PONAŠANJE ZAVARENOG SPOJA KOD ISPITIVANJA ZATEZANJEM NA RAZLIČITIM TEMPERATURAMA

WELDED JOINT BEHAVIOR DURING TENSILE TESTING AT DIFFERENT TEMPERATURES

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REZIME

Eksploatacijski uslovi imaju velik uticaj na ponašanje materijala od kojih su izrađene čelične konstrukcije. Jedan od bitnijih parametara je radna temperatura koja može znatno da promijeni mehaničke osobine čelika, čime konstrukcija postaje nepouzdana za upotrebu. Problem se usložnjava ako se radi o zavarenim konstrukcijama. Tada treba uzeti u obzir i zavareni spoj i njegovu neposrednu blizinu gdje su pri zavarivanju zbog unosa toplote već nastale promjene unutar samog materijala. U ovom radu bit će prikazani rezultati ispitivanja osnovnog materijala i zavarenog spoja, i to postupkom zatezanja. Epruvete korištene u eksperimentu su izrađene od niskolegiranog ugljeničnog čelika A516 r. 70. Ispitivanje je rađeno na pet različitih temperatura za osnovni materijal i jednoj temperaturi za zavareni spoj. Rezultati i njihova komparativna analiza predstavljeni su dijagramski u radu, urađena je analiza podataka te doneseni zaključci. Na ovaj način je potvrđena širina eksploatacijske namjene ovakve vrste čelika i pouzdanost konstrukcija izrađenih od ovog materijala. Nalazi ove studije mogu pomoći inženjerima i dizajnerima da bolje razumiju ponašanje čeličnih konstrukcija u različitim radnim uvjetima i donesu informirane odluke o njihovoj specifičnoj upotrebi.

Professional paper

SUMMARY

The mechanical properties of steel structures are largely dependent on their operating conditions, with the operating temperature being a crucial factor. Welded constructions require even more attention as the welded joint and its surrounding areas are affected by changes in material during the welding process due to heat input. A study was conducted to test the base material and welded joint made of low-alloy carbon steel A516 Gr. 70 using the tensioning method at five different temperatures for the base material and one temperature for the welded joint. The results and comparative analysis were presented in graphical form in the article, and data analysis was carried out to draw conclusions. The study confirmed the wide range of applications of this type of steel and the reliability of structures made from it. The findings of this study can help engineers and designers to better understand the behavior of steel structures under different operating conditions and make informed decisions regarding their use in specific applications.

1. INTRODUCTION

The need to use one material for multiple purposes arose with the development of the industry and the production of a wide range of products for various plants. These elements can have specific operating conditions, so it's important to choose a material that can adapt to different environments with minimal changes to its mechanical properties. Temperature is a crucial factor in the behavior of materials, particularly steel.

One such material is the low-alloy carbon steel marked A516 Grade (Gr.) 70, which is widely used for producing pressure vessels, bridges, railway wagons, cargo containers, car and truck parts, construction elements of gas installations in the chemical and petrochemical industry, and thermal power plants. Its versatility allows it to

work effectively in conditions of low and elevated temperatures.
In order to ensure that materials are of good quality, have the necessary properties, and can withstand the loads they will encounter when in use, it is important to carry out experiments. By doing this, we can make conclusions that will help extend the life of structures. These experiments are typically based on standard test methods, with the most important one being the tensile test. This test is commonly used for metallic materials and can provide information about strength, plasticity, and modulus of elasticity. Engineers can use this information to design structures that account for possible notches or fatigue due to long-term use. [1,2,3]
In the case of welded structures, most problems occur in the welded joint or nearby area. Therefore, it is essential to test the properties of the welded joint, such as tensile testing, impact toughness, and hardness. These properties provide a comprehensive understanding of the welded joints of low-alloy steels and their characteristics, and then are compared with international standards in the field of electric arc welding. Material properties differ at different operating temperatures, which can lead to fractures in welded steel structures. Hence, it is crucial to identify the temperature that can cause brittle fractures. [4,5]
Residual stresses and deformations occur in welded joints, in addition to the operating temperature which affects the lifetime of the structure. It is crucial to select and understand the welding parameters, such as the heat input, which can be verified by testing [6]. These factors necessitated the development of new materials by enhancing existing ones, and various strengthening procedures, including heat treatment after welding [7,8].
Various tests are conducted to assess the behavior of welded joints on structures. One such test is the concrete tensile test, which checks the durability of the structure and predicts any changes that may occur within the material due to temperature changes during exploitation. These changes directly affect the service life of the structure. In addition to analyzing the obtained values conditioned by the heating temperature of the base material, the results of the tested welded test tubes are also analyzed.
This paper presents the results of tension tests conducted on low-alloy carbon steel A516 Gr. 70 and its welded joint at different temperatures.

2. MATERIALS AND METHODS

The tensile test is performed on standardized test tubes. For this experiment, test tubes made of low-alloy carbon steel A516 Gr. 70 were used. Their basic physical and mechanical properties are shown in Table 1.

Table 1 Physical and mechanical characteristics of steel A516 Gr. 70

Description - physical and mechanical characteristics	Values	
Density	7,80 g/cc	
Yield stress	355 MPa	
Tensile strength	485-620 MPa	
Impact energy	41 J	
Elongation at break	by 200 mm	17 %
	by 50 mm	21 %
Modulus of elasticity	200 GPa	

The test tubes used for this experiment have a circular cross-section. The geometry of these tubes depends on the temperature at which the test was conducted. The following standards were used:
- EN ISO 6892-1 [9], for testing at room and reduced temperature (-40 ˚C), as shown in Figure 1, and
- EN ISO 6892-2 [10], for testing at elevated temperatures (in this case 200 ˚C, 400 ˚C and 540 ˚C), Figure 2.

The test is conducted using 15 test tubes, with three test tubes used for each temperature.
Figure 1 shows the geometry and actual appearance of the test tubes for room and reduced temperatures.

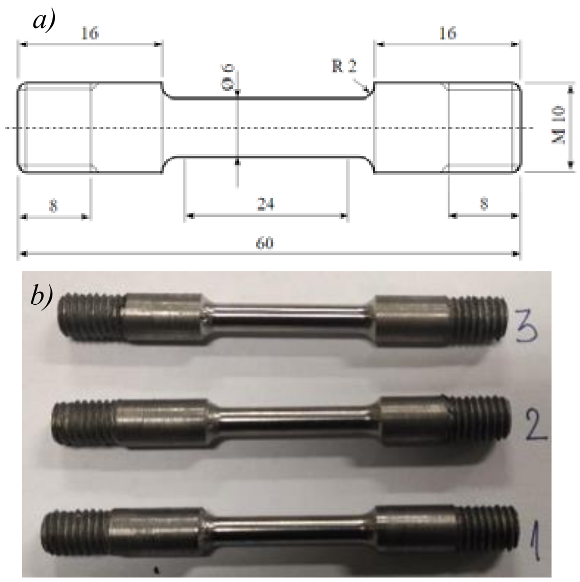

Figure 1 *Review of: a) geometry of test tubes of basic material for testing tensile properties at room and reduced temperature, b) actual appearance of these test tubes*

The geometry of test tubes for testing at elevated temperatures is significantly different from the previous ones, which is shown in Figure 2.

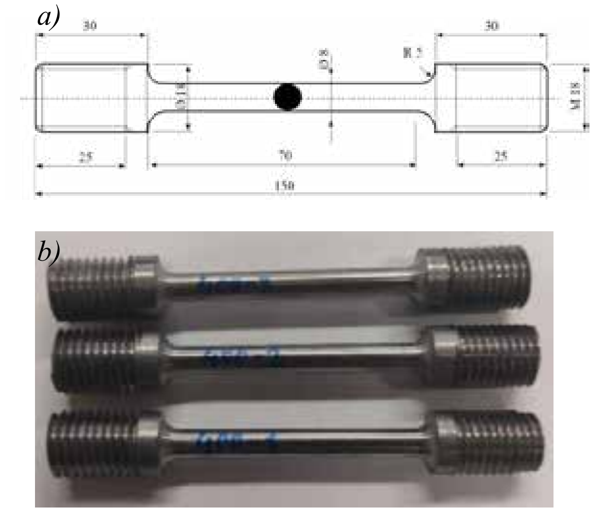

Figure 2 *Test tubes for testing the tensile properties of the base material at elevated temperatures, a) geometry of the test tube, b) appearance of the test tube*

Moreover, the experiment included checking the welded joints on flat test tubes, designed for such tests and according to the standard (EN ISO 4136:2013), as shown in Figure 3.

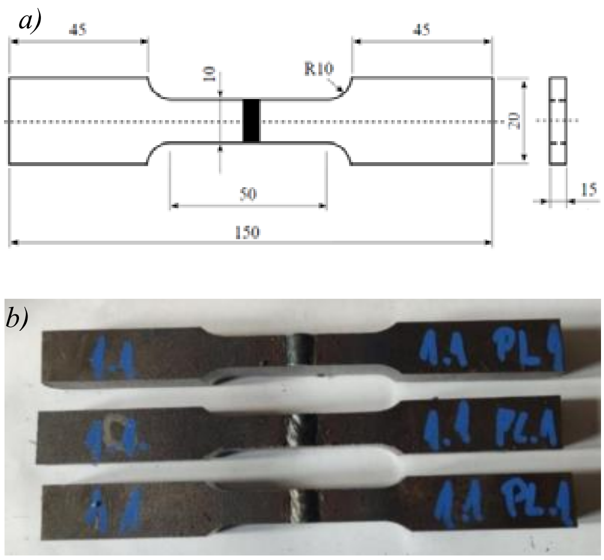

Figure 3 *Test tubes for testing the tensile properties of the welded joint*

Nine test tubes were used for a particular test. These test tubes were obtained from three different welded plates, with three samples taken from each plate. The X-shaped butt-welded joint was created using the REL procedure (procedure 11 according to EN ISO) with the EVB 60 electrode. The welding was carried out in nine passes, where the same electrode was used, but with different diameters: 2.5 mm (passes 1 to 7) and 3.25 mm (passes 8 and 9). The mechanical properties of the additional material EVB 6 are shown in Table 2.

Table 2 Mechanical characteristics of additional material EVB 60

Description - mechanical characteristics	Values
Yield stress $R_{p0.2}$, min.	520 MPa
Tensile strength R_m	620-720 MPa
Elongation A, min.	22 %
Impact energy, A_{uk}, at 40 °C, min.	47 J

The tension of the base material in test tubes was tested at both room temperature and reduced temperature. The test was conducted using a SHIMADZU servo-hydraulic breaker. To test the base material at elevated temperatures and check the test tubes with a welded joint at room temperature, an electromechanics breaker of the same brand was used. During all tests, the load was introduced at a speed of 5 mm/min in both breakers.

3. RESULTS AND DISCUSSION

The test results have shown the introduction of loads has caused significant structural changes, leading to a change in mechanical properties. To illustrate the resulting modifications, Figure 4 displays representative stress-elongation diagrams for three characteristic temperatures: room temperature, lowered temperature of -40 ˚C, and raised temperature of 400 ˚C. These diagrams represent randomly selected test tubes.

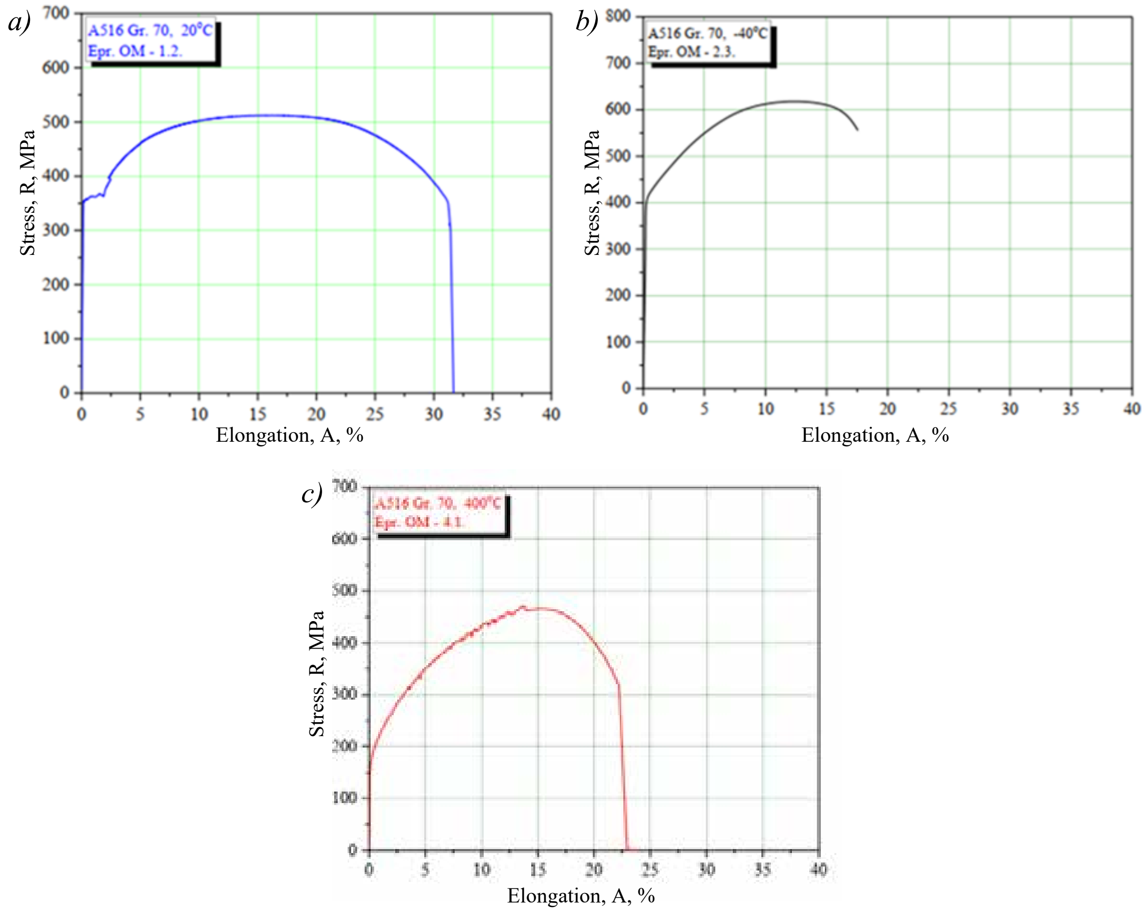

Figure 4 *Representative examples of stress-elongation diagrams of base material test tubes at a) room temperature, b) reduced temperature -40 ˚C and c) elevated temperature 400 °C*

The tests were conducted at five different temperatures, including room temperature, reduced temperature of -40 °C, and elevated temperatures of 200, 400, and 540 °C. The results obtained from each temperature were different from one another. The testing of the base material was done within the standard prescribed values for that material at room temperature. The average value of the yield stress was found to be 370 MPa, the tensile strength was 520 MPa, and the average elongation was 35 %, which represented the largest deformation for all cases.

At a reduced temperature of -40 °C, the deformation value decreased, but the strength value increased. The average yield stress was found to be 414 MPa, the tensile strength was 615 MPa, and the deformation was 18.3 %.

An increase in temperature causes a decrease in yield stress and tensile strength, which in turn leads to a decrease in deformation. At 200°C, the average yield stress is 238 MPa, which decreases to 215 MPa at 400 °C and to 122 MPa at 540 °C. The tensile strength at 200 °C and 400 °C is approximately the same (458 MPa), but it drops to 325 MPa at 540 °C. The percentage of deformation at 200 °C is 18 %, which increases to 22 % at 400 °C and then decreases again to 18 % at 540 °C.

All the mentioned values are shown in the diagram in Figures 5 and 6.

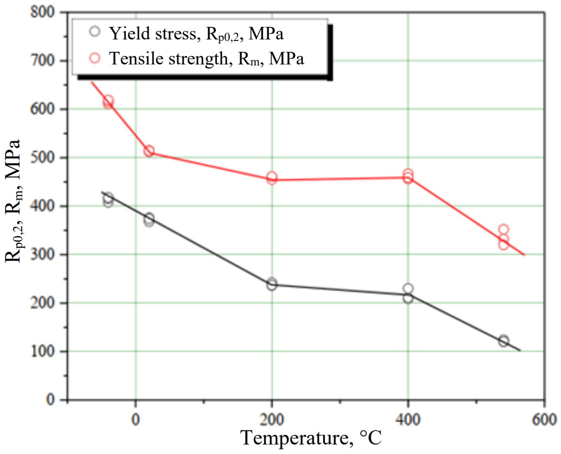

***Figure 5** Change in yield stress $R_{p0.2}$ and tensile stress R_m of the base material depending on the test temperature*

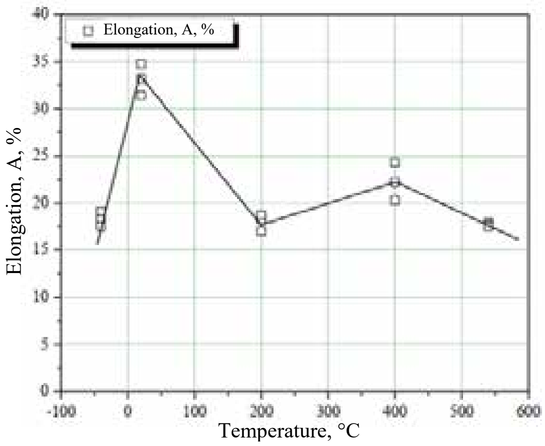

***Figure 6** Change in the elongation value A of the base material depending on the test temperature*

After conducting tension tests on test tubes made of the base material at room temperature, reduced temperature, and elevated temperature, it can be concluded that the results fall within the limits set by the standard for low-alloy carbon steel of quality A516 Gr. 70. This confirms this type of low-alloy carbon steel can be used for a wide range of purposes.

Figure 7 displays a stress-elongation diagram obtained from testing a test tube with a welded joint, which serves as a representative example.

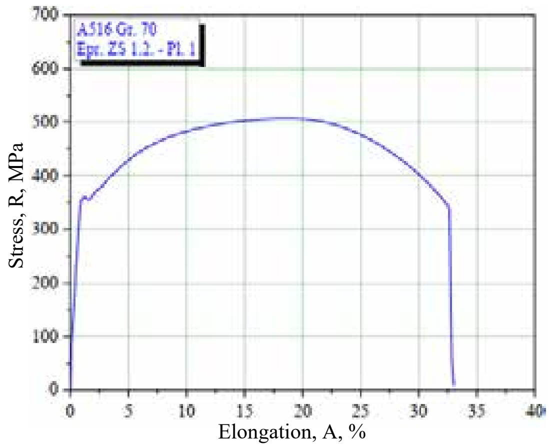

***Figure 7** Representative example of the stress-elongation diagram of a welded tube tested at room temperature*

During the testing of test tubes with a welded joint at room temperature, the aim was to confirm the correct selection of welding technology, which has a direct impact on the strength of the welded joint. All of the tested test tubes broke in the base material, indicating that the welding parameters were chosen correctly. This successful outcome was achieved through the 'over-matching' procedure, in which the strength of the weld metal is greater than the strength of the base material.

4. CONCLUSION

The experimental tensile test results presented in this paper are significant in two segments. Firstly, they confirm that the low-alloy steel A516 Gr. 70 is suitable for use at different temperatures. Secondly, they evaluate the quality of the welded joint. After analysing and discussing the results, the following conclusions can be drawn:

• An increase in temperature leads to a reduction in mechanical properties of strength, such as yield stress and tensile strength.

• Elongation is highest at room temperature, as the overall plasticity of the material increases. Elongation decreases as temperature lowers or increases.

• Welding with the 'over-matching' principle results in a better characteristic of the seam material and greater strength compared to the base material. Experimental testing proved this. At room temperature, tearing occurred in the base material. This suggests that the same could have happened at other temperatures because the weld material created by the over-matching principle is of higher quality.

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