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Testing the influence of creep on fire-exposed aluminium columns

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Abstract. *This paper aims to propose a novel heating scheme for conducting the transient creep tests for aluminium columns exposed to fire. Three specimens of aluminium alloy EN6082AW T6 were tested with the radiation heating scheme. The tests were conducted with a lower heating rate which represents a heating regime when fire protection is applied on the column. Applied fire protection generally imposes slower heating regime on the columns. The main motivation for the paper is that the behaviour of fire-exposed aluminium is relatively unknown in scientific literature. Since aluminium structures are being used in everyday construction practice, this paper aims to set the basis for further research within this field of study.*

1 Introduction

In the past few decades, aluminium is being considered as construction material of the future because of its favourable mechanical properties in comparison to steel. Significant quantity worldwide favours the idea of implementing aluminium alloys in everyday civil engineering practice. Currently there are lots of famous objects in the world made of aluminium, for example the roof structure for Inter-American Exhibition Centre in Sao Paolo (Figure 1.) which covers an area of 67.600 m^2 with 60x60 mesh and truss height of 2.36 m [1].

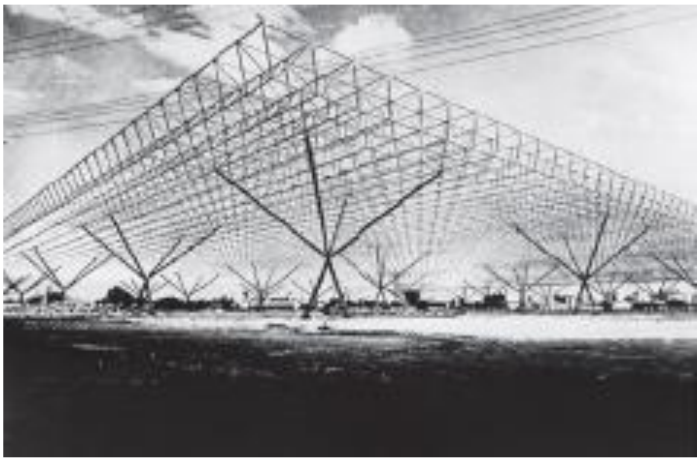

Figure 1: Roof structure for Inter-American Exhibition Centre, Sao Paolo, Brasil

Another good example is the aircraft Spruce Goose Dome (Figure 2.) made for heavy transport flying boat H-4 Hercules. Besides attractive design, its interest lies in efficient handling of a vast span of 125 meters in diameter with aluminium [1].

Figure 2: Spruce Goose Dome, Long Beach, California

Although the fire resistance of aluminium is lower than common structural steel, its corrosion resistance, ease of forming and extruding and relatively high ratio between strength and density is what makes notable difference compared to steel. Since aluminium has the potential of becoming one of the alternative building materials because of his aforementioned characteristics, there is a need for detailed testing and observing material behaviour under extreme actions and their effects on load bearing capacity.

The influence of creep on fire exposed aluminium columns is currently quite vague in scientific literature. This paper presents results of transient experimental tests conducted with low heating rate which represents a heating regime in fire-protected aluminium columns in real fire conditions. The developed heating rate for this experiment in the middle of the column (critical section) was in range between 2.5°C/min and 3.5°C/min. Specified heating rate was conducted on three identical specimens of aluminium alloy EN

6082AW T6 loaded with constant vertical and axial compressive force. Geometric column specifications and material properties of test specimens were determined to satisfy main requirements for ordinary everyday constructions in two main ways, functional and economic.

Corresponding aluminium alloy 6082AW T6 was used because it is a structural alloy and can be compared with steel grade S275 in terms of yielding strength since 6082-T6 proof strength at normal temperature is above 260 MPa. Presented research is a part of a large three-year collaborative research project [2-4] between Universities of Split and Sheffield. Its aim is to explore the influence of creep on the reduction of load bearing capacity of steel and aluminium columns exposed to fire.

2 Test setup

All experiments were performed in the Structures laboratory at Faculty of Civil Engineering, Architecture and Geodesy, University of Split. The 2579 mm long aluminium specimens chosen for the tests were I profiles with flange width 220 mm and web height 170 mm (Figure 4).

2.1 Testing framework

The testing framework is made of massive UPN profiles connected with high quality bolts to ensure sufficient rigidity and to disable possible unwanted influences in terms of deformations and displacements during the tests. As shown in Figure 3, the 2270 mm high and 6000 mm wide loading frame is mounted on concrete base.

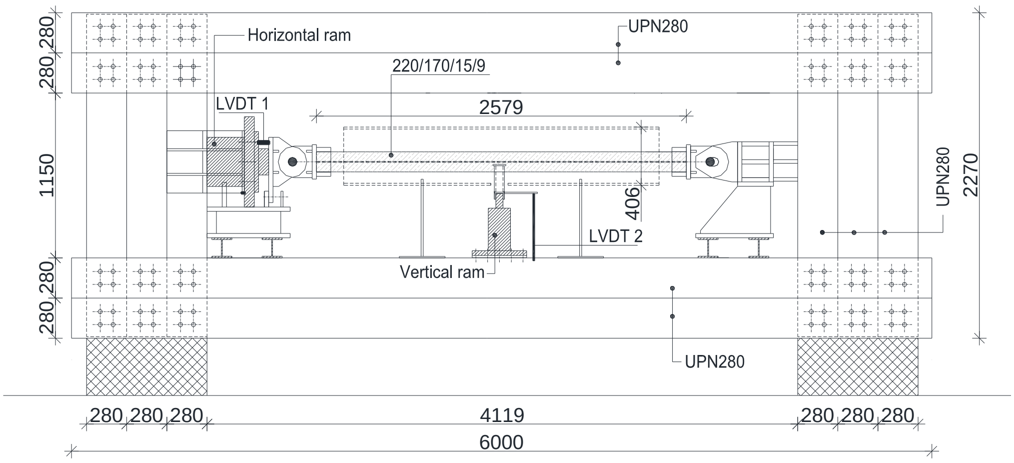

Figure 3: Testing framework arrangement

Centre of the frame consists of steel stands used as a support and as an attachment for bearings on each side. On the left side and in the middle of the frame the hydraulic rams were placed to ensure enough force in both horizontal and vertical direction. The rams were installed with precise adjustable cylinder for effective and controlled load intake. The circular steel tube placed in the centre of the frame with diameter of 406 mm was wrapped with 50 mm ceramic fibre blanket which serves as an efficient thermal isolator. The chosen diameter of the tube is sufficient to allow the elasto-plastic deformations of the specimen during the test without any contact whatsoever with the tube's inner jacket. The aluminium specimen (Figure 5.b) is inserted into the tube and mounted on the frame with bearings. High quality steel pins with 60 mm diameter were used as an attachment for bearings and the frame. The pins were made with circular cuttings and lubricated with special mechanical grease in order to reduce the friction between the pin and the bearing plate during the test (Figure 4).

Figure 4: Steel pin before (left) and after the (right) lubrication

For horizontal and vertical displacements, two linear variable differential transformers (LVDT) with high accuracy were used. Horizontal LVDT (LVDT 1, Figure 3) was placed on top of the horizontal ram on the left movable bearing. Vertical LVDT (LVDT 2, Figure 3) was assembled in the centre of the frame, attached to the vertical hydraulic ram and supported on the high quality steel tube extension for the ram. This extension was used to increase vertical range of the hydraulic ram and simultaneously enhancing the maximum level of applied vertical force during the tests.

2.2 Heating arrangement

ProHeatTM Induction Miller machine with liquid-cooled cables was used for heating of the specimen. The novel heating scheme based on induction heating is used to create magnetic field around the induction cables which are mounted on the tube. The field induces rapid heating of ferromagnetic materials based on machine power (up to 35 kW).

a) Test setup

b) Column specimen

Figure 5: Presentation of the test setup

The steel tube heats the aluminium specimen by means of radiation heat transfer which in this case represents a uniform heating source of the cross section along the element due to the round shape of the tube which in this way serves as a furnace. During the test, the fastest and greatest temperature growth develops in the middle of the column whilst the edges reach slightly lower temperature levels.

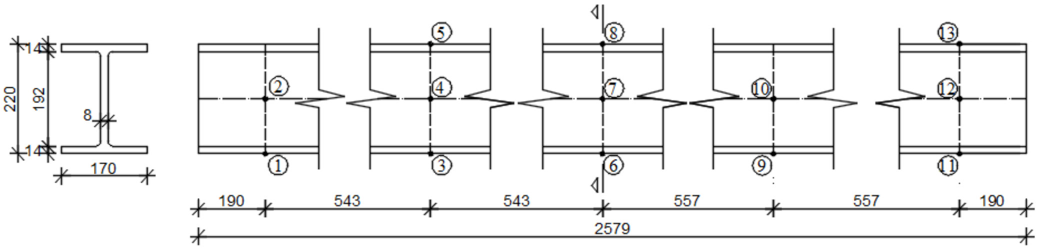

Figure 6: Aluminium specimen in the preparation for the test (left) and mounted specimen for the test (right)

Heating of the specimen was measured by a series of thermocouples in multiple sections along the specimen (Figure 6). At each section the thermocouples were placed on the flanges and web in order to measure the uniform heating regime. A large number of the thermocouples and short time step for recording of the temperature (0.5 seconds) ensured high precision and validity of the results during the test.

3 Results and discussion

3.1 Test performance

The transient tests were performed in three phases: axial and transversal loading of the column, heating of the specimen and unloading of the column with progressive cooling. First phase was preliminary axial loading of the column with axial compressive force of approximately 61 kN. This preliminary axial loading was necessary to prevent unwanted vertical displacements of the column during the transverse load intake. Full application of the both forces on the specimen concludes first phase of the test.

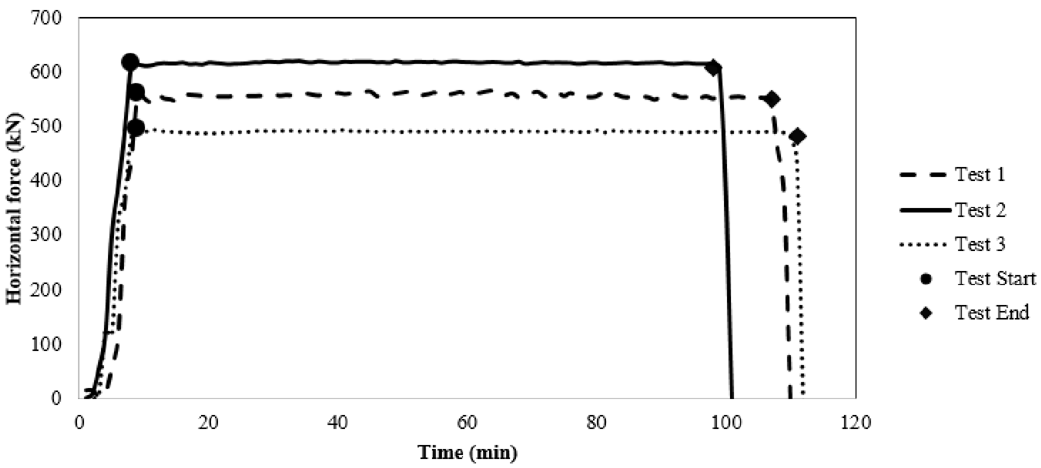

Figure 7: Applied horizontal force on the column

The transient test starts with the second phase (heating phase) where the machine was started with the infliction of the temperature to the column. The power output used in the tests was approximately 17 kW which provides the presented heating rates on the aluminium specimen (Figure 8) with the help of radiative heat transfer.

Since the columns were heated up with radiation heating scheme, it takes time to develop the constant heating rate on the aluminium specimens. We can notice slow temperature growth in the first hour of the experiment that is caused by progressive heating of the steel tube.

The points given on the graphic presentation of the heating rates in Figure 8 correspond to the positions of the thermocouples along the specimen shown in Figure 4. The heating rates on the specimens were highest in the centre of the furnace and lower on the edges.

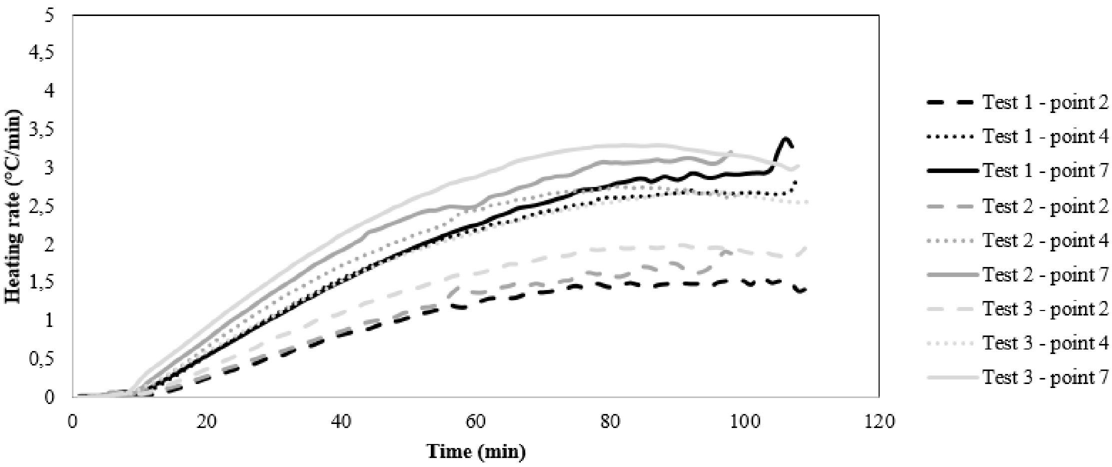

Figure 8: Heating rates in °C/min

The transient test ends with the second phase where the failure of the column occurs. The failure time specified in Table 1. represents the time duration of the heating phase.

The third phase presents the unloading of the specimen and controlled cooling after the test ends.

3.2 The results

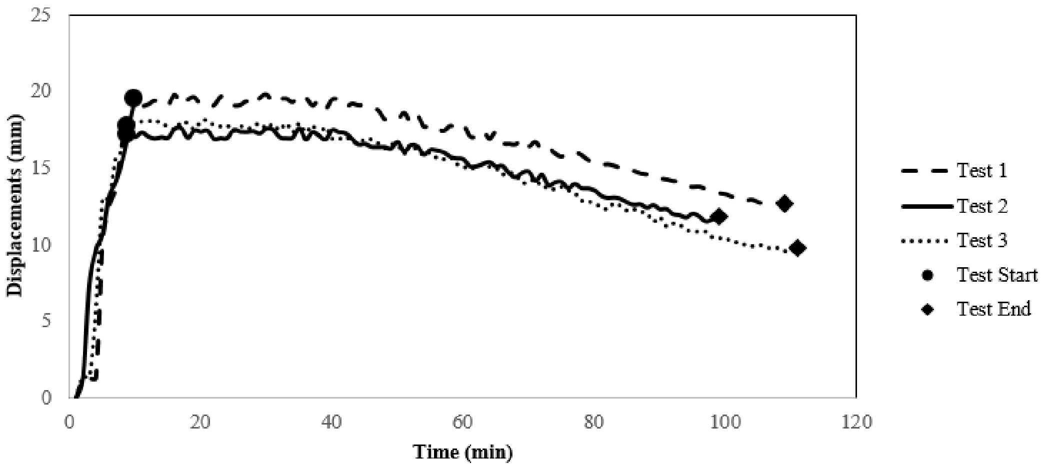

Figure 9: Horizontal displacements of the columns

Horizontal displacements of the columns presented in Figure 9. shows the thermal expansion effect in the specimens. Since the horizontal LVDT was attached to the horizontal hydraulic ram, the thermal expansion increased the column length and pushed the ram backwards what caused the downtrend of horizontal displacements presented in the Figure 9. Fluctuations on the specimens noticed in Figure 9. were caused while trying to maintain required constant force for efficient implementation of the transient fire test.

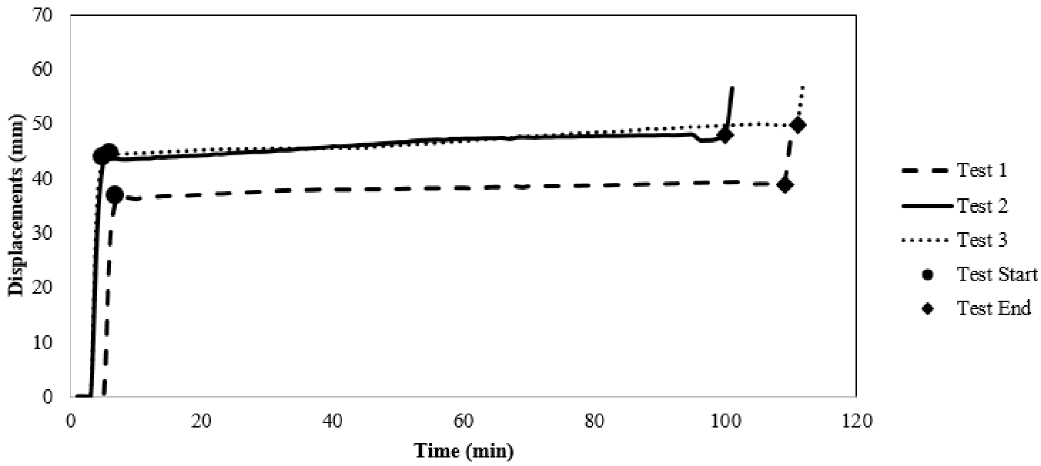

Figure 10: Vertical displacements of the column

The influence of creep component during conducted transient tests is visible on vertical displacements of the column (Figure 10). Presented growth in vertical displacements was the result of the cross section rotation during the application of the temperature. It shows progressive decrease of the bearing capacity what culminates with plastic deformations of the specimens when they fail.

3.3 Discussion

Table 1: Transient test-results

	Total horizontal displacements (mm)	Total vertical displacements (mm)	Average heating rate (°C/ min)	Failure time (min)	Horizontal force (kN)	Vertical force (kN)
Test 1	19.79	39.34	2.31	98	562	39
Test 2	17.6	48.12	2.29	90	615	39
Test 3	18.1	50.09	2.58	102	495	39

Loads chosen for the tests were based on previous research on capacity tests conducted at different temperature levels (20°C, 160°C, 220°C and 260°C) for aluminium columns [5]. The axial and transversal forces selected for the tests were approximately 80% of the load capacity of the column heated at 160° what is considered to be the lower limit for the creep affecting the bearing capacity of the columns [5].

Total horizontal displacements shown in Table 1. provide information on the maximal horizontal deformation at the beginning of the test while presented vertical displacements are the ones that occur just before the failure of the specimens. Average heating rate was calculated with the results of the thermocouples in the centre of the specimens (points 3-10 based on Figure 6) when the stable heating rate was established which was approximately 60 minutes after the test started. The failure time corresponds to the difference of the test start time and end points presented in Figures 7, 9 and 10.

4 Conclusions and further research

This study covered the experimental research of the aluminium columns under low heating-rate exposure which represents realistic heating of the fire-protected columns in fire conditions. Some positive conclusions can be laid out based on this study:

- Creep plays significant role on the reduction of load bearing capacity and accelerates the failure of the aluminium columns loaded with the 80% of the column’s buckling force at 160°C

- Conducted research can be accepted as successful and innovative experimental heating scheme for simulation of columns exposed to fire for transient creep testing

This study serves as a base for various modifications and options of transient tests in the further research. First option is aa detailed modelling study of the behaviour of aluminium I sections which will be presented in the future by the authors. Second option is to vary heating rates or create local heating on the web or the flange of the column.

Acknowledgement

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