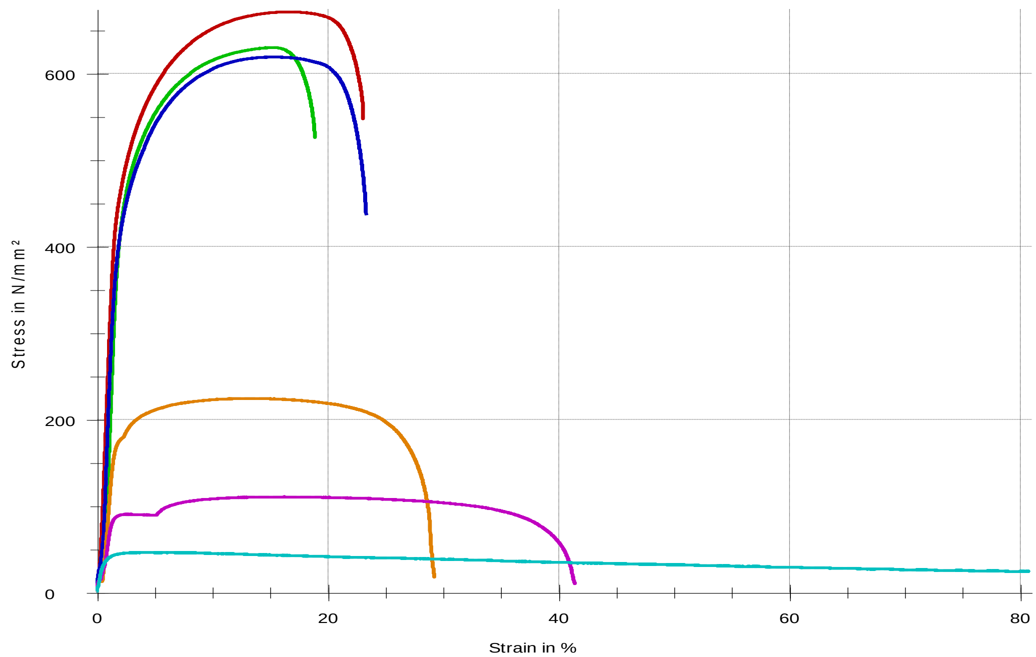

Fig. 3. Stress–strain curves at different temperatures of the DP 600 steel

Table 2. Elastic modulus reduction factors, yield strength reduction factors and ultimate strength reduction factors for different temperatures of the DP 600 steel

Temperature (^oC)	***E_T / E_{20}***	***$(Rp_{0.2\ T}) / (Rp_{0.2\ 20})$***	***$(Rm_T) / (Rm_{20})$***
20	1,000	1,000	1,000
200	0,998	0,958	0,939
400	0,987	0,877	0,923
600	0,484	0,390	0,334
700	0,270	0,195	0,164
800	0,132	0,088	0,069

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 2. It shows that the yield strength reduction characteristics of low and high temperatures are different. It appears that the yield strengths of DP 600 steels do not decrease much up to 400 ^oC and then decrease at a rapid rate. Similar observation was also made by Kankanamge et. all. and Ferraiuolo et. all.[3,10].

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 2. Similar to ultimate strength reduction factor was calculated at different temperatures. These factors show the same characteristic of yield strength reduction factor (Fig. 4).

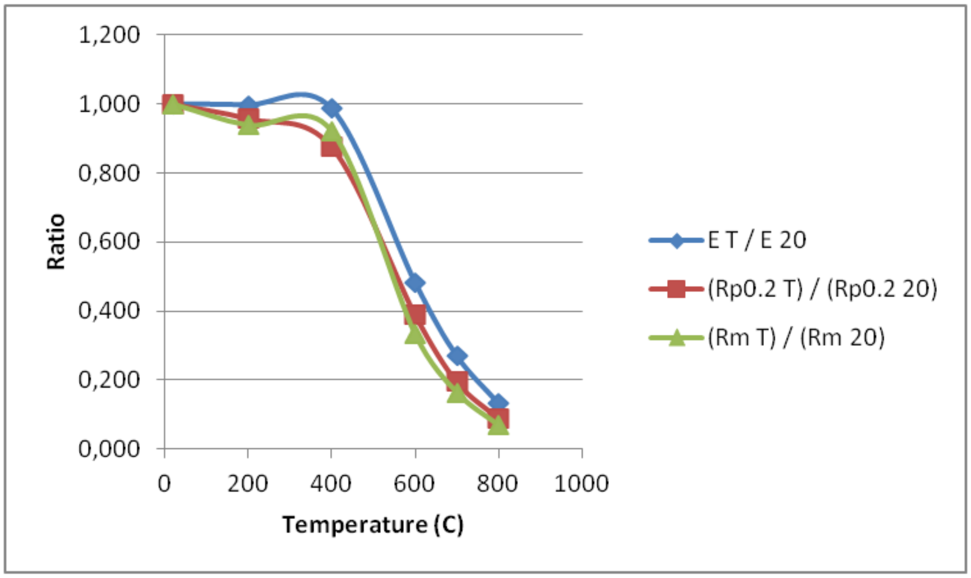

Fig. 4. The reduction factors (ratio) of Elastic modulus, Yield strength and Ultimate strength versus temperature

Typical failure modes for DP 600 cold-formed steel at different temperatures are shown in Fig. 5, respectively. Up to 600 ^{o}C, DP 600 steels showed less ductile failures and there after their failures became more ductile at higher than 600 ^{o}C.

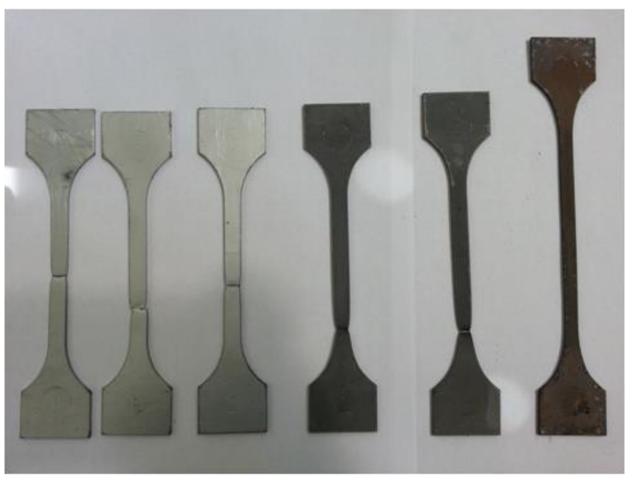

Fig. 5. Failure modes of tensile specimens at elevated temperatures (20 to 800 ^{o}C)

4. Conclusions

This paper has presented a detailed experimental study of the mechanical properties of DP 600 cold-formed steel at elevated temperatures range 20 – 800 ^{o}C.
Conclusions can be outlined as follows:

a. The ultimate tensile strength at 600 ^{o}C of DP 600 specimen showed decreasing about 66 % and 800 ^{o}C decreasing 93 % according to 20 ^{o}C test.
b. The reduction factors do not decrease much up to 400 ^{o}C and then decrease at a rapid rate.

Up to 400 ^{o}C, the reduction factors varies within about band of 0,1. It is decrease about 50 % in 600 ^{o}C.

c. Total strain at 800 ^{o}C increased about 3,5 times according to 20 ^{o}C.

References

[1]. American Iron and Steel Institute; “The UltraLight Steel Auto Body (ULSAB)”, http://www.autosteel.org/AM/Template.cfm?Section=ULSAB1

[2]. Long, X., Khanna, K., Fatigue properties and failure characterization of welded high strength steel sheet, International journal of fatigue, 29, 2007, 879-886

[3]. N.D. Kankanamge, M. Mahendran, Mechanical properties of cold-formed steels at elevated temperatures, Thin-Walled Structures 49, 2011, p.26–44

[4]. B. C. De Cooman, Kwang-geun Chin and Jinkyung Kim (2011). High Mn TWIP Steels for Automotive Applications, New Trends and Developments in Automotive System Engineering, Prof. Marcello Chiaberge (Ed.), ISBN: 978-953-307-517-4

[5]. Chen J, Young B. Experimental investigation of cold-formed steel material at elevated temperatures. Thin-walled Structures 2007;45:96–110

[6]. Lee J, Mahendran M, Makelainen P. Prediction of mechanical properties of light gauge steels at elevated temperatures. Journal of Constructional Steel Research 2003:15,17–32

[7]. Ranawaka T, Mahendran M. Experimental study of the mechanical properties of light gauge cold-formed steels at elevated temperatures. Fire Safety Journal 2009;44:219–29

[8]. EN ISO 6892-2, 2011, Metallic materials -- Tensile testing -- Part 2: Method of test at elevated temperature

[9]. EN ISO 7500-1, 2004, Metallic materials -- Verification of static uniaxial testing machines -- Part 1: Tension/compression testing machines -- Verification and calibration of the force-measuring system

[10]. A. Ferraiuolo, A. Smith, J. G. Sevillano, F. de las Cuevas, P. Karjalainen, G. Pratolongo, H. Gouveia, M. Mendes Rodrigues, 2012, EUR 25063 — Metallurgical design of high-strength austenitic Fe-C-Mn steels with excellent formability (Metaldesign), ISBN 978-92-79-22205-4, doi:10.2777/14874