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Impact of High Temperature Creep on the Buckling of Axially Compressed Steel Members

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Abstract. The paper presents results of the laboratory tests of the impact of creep on the buckling of axially compressed steel members at elevated temperatures. Tests were conducted on samples prepared of normal strength steel (S235JR) and high strength steel (S355J2). Samples were made in the form of a prismatic bar of a rectangular cross section 12 x 30 mm and a length of 500 mm. Support type of the specimens during tests was hinged on both ends. The tests were done at 600, 700 and 800°C. Experiments were carried out at static loads corresponding to values $0{,}8N_{cr,T}$, $0{,}9N_{cr,T}$, $1{,}0N_{gr,T}$, where $N_{cr,T}$ was theoretical value of Euler's critical load at given temperature. Short-term creep analyses were performed in the universal testing machine Instron/Satec KN 600 equipped with a furnace for high-temperature testing type SF-16 2230, that enables testing at temperatures up to 1200°C. Temperature of the sample placed inside the furnace was verified and recorded with use of the compact RIO cRIO-9076 controller, equipped with a module for the connection of NI 9211 and K-type thermocouples. The system for the measurement and recording of the temperature of the analysed samples operated in the LabVIEW software environment. To measure lateral and longitudinal displacements LVTD Solatron ACR 100 displacement transducer was used. During the tests, the samples were heated to the given temperature (600, 700 or 800°C) and then subjected to a constant compressive load. During each test, for each sample following data was registered: the temperature on the surface of samples, longitudinal and lateral displacements in the middle of the sample. Basing on the conducted tests it was noted, for both analysed steel types, at the temperature of 800°C, growth of lateral displacements due to creep was very rapid, and tested elements were losing bearing capacity over the period of tens to hundreds of seconds, depending on stress level and the grade of the steel. At a temperature of 700°C growth of lateral displacements was much slower and the total loss of the bearing capacity of tested samples has occurred after 2 to 5 hours. At the temperature of 600°C samples did not show significant increments of lateral displacements at the test duration more than 6 hours, while maintaining throughout the test rectilinear form.

1. Introduction

Steel structures at elevated temperatures, are characterised by a significant decrease of bearing capacity, increased flexibility and deformations. Method of designing steel structures in the case of fire are included in code PN-EN 1993-1-2 [1]. This standard takes into account the temperature-dependent material properties and stiffness of the elements and loads associated with the thermal deformation. It also allows, provided the use of code depending on the stress-strain, to omit the effects associated with high temperature creep. However, literature studies of this problem, indicate that the impact of high temperature creep on bearing capacity of steel elements under compressive load may be important and should not be overlooked [2, 3].

Presented in this paper results of investigation aimed to determine the influence of short-term creep at elevated temperatures on buckling of axially compressed steel elements. The data collected during tests can be used in future to create numerical model, which will allow predict bearing capacity of axially compressed elements at elevated temperatures.

2. Materials and methods

Study on the influence of creep on the buckling of axially compressed steel members at elevated temperatures was conducted on samples prepared of normal strength steel (S235JR) and high strength steel (S355JR). Chemical composition of analysed steels is shown in table 1. Basic mechanical properties of steel, according to PN-ISO 6892-1 [4], are shown in table 2.

Table 1. Chemical composition of the tested steels

	Chemical composition (mass %)											
	Fe	C	Mn	Si	P	S	Cr	Ni	Mo	V	Cu	Ti
S235JR	98,681	0,133	0,575	0,188	0,021	0,026	0,044	0,098	0,022	0,001	0,208	0,003
S355J2	97,981	0,157	1,388	0,203	0,025	0,019	0,064	0,044	0,020	0,043	0,054	0,004

Table 2. Basic mechanical parameters of the tested steels

	R_{eL} [MPa]	R_{eH} [MPa]	R_m [MPa]	R_t [MPa]
S235JR	342	359	448	322
S355J2	409	431	530	361

Samples from both analysed steels were made in the form of a prismatic bar of a rectangular cross section 12 x 30 mm and a length of 500 mm.

All provided tests were done at 600, 700 and 800°C. Experiments were carried out at static loads corresponding to values $0.8N_{cr,T}$, $0.9N_{cr,T}$, $1.0N_{gr,T}$, where $N_{cr,T}$ was theoretical value of Euler's critical load at given temperature calculated according to formula (1):

$$N_{cr,T} = \frac{\pi^2 E_{a,\theta} J}{l_{cr}^2} \quad (1)$$

where:
$E_{a,\theta}$ – theoretical value of elasticity modulus at given temperature,
J – minimum moment of inertia of the cross section,
l_{cr} – buckling critical length

Theoretical values of elasticity modulus at given temperature $E_{a,\theta}$, were established according to code PN-EN 1993-1-2 [4], using coefficient $k_{E,\theta.}$

Short-term creep analyses were performed in the universal testing machine Instron/Satec KN 600 equipped with a furnace for high-temperature testing type SF-16 2230, that enables testing at temperatures up to 1200°C. Temperature of the sample placed inside the furnace was verified and recorded with use of the compactRIO cRIO-9076 controller, equipped with a module for the connection of NI 9211 and K-type thermocouples. The system for the measurement and recording of the temperature of the analysed samples operated in the LabVIEW software environment. To measure lateral and longitudinal displacements LVTD Solatron ACR 100 displacement transducer was used. Displacements parallel to the longitudinal axis of the bar was monitored by a sensor connected to the hydraulic cylinder of the testing machine. Anchorage of the samples was made using a specially designed adapters, fastened to the clamps of Instron machine. Support type of the specimens during tests was hinged on both ends. The view of the test stand is shown in Figure 1.

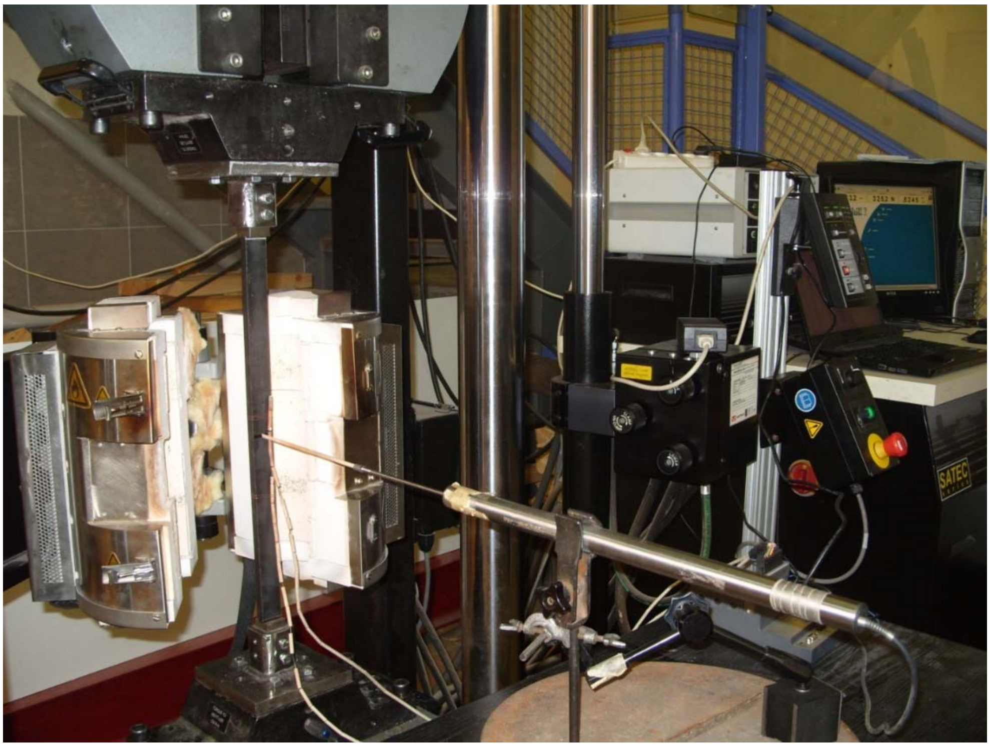

Figure 1. Test stand

Unloaded samples were heated to achieve the assumed level of temperature, and then maintained at this temperature for 60 minutes. After this time samples were loaded with constant force of the determined level. During each test, for each sample following data was registered: the temperature on the surface of samples, longitudinal and lateral displacements in the middle of the sample.

3. Results and discussions

The studies indicated relationship between the time of creep and displacement perpendicular to the longitudinal axis of the test piece. Examples of the measurement curves for samples of steel S235JR is given in Figure 2, for steel S355J2 in Figure 3.

In figure 4 and 5 was shown relationship between average time of creep, after which was followed a total loss of stability (as a result of creep) of tested elements, and compressive stresses caused by constant load.

Analysing the data summarized in the drawings it can be concluded that the effect of growth of creep displacement perpendicular to the axis of the compressed axially bar is significant at temperatures of 700°C and 800°C. This effect is revealed more clearly in higher temperatures and stresses in the cross-section of tested samples. At the temperature of 800°C, growth of lateral displacements due to creep was very rapid, and tested elements were losing bearing capacity over the period of tens to hundreds of seconds, depending on stress level and the grade of the steel. At a temperature of 700°C growth of lateral displacements was much slower and the total loss of the bearing capacity of tested samples has occurred after 2 to 5 hours. At the temperature of 600°C samples did not show significant increments of lateral displacements at the test duration more than 6 hours, while maintaining throughout the test rectilinear form.

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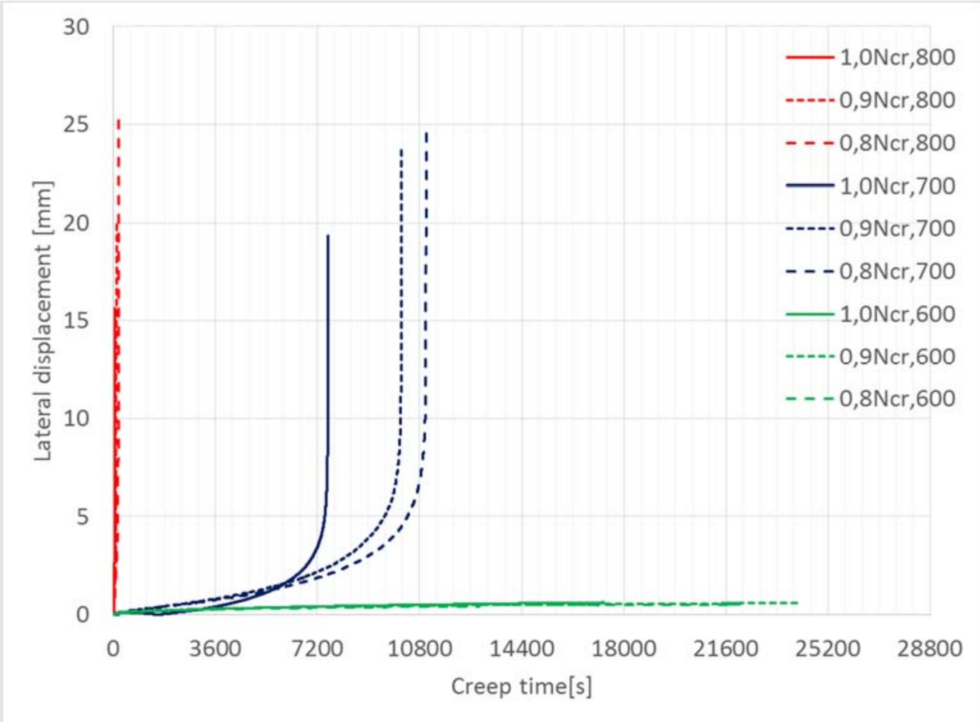

Figure 2. Sample relations of lateral displacement and creep time, steel S235JR

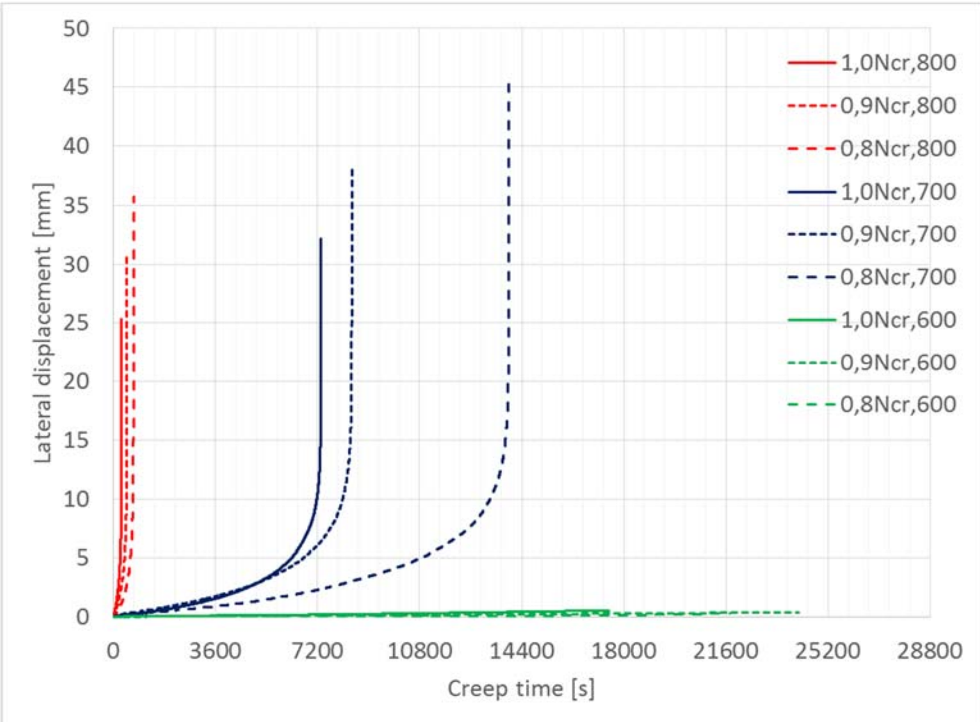

Figure 3. Sample relations of lateral displacement and creep time, steel S355J2

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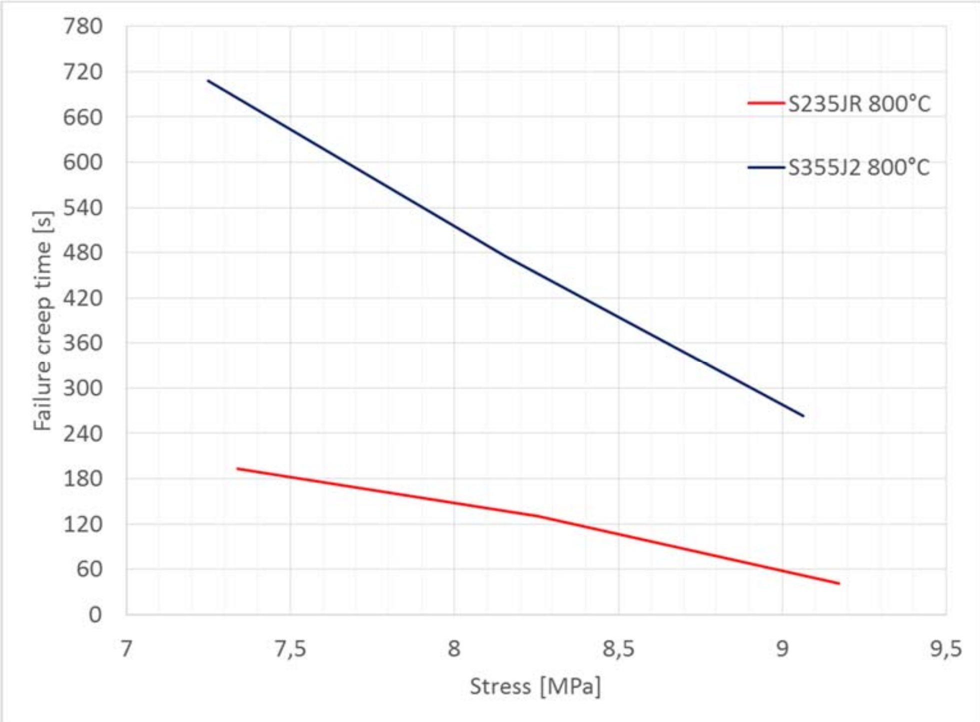

Figure 4. Dependence of failure creep time on compressive stress at temperature of 800°C

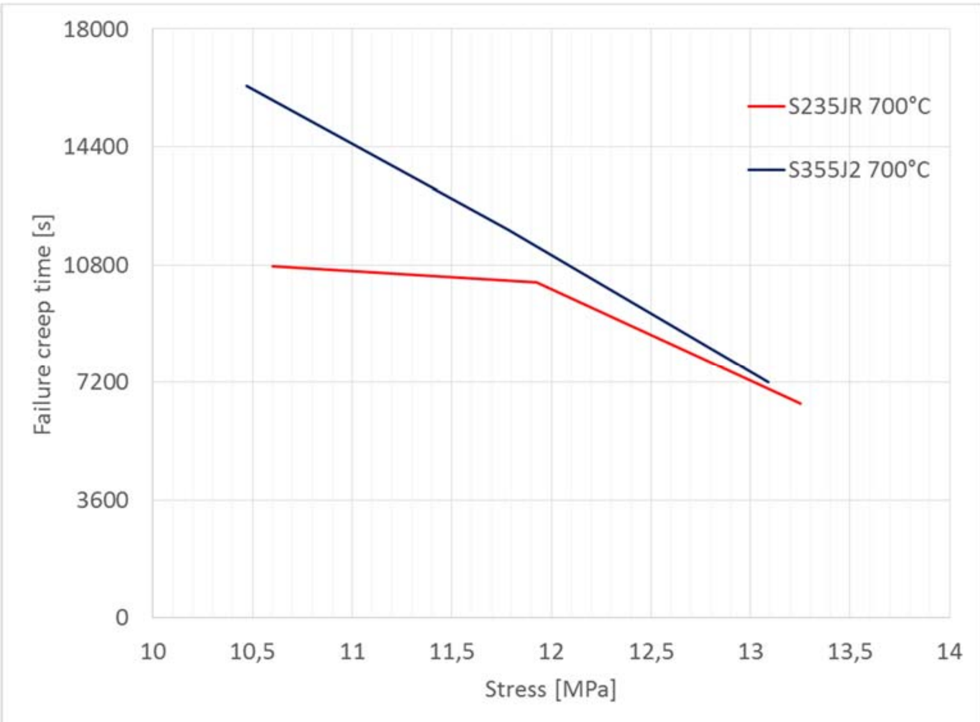

Figure 5. Dependence of failure creep time on compressive stress at temperature of 700°C

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4. Conclusions
The results show a significant effect of short-term high-temperature creep on increase of lateral displacement of axially compressed steel elements at temperatures above 600ºC. Influence of creep on bearing capacity of axially compressed elements, increases with temperature and magnitude of acting loads. In temperature equal to 600°C there was no significant influence of short-therm creep on buckling capacity of tested elements even after 6 hours of tests.

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