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Experimental Investigations Of Tensile Properties Of Ultra-High Strength Steel S1100QL At Room And Elevated Temperatures

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Abstract

The aim of this paper was to present experimental study into the influence of elevated temperatures on mechanical properties of Ultra-High-Strength Steel (UHSS) S1100QL. This steel belongs to the group of structural steels and it is primary used for designing various types of lifts and cranes with the goal to decrease mass of the structures with simultaneous increase of load capacity. During the first part of testing tensile tests were conducted on room and several other elevated temperatures (100°C, 400°C and 700°C). Results showed that steel's properties at 100°C are similar to properties at room temperature. Drastic changes in strength and other tensile properties occur at 400°C and 700°C. From obtained results can be seen that this steel could not be used at those elevated temperatures.

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1. Introduction

In the late 20th century as new regulations regarding fuel preservation and reducing emission of greenhouse gasses have met the automotive industry, a need for newer grades of steels had appeared, Demeri (2013). Main goal of this newer steel grades was to allow for automotive structures to be lighter or to allow for structures in the transportation industry to carry greater loads (increased load capacity). As the result of research efforts, a newer group of steel grades

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had emerged and they were called Ultra-High Strength Steel or shorter UHSS. All steels that are classified as UHSS have ultimate tensile strength at minimum of 1000 MPa. Their high strength resulted from complex microstructure (mainly martensitic and bainitic phases) achieved through complex heat-treatment process. UHSS unfortunately have low ductility and bad weldability since they are prone to cold cracks, Demeri (2013).

Investigation of tensile properties of various materials at elevated temperatures is a common praxis among the researchers. The ultimate goal is to determine the highest temperature up to material holds its mechanical properties.

Investigation of other properties on elevated temperature, such as normal anisotropy coefficient can be founded Arsić et al. (2015). Some researchers have investigated tensile and other properties of hot-work steel, Arsić et al. (2018), Arsić et al. (2025). Hot-work steels are mainly used for machining different tools used for forging, Jovanović et al. (2017). This is standard procedure to check their behavior at elevated temperatures. In literature can be also found that similar studies were conducted on some grades of high-strength steels, even that it is not a common practice, Arsić et al. (2016). This motivated authors of this paper to conduct similar study of S1100QL.

2. Materials and testing

In this article main focus is put on the tensile testing of the S1100QL steel. Steel was tested at room and elevated temperatures. specimens for tensile testing were machined from steel plates with gage diameter d_0= 8 mm and gage length 80 mm according to drawing displayed on Fig. 1. Declared chemical composition and mechanical properties of plates used for specimen preparation are presented in tables 1 and 2.

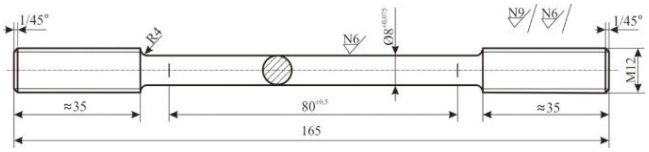

Fig 1. Specimens machined for tensile testing

Table 1 Declared chemical composition of S1100QL

%C	%Si	%Mn	%P	%S	%Cr	%Cu	%Ni	%Mo	%B
max 0.21	max 0.5	max 1.4	max 0.02	max 0.005	max 0.8	max 0.3	max 3	max 0.7	max 0.005

Table 2 Declared Mechanical properties of S1100QL

Proof stress, MPa	Ultimate tensile strength, MPa	Elongation, %
min 1100	1250-1550	min 10

Tensile test at both room and elevated temperatures, was completed on universal testing machine ZWICK ROELL Z100 (Fig. 2.). For tensile testing at elevated temperatures an additional MAYTEC heating chamber (Fig. 3) was used. This heating chamber can be used for experiments at various temperatures up to 1000°C. All specimens were heated in the chamber approximately 2 min per one millimeter of thickness.

Testing at room temperature was completed with six gages and testing at elevated temperatures was completed at three different temperatures (100°C, 400°C and 700°C). For each temperature three specimens were broken.

Fig. 2 Universal testing machine ZWICK ROELL Z100

a  b 

Fig 3. (a) Heating chamber (b) and its control unit

3. Results and discussion

Results obtained through tensile testing of S1100QL at room temperature are shown in table 3. During the tensile test stress-strain curves for all six specimens were recorded and they are presented on Fig. 4.

Table 3 Experimental values of tensile properties S1100QL at room temperature

Specimen	Rp0,2, MPa	Rm, MPa	A, %	Z, %
1	1141	1392	7.30	64.00
2	1192	1395	7.73	63.24
3	1184	1386	7.62	62.48
4	1169	1397	7.25	64.00
5	1196	1401	7.29	64.00
6	1164	1391	9.01	65.48

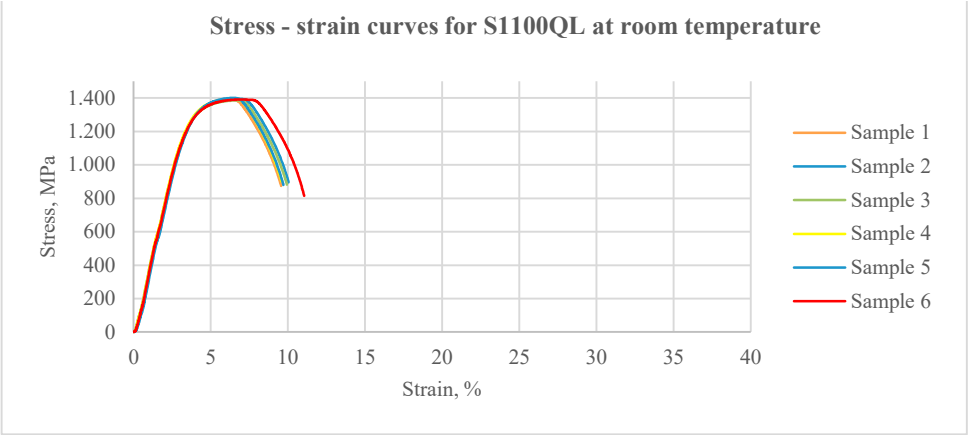

Fig. 4 Stress-strain curves for S1100QL recorded at room temperature

Results of tensile tests recorded at elevated temperatures are displayed at table 4 and recorded stress-strain curves are presented on Fig. 5

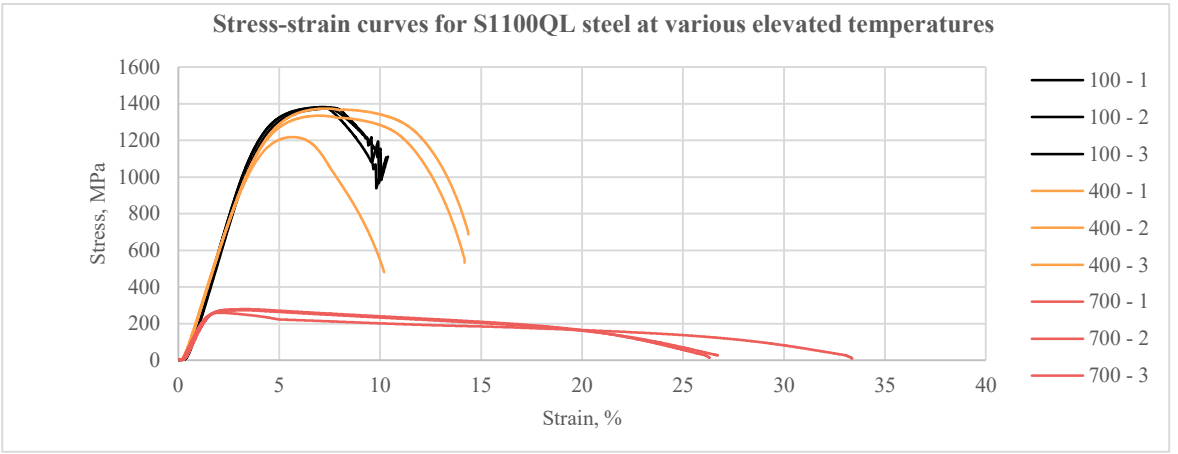

Fig. 5. Stress strain curves for S1100QL steels at different elevated temperatures

4. Discussion

Obtained results during test at room temperature show that values of proof stress range from 1141 MPa to 1196 MPa. All values of proof stress obtained through testing are above minimal values stated by the producer. Values of ultimate tensile strength range from 1386 MPa to 1401 MPa and are within value range declared by the steel producer. Regarding elongation values, they range from 7.25% to 9.01%. All obtained values are below minimal declared values. With this example, authors of this paper like to point out the significance of existing entry control of material's properties before production. All materials that don't meet the required specifications should not be accepted and put into production process. Cross-section reduction values range from 62.48% to 65.48%.

Results of tensile test at elevated temperatures are displayed in table 4 and are as follows, at 100°C proof stress is between 1113 and 1132 MPa. Ultimate tensile strength differs from 1374 to 1382 MPa. Elongation values range from 6.77 to 6.98%. Cross-section reduction is between 60.93 and 61.71%. In comparison with values obtained at room temperature, a slight drop in material's strength is noticed, as well as drop of elongation and cross-section reduction values. Strength drop is expected to occur since the temperature changes. It is necessary to point out the strange

behavior of material a few moments before the specimen is broken. Strange pops and bangs occur at that stage of the testing. Every pop and bang are on a stress-strain curve followed as combination of sudden peak and drop of strength. This phenomenon potentially results in the drop of other two mentioned properties. Stress-strain curves recorded at 100°C are displayed at Fig. 6.

Table 4 Tensile properties of S1100QL at 100°C

Specimen	Rp0,2, MPa	Rm, MPa	A, %	Z, %
1	1132	1379	6.86	60.93
2	1113	1374	6.77	61.71
3	1128	1382	6.98	61.48

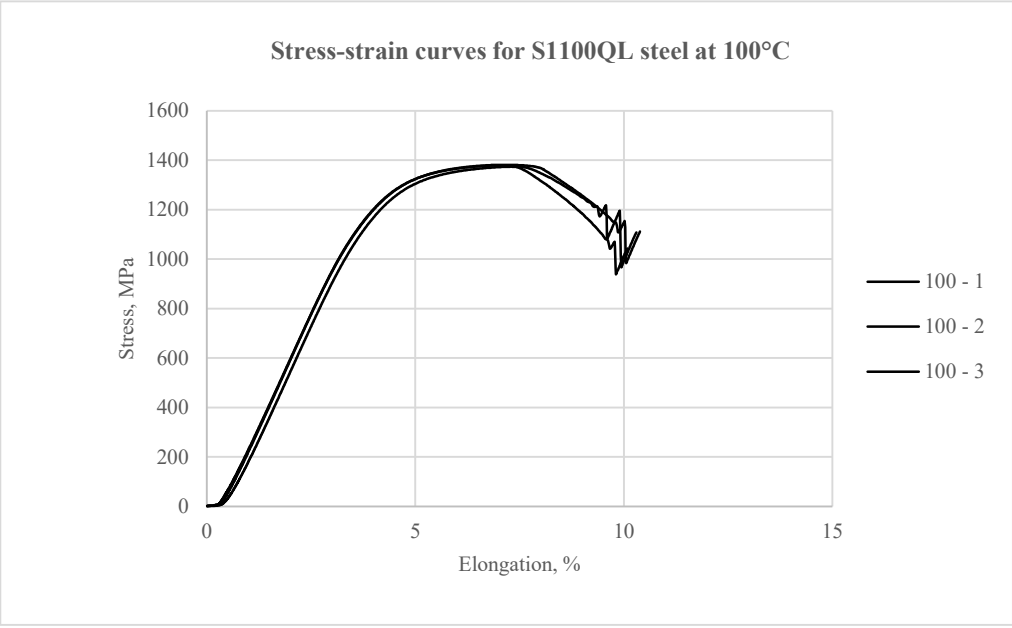

Fig. 6 Stress-strain curves of S1100QL steel recorded at 100°C

At 400°C tensile properties, especially values of proof stress begin to change. Proof stress values range from 964 to 1046 MPa. Ultimate tensile stress values range from 1218 to 1374 MPa. Elongation values are higher than values of elongation at room temperature and at 100°C. Cross-section reduction values are also higher than in previous two cases and range from 63.36% to 73.73%. Obtained experimental results are presented at table 5 and recorded stress-strain curves are displayed at Fig. 7.

Table 5 Experimental values of tensile properties of S1100QL at 400°C

Specimen	$R_{p0,2}$, MPa	R_m, MPa	A, %	Z, %
1	1046	1374	12.07	65.48
2	1032	1335	12.35	73.73
3	964	1218	8.54	63.36

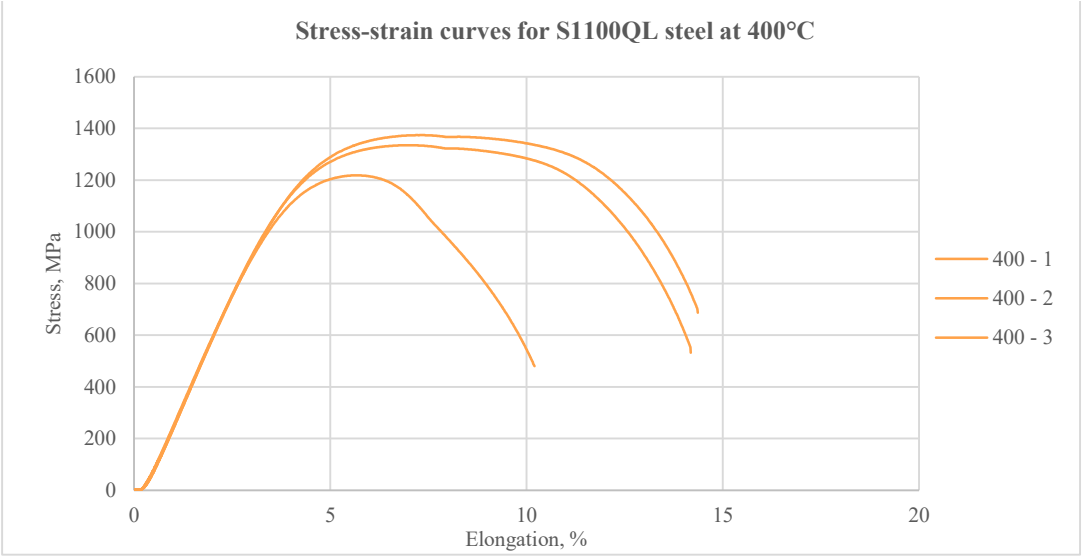

Fig. 7 Stress-strain curves for S1100QL at 400°C

Tensile properties of S1100QL steel at 700°C meet great strength drop and rising values of elongation and cross-section reduction. Values of proof stress range from 242 to 260 MPa. Ultimate tensile strength is also far lower than in previous cases. Values range from 259 up to 279 MPa. Elongation values are within range of 30.07 up to 38.8%. Values of cross-section are higher than in last two cases and range from 95.54 to 96.48%. All results obtained in this segment of experiment are as expected. Values obtained in experiment are displayed in table 6 and recorded stress-strain curves are displayed on Fig. 8.

Table 6. Experimental values of tensile properties of S1100QL at 700°C

Specimen	Rp0,2, MPa	Rm, MPa	A, %	Z, %
1	254	272	30.07	96.24
2	242	259	38.80	96.48
3	260	279	30.80	95.54

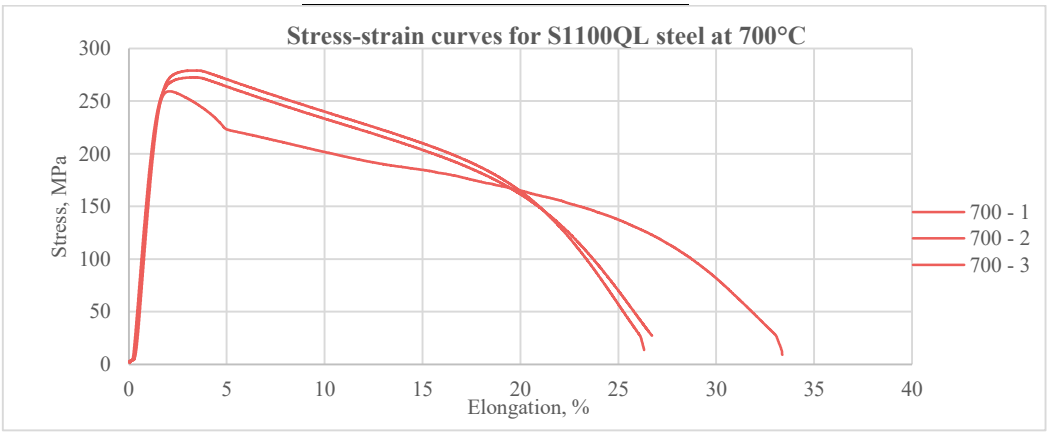

Fig. 8 Stress-strain curves for S1100QL at 700°C

5. Conclusion

With newer regulations in automotive, transportation and other industries, a need for stronger steel materials had appeared. Extensive research in the field of metallurgy resulted in producing newer grades of steel whose value of ultimate tensile strength excided values of 1000 MPa. This type of steel was sorted in special group called Ultra-High Strength Steels (UHSS). The structure of this steels is manly consisted of martensitic and bainitic structures, consequently elongation values are lower than values compared to common carbon steels. Due to their structure, the weldability of these steel grades is also bad.

S1100QL belongs to the group of UHSS steels. Declared mechanical properties and chemical composition declared by the producer of this steel are shown in tables 1 and 2. Aim of study presented in this paper was to investigate the behavior of this steel at some elevated temperatures (100°C, 400°C and 700°C).

Results of tensile tests conducted within this study are presented in this paper. Almost all properties fulfil the expected trends which occur with elevation of specimen temperature. Strength drops drastically with increasing the examination temperature. Vice versa, elongation values as well as cross-section reduction are rising. Based on data displayed in this paper, application of this steel at temperatures above 700°C is not recommended since drop of the strength is great. For other tested temperatures it could be said that steel could be applied, but only if the exposure to the heat is shorter. For the behavior of this steel in the long term, special investigation needs to be conducted.

In further studies it is planned to prepare some specimens to investigate properties at other elevated temperatures. Also, in future studies it is planned to investigate the behavior of butt welded joints at same elevated temperatures, with goal to sum up the possibility of applying this steel grade in environments with elevated temperatures.

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