High-temperature properties of aluminum alloy EN6082AW T6

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ABSTRACT: Aluminium structures have slowly begun to take their place in modern engineering practice as a suitable material for building structures. However, the mechanical properties of aluminium at normal and high temperature are relatively unknown due to large number of available alloys on the market. High-temperature behaviour of aluminium alloys is especially important to explore due to fast degradation of aluminium's mechanical properties when exposed to temperatures up to 400°C. The paper presents constant stress-rate and stationary creep tests conducted on aluminium alloy EN6082AW T6 and analyses its performance with respect to common fire resistance intervals. The paper also presents an insight into ongoing research project concerning mechanical and creep properties of mentioned aluminium alloy, from which the presented data stems from.

1 INTRODUCTION

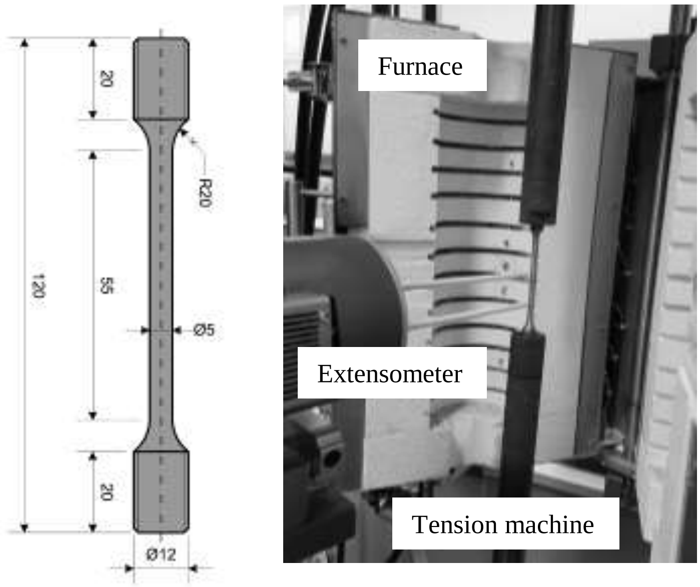
Although aluminium is slowly being accepted as a construction material, its properties and behaviour at high temperatures are still subject of various research studies (Maljaars et al. 2009; Maljaars et al. 2010). When subjected to fire, creep deformations play a significant part in overall increase of the displacements (Maljaars et al. 2010; Zheng and Zhang 2016), and its value is highly dependent on the type of aluminium alloy being used for construction (Maljaars et al. 2010). Moreover, increased deformations are paired with rapid reduction in strength and stiffness within the temperature interval of 100-400°C (Maljaars et al. 2010). The development of European design codes (Eurocode 9, 2007) has significantly facilitated structural applications for aluminium (Skejić et al. 2015), but with very little information regarding alloys' creep properties at high temperatures.

The paper presents mechanical and creep properties of aluminium alloy EN6082AW T6, which is commonly used for structural application. Its main characteristic is high proof strength ($f_{0.2}$), which has a value above 260 MPa at normal temperature, which makes it comparable to steel grade S275 when comparing strength classes. A motivation for the research of creep properties arises from the fact that at the moment there is no valid creep model for this alloy present in the European scientific community.

The coupon study presented here is part of a joint research programme (Croatian Science Foundation project no. UIP-2014-09-5711) conducted by Universities of Split and Sheffield, aiming to explore the influence of creep on the behaviour of steel and aluminium columns in fire, and to develop new creep models for current steel and aluminium alloys. The creep tests are currently being conducted at University of Rijeka. The research within the project is momentarily focused on conducting stationary creep tests and determining time-dependent creep strain values within the range 150-300°C. Additional tests for the mentioned alloy include constant stress-rate tests on coupons for the purpose of determining the mechanical strain model for aluminium.

2 TEST SETUP

In order to evaluate the influence of creep strain on aluminium columns, analysis of mechanical and creep properties of alloy EN6082AW T6 has been carried out. Test coupons for stationary creep and constant stress-rate tests were manufactured from the column flanges of an aluminium H-section 220x170x9x15mm, as shown in Figure 1a.



(a) (b)

Figure 1. Test coupon and setup for determining the creep properties of alloy EN6082AW T6

These columns are planned for testing in later stages of the project by using fire scenarios that will induce significant development of creep strain. The test procedure for determining mechanical properties of aluminium is as follows. The coupons are pre-heated at a rate of 15°C/min up to the target temperature, soaked at the target temperature for 30 minutes and then loaded at a uniform stress-rate of 10MPa/s. Coupons intended for creep tests are subjected to a stationary creep testing procedure. Pre-heating is likewise done at a rate of 15°C/min up to the target temperature, while soaking of the specimen lasts for 60 minutes. Thereafter the loading is applied and maintained at the prescribed stress-level value.

The test setup within the study is presented in Figure 1b. The test rig consists of a mobile electric furnace capable of heating the coupon up to 800°C and a hydraulic tensile testing machine. The specimen's displacement is recorded using high-temperature extensometers. The setup is located at the Engineering Mechanics laboratories at the University of Rijeka-Faculty of Engineering, where all tests have been carried out by following the guidelines of ASTM:E21-09 for conducting high temperature material tests (ASTM International 2009) and of ASTM:E8M-11 for conducting normal temperature tests (ASTM International 2011).

3 TEST RESULTS AND DISCUSSION

Constant stress-rate and stationary creep tests have been conducted at 20°C, 150°C and 200°C so far. The tests are planned up to approximately 400°C. This temperature test range is chosen since aluminium experiences strength reduction at moderately elevated temperatures, at which fire insulation materials should be applied as a fire safety measure. Constant stress-rate test results are shown in Figure 2.

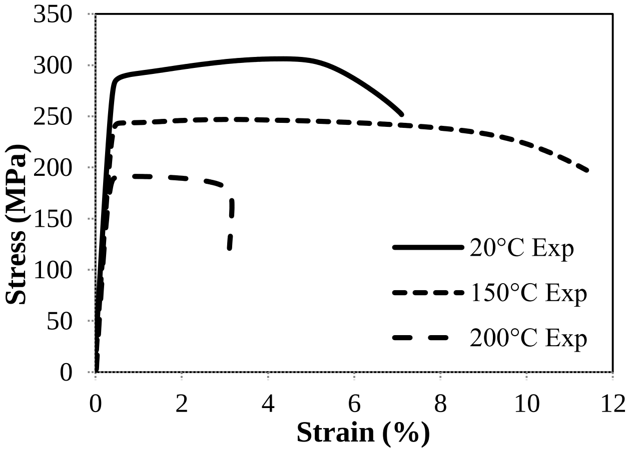


Figure 2. Constant stress-rate test results at 10MPa/s (engineering values).

By applying the test result to a well-known Ramberg-Osgood model, an analytical expression for stress-strain curve can be obtained. The strain at given temperature *Θ* is defined as:

$$\varepsilon_\sigma = \frac{\sigma}{E_{y,\theta}} + 0.002\left(\frac{\sigma}{f_{0.2,\theta}}\right)^n \tag{1}$$

where *n* is an exponent which characterizes the degree of hardening of the curve, and within the range of plastic deformations is defined as:

$$n = \frac{\ln(0.002/\varepsilon_{u,\theta})}{\ln(f_{0.2,\theta}/f_{u,\theta})} \tag{2}$$

Where: the elasticity modulus ($E_{y,\Theta}$), proof strength ($f_{0.2}$), ultimate strength ($f_{u,\Theta}$) and residual strain ($\varepsilon_{u,\Theta}$) can easily be obtained from the test results presented in Figure 2. Values obtained from the presented tests are shown in Table 1.

Table 1. Parameters obtained from constant stress-rate tests.

Temperature	$E_{y,\Theta}$	$E_{y,\Theta}/E_{y,20}$	$f_{0.2.\Theta}$	$f_{0.2.\Theta}/f_{0.2}$	$f_{u.\Theta}$	$\varepsilon_{u,\Theta}$	n
°C	GPa		MPa		MPa	%	
20	71	1	288.0	1	306.2	3.9	49
150	65	0.92	243.3	0.84	246.9	2.8	179
200	65	0.92	190.4	0.66	191.3	4.0	144

Comparison between the experimental results and the Ramberg-Osgood model is shown in Figure 3.

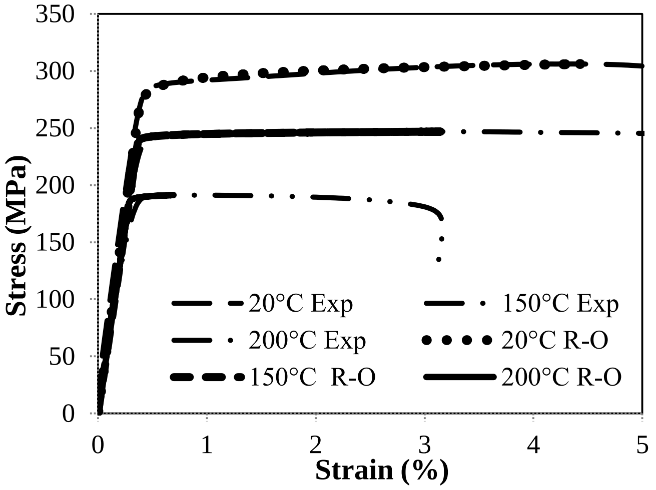


Figure 3. Ramberg-Osgood model compared to experimental results.

The output of the entire coupon study will include a full mechanical stress-strain model up to 400°C. Results of preliminary stationary creep tests at 150°C and 200°C are shown in Figure 4. They were performed at constant stress level which is defined as a percentage of proof strength at particular temperature level ($f_{0.2,\theta}$), as specified in Table 2.

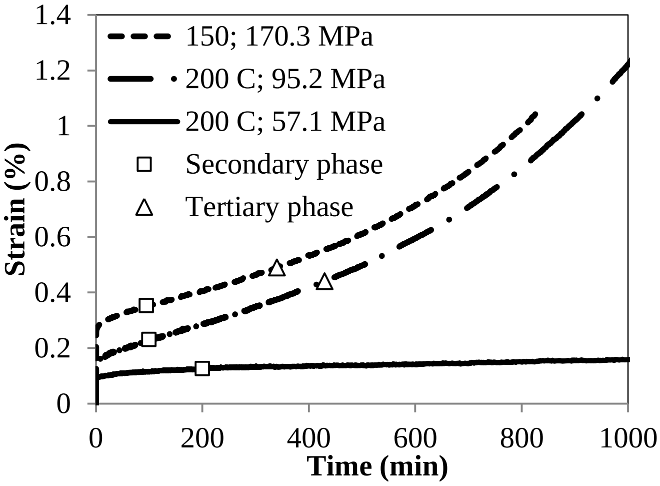


Figure 4. Stationary creep test results (150-200˘C).

As expected, creep tests from Figure 4 show primary, secondary or steady-state creep stage at each temperature level and the occurrence of tertiary creep phase at 150-200°C at higher stress levels. It can be seen that the tertiary creep phase, i.e. the range in which creep strain rate increases exponentially with time until steel rupture occurs, does not occur at stress level of $0.3f_{0.2,\theta}$ at 200 °C. Table 2 also shows the time points when each of the creep phases have manifested itself, including the strain level. It can be seen that the secondary creep phase manifest itself during the first 240 minutes for all creep tests, which can be considered as a relevant in fire conditions which may last up to four hours. Additionally, it can be assumed that at slightly higher stress level (in the temperature range of 150-200°C) the occurrence of tertiary creep phase will manifest itself within the interval of 240 minutes.

Table 2. Parameters of creep tests.

Temperature	Stress σ	$\sigma/f_{0.2}$	Secondary phase		Tertiary phase	
°C	MPa	%	min	%	min	%
150	170.3	70	95	0.35	340	0.49
200	57.1	30	200	0.13	-	-
200	95.2	50	100	0.23	430	0.44

4 CONCLUSIONS AND FURTHER RESEARCH

The test results presented in the paper have shown that creep in aluminium develops within the temperature interval at which mechanical properties are starting to reduce (100°C and beyond), indicating that creep should be taken into account in structural fire modeling together with the reduction of mechanical properties. Creep tests in temperature interval up to 200°C have shown that secondary creep phase manifests itself within the time interval of 240 minutes, which may induce potential failure mechanisms in columns during fire exposure. Further tests within the project will focus on a development of a mechanical stress-strain model up to a temperature of 350-400°C, including the development of an analytical creep model that takes into account all three distinctive creep phases. The temperature interval in which creep tests are planned will be marked with two distinctive temperature values: the temperature value at which creep starts to develop (i.e. insignificant creep temperature) and up to a temperature value where the alloy has minimal creep resistance (ultimate creep temperature).

5 ACKNOWLEDGEMENT

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