SUSTAINIBILITY OF ALUMINIUM IN CONSTRUCTION PRACTICE – RECENT FIRE RELATED RESEARCH

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SUMMARY: The positive attributes of aluminium as a modern building material in construction practice have been used as background for a more intense application of this material type throughout the 21st century. Favourable properties of aluminium include most of the aspects of sustainability within the period of exploitation of the structure. One of the major problems with the application of aluminium in construction industry is the inherent fire resistance which needs further research if aluminium is to be more widely applied in construction practice. This paper describes research activities of an ongoing research project examining the mechanical and creep properties of aluminium alloy EN6082AW T6 exposed to fire. The research presented here is part of a joint research programme (the Croatian Science Foundation project No. UIP-2014-09-5711) conducted by the Universities of Split and Sheffield, whose aim is to explore the influence of creep on the behaviour of steel and aluminium columns in fire, as well as to develop new creep models for structurally relevant steel and aluminium alloys. The output of this research can be used to assess the level of sustainability of aluminium in construction practice with respect to fire resistance requirements.

KEY WORDS: Sustainability, fire, creep, aluminium, EN6082AW T6.

1 INTRODUCTION

Within the last seven decades aluminium has taken its position in civil engineering as a material for both, structural and non structural applications. Late application of this material can be explained trough high initial costs and great amount of energy consumption during production [1], which also resulted in later development of the design codes [2, 3]. Competitive features of aluminium in construction practice include good mechanical behaviour paired with low weight, corrosion resistance, high reflectivity and various design possibilities [4, 5]. Consequently, aluminium structures are most likely to be used in not easily accessible areas where erection and maintenance phases need to be simplified, or in highly corrosive environments (roof trusses, transmission line towers, window frames, cladding systems, bridges, etc.).

Despite the mentioned shortcomings in the initial stage, when considering its overall lifecycle, aluminium produces a significant reach in the framework of sustainability. Its advantages make it an ideal fit for building energy efficient building envelopes, or for improving energy efficiency of existing buildings. Aluminium also has a very long life cycle (30-50 years) paired with low maintenance costs [1]. Moreover, aluminium has an excellent recyclability, with its life cycle being almost indefinite and the energy required for recycling being only 5% of the energy required for its original manufacture [6]. As a consequence, the majority of the aluminium in the EU today is made out of the recycled materials [6], and the amount of aluminium produced today creates new reserves. It should be also noted that aluminium has a wide family of alloys. The ones we refer here are heat treatable wrought alloys of 6xxx series, as they are the most commonly used in the construction industry today. In general, mechanical properties of aluminium are the key parameter in quantifying the response of aluminium structures in fire conditions. This represents the main motivation for exploring the mechanical and creep properties of alloy 6082AW T6 with the aim of further exploring its sustainability aspects. The paper presents a description of tests conducted at University of Split and University of Rijeka, including some test results.

2 TEST SETUP AND METHODOLOGY FOR DETERMINING HIGH-TEMPERATURE PROPERTIES

In metals, three different strain components exist when exposed to high temperature. Each of these components requires a specific test methodology for quantifying its values. Testing within the research project is planned in such a way as to obtain the stress-related strain and creep strain separately at different temperatures, according to the total temperature-dependent strain relationship [7]:

$$\varepsilon_{tot} = \varepsilon_{th}\left(T\right) + \varepsilon_{\sigma}\left(\sigma, T\right) + \varepsilon_{cr}\left(\sigma, T, t\right) \qquad (1)$$

where: ε_{tot} – total strain, $\varepsilon_{th}(T)$ – thermal strain (function of temperature T), $\varepsilon_{\sigma}(\sigma,T)$ – stress related strain (functions of both the applied stress σ and temperature T) and $\varepsilon_{cr}(\sigma,T,t)$ – time-dependent creep strain (function of stress, temperature and time). It can be seen from Equation (1) that creep strain is dependent on all three variables, which makes it the most complex of the strain components.

Generally, there are three main creep phases during exposure to a constant stress and temperature, as seen in Figure 1. In the primary creep stage, the creep strain rate is relatively high, but decreases with time. During the secondary creep phase, creep strain rate gradually becomes constant. This is also known as steady-state creep. During the tertiary creep phase, creep strain rate increases exponentially with time until steel rupture occurs. It can be observed from Figure 1 that, at higher temperatures and stress levels, the boundaries between the three stages is not as evident as in it is the case of lower temperature and stress exposure. Consequently, only the primary and secondary creep phases are usually taken into account in most structural fire resistance analyses.

Material parameters represent an important factor in the creep analysis, since the metallurgical composition of an alloy has a significant effect on the creep strain development at different temperature levels. Subsequently, a new study within the project for deriving material parameters for steel and aluminium creep analysis is planned.

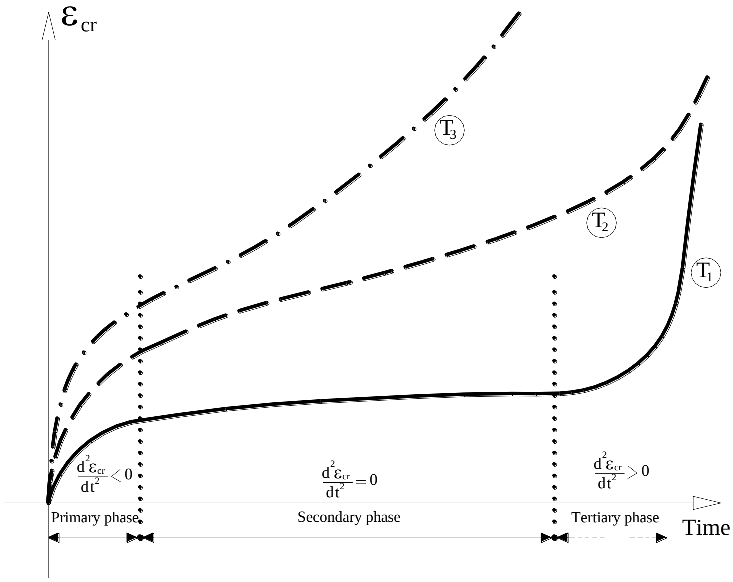

Figure 1. Creep phases at high temperature (T1< T2< T3)

Two different types of test within the research project were conducted in order to obtain stress-related and creep strains. The first is a constant stress-rate test which is used to determine the stress-related strain. The test procedure consists of a pre-heating phase (heating rate of approximately 15°C/min), soaking phase (approximately 30 min) during which the coupon achieves uniform temperature distribution, and the loading phase (uniform stress rate of10 MPa/s). This test type induces a negligible amount of creep strain during the test since it represents a fast test.

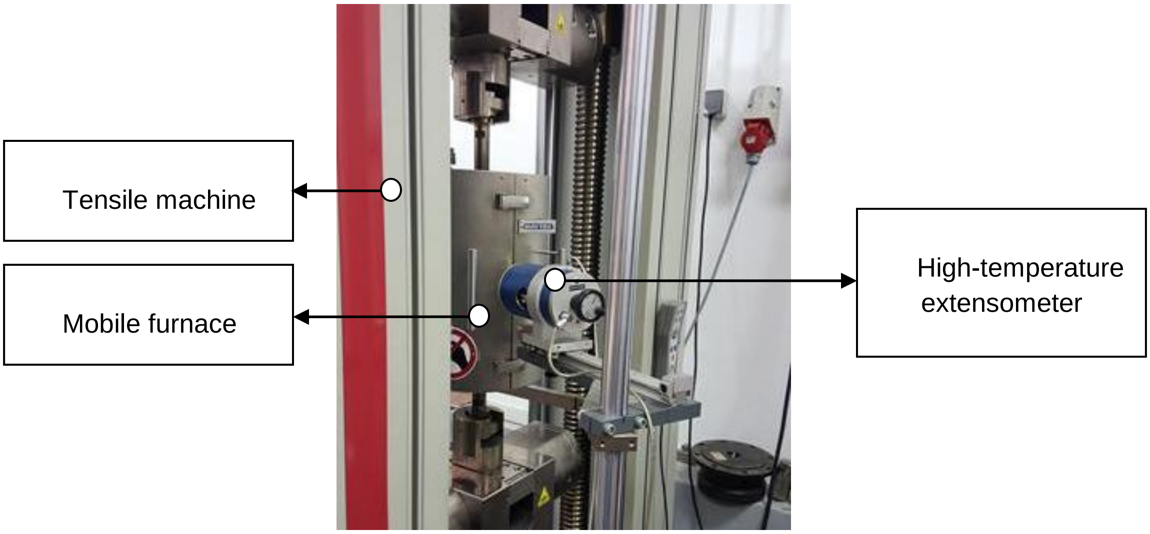

Figure 2: Test setup at University of Rijeka, Faculty of Engineering

The second test type, used mainly to determine creep strain evolution, is based on the stationary creep test. The test procedure for a stationary creep test consists of a pre-heating phase (heating rate of approximately 15°C/min), soaking phase (approximately 60 min) and the loading phase (during which the coupon is exposed to a constant stress level at the constant target temperature). The loading phase can last up to 20 hours depending on the temperature level which is being studied. The standards used for definition of coupon geometry, heating and loading are ASTM:E8M-11 for the ambient-temperature tests [8], and ASTM:E21-09 for the high-temperature tests [9]. Figure 2 presents the test setup for determining mechanical and creep properties at University of Rijeka, Faculty of Engineering.

3 COLUMN TEST SETUP

The research within the project is also planned on quantifying the creep influence on a larger scale, which includes column tests, both steel and aluminium. The testing methodology for the aluminium columns will rely on the stationary testing method where columns are heated to a predetermined temperature and subsequently loaded up to the failure point. Some of the columns will be tested using a transient testing methodology which relies on heating a column at a constant rate while being continually kept under load. Both test methodology will cover most temperature-mechanical boundary conditions that occur in a structure during fire.

The temperature ranges for the stationary tests are planned to be 100-400°C varying different load levels expressed as a percentage of the column load capacity at ambient temperature, which amount to: 20,40,60 and 80%. These tests are planned within the period of 2017/2018. Figure 3 presents the column test facility at Faculty of Civil Engineering, Architecture and Geodesy.

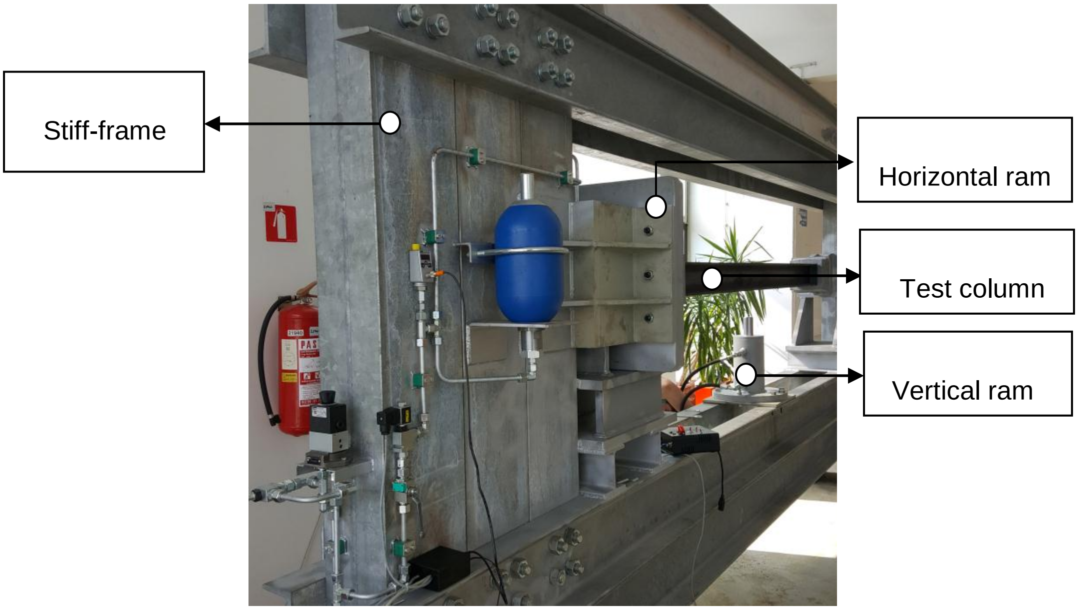

Figure 3: Column test facility at University of Split, Faculty of Civil Engineering, Architecture and Geodesy

4 TEST RESULTS

Figure 4 presents a photograph of the microstructure of a virgin specimen of aluminium obtained by optical microscope at 1000x normal magnification. As can be seen on the figure, the structure consists mostly of aluminium together with visible large rounded particles of Mg_2Si and angular particles of (Fe,Mn) $3SiAl12$.

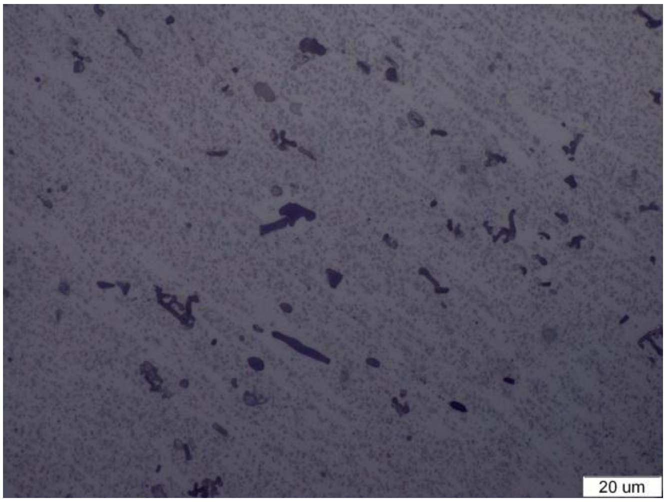

Figure 4: Microstructure of aluminium alloy EN 6082AW T6

Figure 5 presents test results of mechanical properties of the analysed alloy up to 350°C, where: $k_{E,\theta}$ - reduction factor for modulus of elasticity at temperature θ and $k_{0,\theta}$ - reduction factor for stress at 0.2% strain at temperature θ. Additionally, a comparison is given to the proposed reduction factors from Eurocode 9, part 1-2 [10].

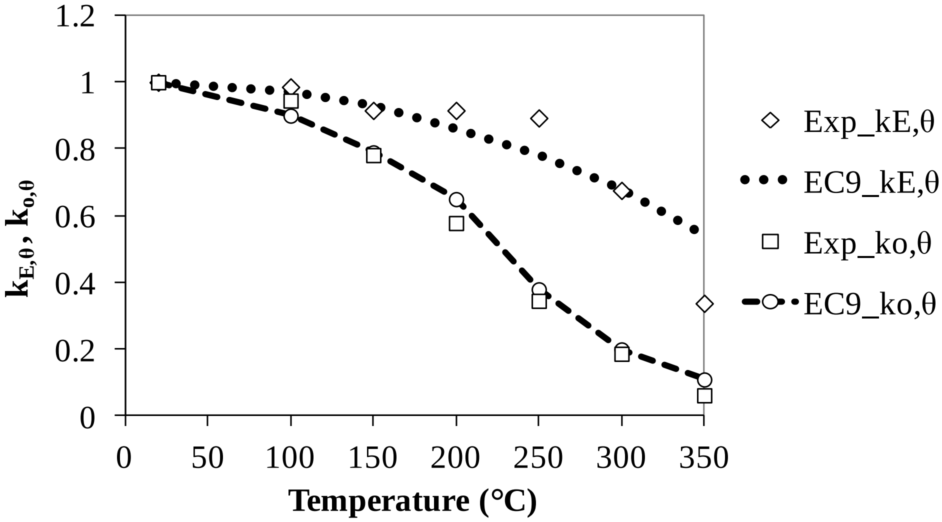

Figure 5: Reduction of mechanical properties of alloy EN 6082AW T6 – constant stress tests

It can be seen from Figure 5 that the temperature interval at which the alloy retains its mechanical properties is up to 350˘C, which is generally lower than the interval for steel (approximately 600°C). Although this interval is significantly less than steels’, an addition of fire protective material can be used to increase the fire resistance rating of aluminium. Additionally, if aluminium is used as a large span roof structure, it is more likely that the fire temperature will not be so high in the far-field temperature region.

5 CONCLUSIONS

The paper presents current research activities concerning mechanical and creep properties of aluminium alloy EN 6082AW T6 at high temperature. The presented test results point out that the temperature interval for reduction of the mechanical properties of alloy EN6082AW T6 is up to 350°C, which is significantly less than steels' temperature interval. Although the temperature interval is smaller if compared to steels', the aluminium can be used regardless as a part of structure if it is not located near the fire origin. Passive fire protection can also be used to increase its fire resistance time and therefore add more value to aluminium's level of sustainability. Further research within the project will be focused on deriving an adequate creep strain model for the analysed alloy.

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