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CREEP PROPERTIES OF GRADE S275JR STEEL AT HIGH TEMPERATURE

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ABSTRACT

The paper describes an ongoing research project which aims to determine the creep properties of European steel Grade 275JR. The purpose of the research is to develop a reliable temperature-, stress- and time-dependent creep model for this alloy, since there is very little information available in the scientific community regarding its creep properties. The research within the project is focused on a series of stationary creep tests, which will be used to obtain time-dependent creep strains in the temperature range 400-600°C. The stress range for which the creep evolution is studied in this project is between 25% and 90% of the value of the stress at 0.2% strain at any particular temperature level. Comparisons between the creep output for the alloy analysed and existing creep data are presented in the paper.

Keywords: Creep strain, Low-carbon steel, S275JR, Fire.

1 INTRODUCTION

Scientific research regarding the creep properties of low-carbon steel has begun to receive broader attention in recent years, because of the increasing use of numerical analysis in performance-based structural fire engineering, and the recognition that its current accuracy is impaired by its reliance on an implicit treatment of creep within a time-independent material model. It is becoming clear that an explicit treatment of high-temperature creep of structural grades of steel is needed; however there is little suitable information available on creep in the scientific literature concerning steels used in the European construction industry. When conducting fire analysis of structures designed to use the grades which are widely used in Europe, such as S235, S275 and S355, structural engineers generally rely on the application of the Eurocode 3 material model [1]. The creep properties of these grades are considered to be represented implicitly in the Eurocode 3 model, which provides data to create a stress-strain curve at any temperature which contains both the stress-related and creep strains. This model was developed mainly from a comprehensive coupon test study conducted by Kirby et al. [2, 3] for steel grades 43A and 50B (S275 and S355) which used transient heating. More specifically, the model was based on coupon tests at various constant stress levels, conducted at a heating rate of 10°C/min. The utilization of such transient testing as a basis for definition of a stress-strain model which includes creep implicitly has left an unanswered question about the validity of this model in cases in which heating rates are below 10°C/min, or even where they vary between different zones of a structural model, which may occur in protected or unprotected steel members exposed to a general fire event.
Recent research [4–6] has pointed out that the implicit material constitutive model from Eurocode 3 cannot be considered as generally applicable for heating rates which differ from 10°C/min, and that it cannot be considered as giving a generally conservative representation of the influence of creep on structural behaviour. This research has also advocated that the creep behaviour of European steel grades should be thoroughly investigated at heating rates other than 10°C/min, and that an explicit creep model needs to be developed in order to take into account the creep evolution in structural fire

analysis in a more appropriate manner. This was the starting ground for a study of the creep properties of steel grade 275JR, which is the current focus of a joint research programme conducted by Universities of Split and Sheffield which aims to explore the influence of creep during fire on the behaviour of steel and aluminium columns, and to develop new creep models for current steel and aluminium alloys.

2 STUDY DETAILS

Creep tests are currently being conducted in the Engineering Mechanics laboratories at the University of Rijeka. The research focuses on conducting constant-stress-rate and stationary creep tests in order to determine time-dependent creep strain values in the temperature range 400-600°C.
Constant-stress-rate tests are conducted at a specified temperature level in order to determine: the stress at 0.2% strain; the yield strength and modulus of elasticity; and the stress-strain curve of the steel. A stationary creep test is a test in which a coupon specimen is heated to a target temperature level and then loaded to a constant stress level which is maintained for a prescribed time period (up to about 20 hours, depending on the temperature level). The stress range within which the creep propagation is analysed in the study will be between 25%-90% of the stress value at 0.2% strain at the corresponding temperature.
The test rig is shown in Figure 1(a). It comprises a mobile electric furnace (1) capable of heating the coupon to 900°C, and a hydraulic tension machine (2) which can apply a maximum tensile force of 400 kN. The coupon displacement is recorded during the test using a high-temperature extensometer (3). Outside the gauge length, both ends of the coupon are threaded to match the platens of the testing machine. Test coupons for constant-stress-rate and stationary creep tests were manufactured from the column flanges of a European HE140B steel section. The HE140B columns are scheduled for testing, and verification of their creep properties, within the third year of the project. The coupon shape and geometry used in these investigations is presented in Figure 1(b).
The test procedure to determine a stress-strain curve includes: pre-heating of the coupon to a target temperature at a heating rate of 15°C/min; soaking of the specimen at the target temperature for 30 minutes; loading the specimen at the prescribed stress-rate of 10MPa/s. The constant-stress-rate tests are planned to use temperatures of 20°C, 100°C, 200°C, 300°C, 400°C, 450°C, 500°C, 550°C and 600°C. In the test procedure to determine a stationary creep curve the pre-heating to the target temperature is conducted at the same heating rate, but soaking to the target temperature lasts for 60 minutes; the specimen loading is then applied and maintained at the prescribed stress-level value. These creep tests are planned to use temperatures of 400°C, 450°C, 500°C, 550°C and 600°C. The constant-stress-rate and stationary creep tests follow the guidelines of ASTM:E8M-11 for ambient temperature tests and ASTM:E21-09 for high temperature tests.

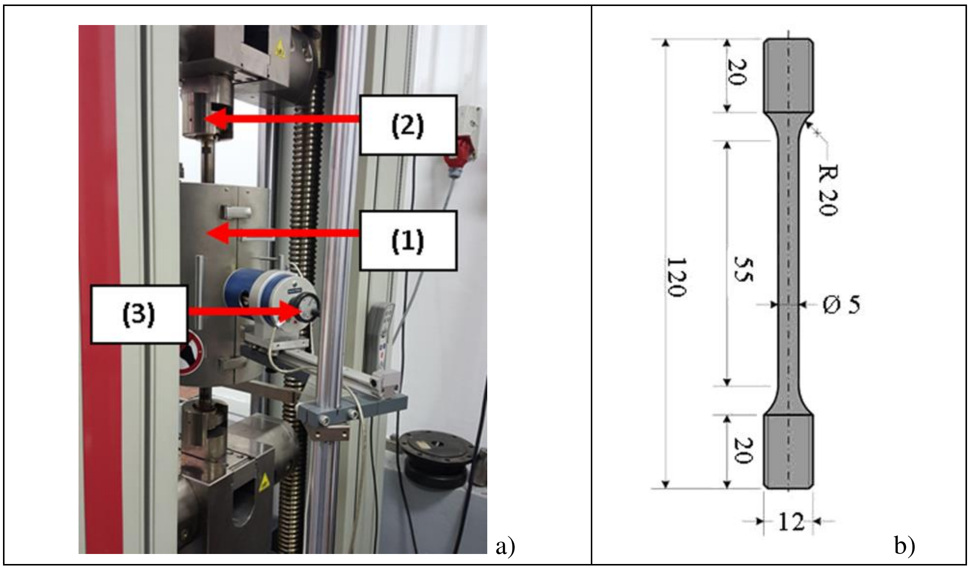

Figure 1. Test details for determining the creep properties of grade S275JR a) Test setup; b) Test coupon.

The chemical composition of the 275JR steel analysed, obtained by optical spectrometer testing is presented in Table 1.

Table 1. Chemical composition mass [%]

C	Si	Mn	P	S	Ni	Cr	Mo	Cu	Al	Rest
0.186	0.245	0.653	0.010	0.005	0.167	0.078	0.028	0.319	0.011	98.30

3 TEST RESULTS AND COMPARISON

A limited sample of the test results is presented in this chapter. Test results, in the form of engineering stress-strain relationships, obtained from constant-stress-rate curves at 10MPa/s are presented in Figure 2.

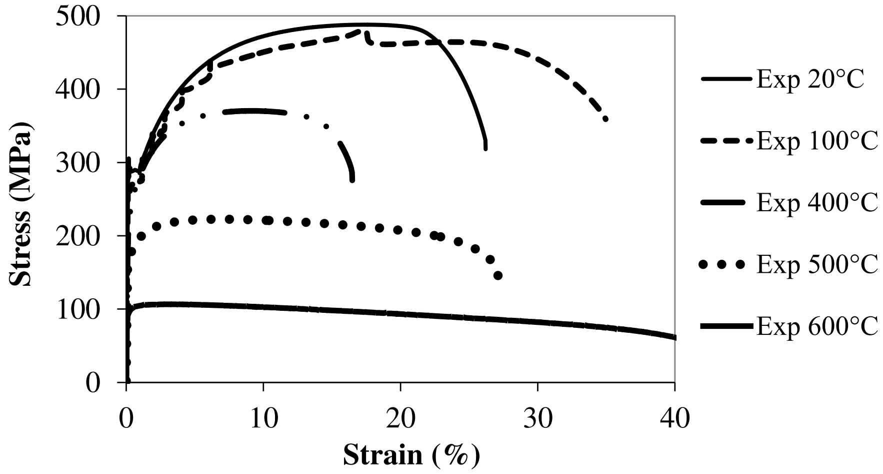

Fig. 2. Constant stress-rate test results at 10MPa/s.

Figure 3 presents a comparison between the stress-strain curves from the current tests and the curves from Kirby et al. [2, 3], normalized with respect to ambient-temperature yield strength for the strain range up to 1%.

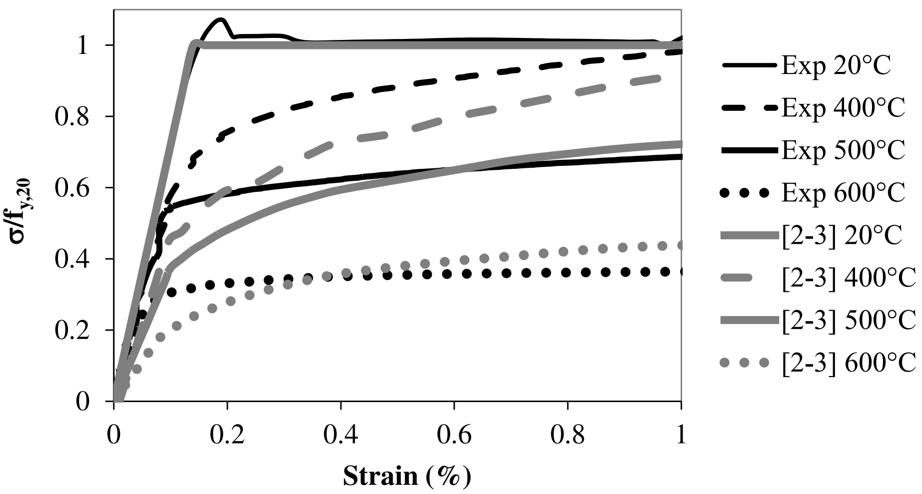

Figure 3. Comparison between the experimental stress-strain curves and the results from studies [2, 3].

Test results, in the form of stationary creep curves at 500°C are presented in Figure 4 for various stress levels.

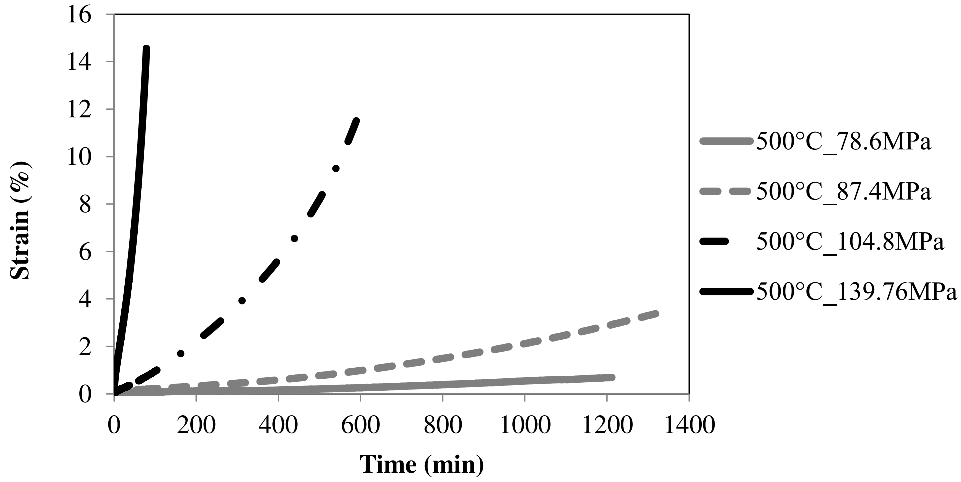

Figure 4. Stationary creep test results – 500°C.

Table 2 presents the test data obtained from constant-stress-rate tests, where $f_{0.2,\theta}$ represents the stress value at 0.2% strain, and $k_{0.2,\theta}$ represents the reduction factor for the stress at 0.2% strain, relative to that at normal temperature.

Table 2. Test results for stress at 0.2 % strain

Temperature (°C)	Stress $f_{0.2,\theta}$ (MPa)	$k_{0.2,\theta}=f_{0.2,\theta}/f_{0.2}$
20	287.5	1.0
100	266.4	0.93
400	239.3	0.83
500	174.7	0.66
600	97.6	0.34

Figure 5 presents a comparison of the newly obtained creep-test results and those published from study [7], which seems the only creep study available in literature for the tested alloy, at 400°C.

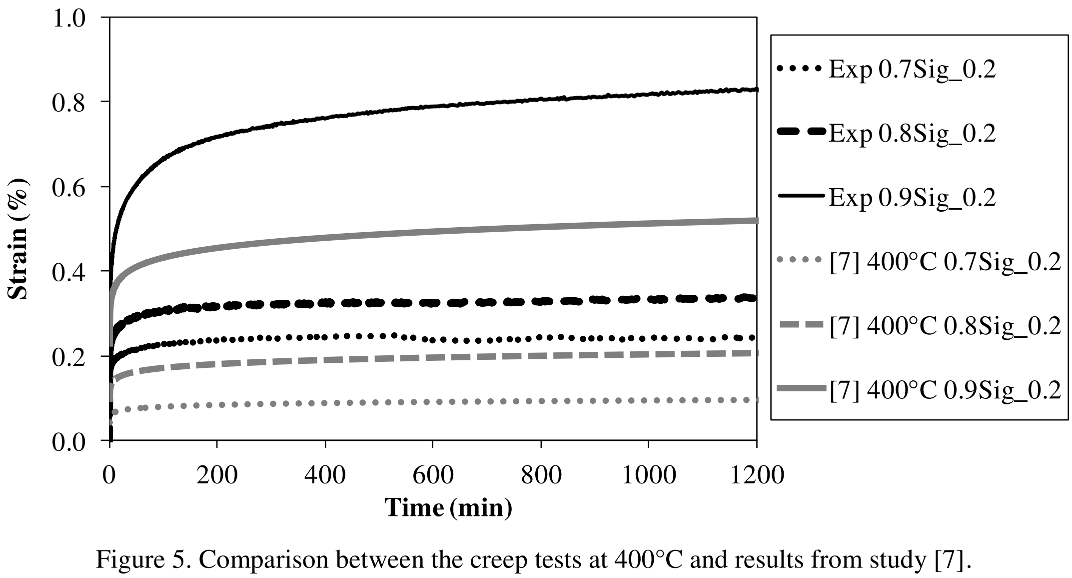

Figure 5. Comparison between the creep tests at 400°C and results from study [7].

4 DISCUSSION OF CURRENT RESULTS AND FURTHER RESEARCH

The curves presented in Figure 3 illustrate the amount of implicit creep which is contained in the Eurocode 3 stress-strain model, since the experimental stress-strain curves originate from fast stress-rate tests embodying a negligible amount of creep, whereas Kirby's tests are closely reproduced in Eurocode 3. The difference between curves at any temperature is pronounced in the region up to 1.0% strain, at which the implicit creep component is approximately twice the stress-related strain. This comparison shows the need for development of a creep-free stress-strain model for structural steels [5, 6, 8] when conducting a proper explicit creep analysis of structural behaviour in fire. This is necessary, so that creep effects are not to be treated twice in a structural fire analysis.

Observation of the test results from Figure 4 shows clearly that Grade 275JR experiences significant creep when exposed to stress values above 87.4 MPa ($0.5f_{0.2,\theta}$) at 500°C. Another parameter which should not be neglected is the time of occurrence of creep phases. A fire duration of four hours can be considered as a general time interval for studying the influence of creep on structural response. It is notable that the tertiary phase at 500°C occurs within this total time interval for all stress values above $0.5f_{0.2,\theta}$. This suggests that the creep resilience of Grade S275 can be considered as rather low at 500°C for mid-range stresses.

Figure 5 indicates that a fairly good estimate of the creep initiation temperature for S275JR is around 400°C; this is emphasized by the very low values of creep strain in the first four hours of the creep test at this temperature. Comparison with the one existing study of the creep properties of S275JR [7] indicates that the order of magnitude of creep strain at various stress levels is comparable to those from creep tests from the current study at 400°C.

Further research on this topic will concentrate on providing a reliable analytical creep model for Grade S275 which is temperature-, stress- and time-dependent, as well as the ultimate creep temperature which should provide the lowest value of creep resilience for the analysed steel grade.

5 ACKNOWLEDGMENT

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