Post Fire Residual Concrete and Steel Reinforcement Properties

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Abstract. The paper presents the results of exposure of normal concrete to high temperatures (400 and 700°C). In addition to the exposure of steel reinforcement bar Ø 12 mm, where two types of steel reinforcement burning situations were performed. Directly exposed to high temperatures (400 and 700°C) and others were covered by concrete layer (15 mm). From the experimental results of fire exposure for 1 hour of 400 and 700°C and gradually cooled, it was found that the residual average percentage of compressive strength of concrete was 85.3 and 41.4%, while the residual average percentage of modulus of elasticity of concrete was 75 and 48%, respectively. The residual average percentage of yielding tensile stress (Ø 12 mm) after burning and cooling at the same conditions was 96.6 and 86.4% for bars covered by concrete and 93.4 and 81.3% for uncovered bars, while the residual average percentage of the ultimate tensile strength (Ø 12 mm) was 94 and 81%, for bars covered by concrete and 91 and 76% for uncovered bars, respectively.

Keywords: Compressive strength; temperature; covered bar; fire flame.

1. Introduction

Although concrete is accepted as a non-combustible material with low thermal conductivity, the thermo-physical and thermo-chemical changes caused in concrete at high temperatures will reduce its performance Bazant [1]. Since the components of concrete have various coefficients of thermal expansion, post-fire-damaged concrete has distributed contact flaws between individual materials. These flaws are shown as cracks and pores in concrete, and the non-destructive assessment of these flaws can be used to assess the extent of fire damage [2]. Rebar is more sensitive than concrete at elevated temperatures. The concrete and steel exhibit a close thermal expansion of temperatures up to 400°C; nevertheless, a notable expansion in steel will happen at elevated temperatures compared to concrete and, if temperatures reach 700°C, the steel bearing capacity will be reduced to about 20% of it [4]. Structural failure chiefly occurs when the reinforcement loses its effective strength after burning. Thus, most researchers propose that with enough cover for reinforcement will have acceptable fire endurance [5]. Roman [6] investigated a method to evaluate layer thickness to remove due to fire hurt. The presented ultrasound method helps decide the actual strength of concrete at a depth of the fire exposed structural member and can be serious in evaluating the compressed zone.

This study aims to understand the behavior of concrete and steel bars during exposure to fire; it is necessary to predicate the properties of the materials that determine the behavior of the structural member at different temperatures including, compressive strength, splitting tensile strength, the elastic modulus, and the modulus of rupture for concrete and yield and ultimate steel tensile stress. Tests were conducted to denote the true values after firing and the residual material properties and examine and predict the fire resistance of the structural member.
2. Properties of used materials

2.1 Cement
An Iraqi Production Ordinary Portland Cement (type 1) has been used in this research. The Chemical and physical tests show that the cement used meets the Iraqi specification No.5/1993 [7].

2.2 Fine Aggregate
Al-Akhaider natural sand was used in the concrete mix. Table 1 shows the sieve analyses of the used sand in this work, while Table 2 lists its physical and chemical characteristics. Results point that the sand grading and the sulfates content percent are within the requirements of the Iraqi Specification No.45/1984 [8].

2.3 Coarse aggregate
Crushed gravel of 10 mm max. size brought from Al-Nibaa'ee region was used. Coarse aggregate was washed and dried by air. Table 3 shows the grade of coarse aggregate that used in this research, while Table 4 shows the physical and chemical characteristics. All results show that the coarse aggregate grade and the sulfates content meet the requirements of the Iraqi Specification No.45/1984 [8].

### Table 1. Sieve analysis (grading) of the used fine aggregate.

| Sieve size (mm) | % (Passing by weight) | Limits of the Iraqi specification No.45/1993 Zone 2 |
|-----------------|-----------------------|-----------------------------------------------|
| 10              | 100                   | 100                                           |
| 4.75            | 91                    | 90-100                                        |
| 2.36            | 76                    | 75-100                                        |
| 1.18            | 63                    | 55-90                                         |
| 0.60            | 51                    | 35-55                                         |
| 0.30            | 22.5                  | 8-30                                          |
| 0.15            | 7.9                   | 0-10                                          |

### Table 2. Physical and chemical characteristics of the used fine aggregate.

| Physical properties | Test results | Limit of Iraqi Specification No. 45/1993 |
|---------------------|--------------|------------------------------------------|
| Specific gravity    | 2.60         |                                          |
| Sulfates content (SO₃) | 0.41%      | 0.5% (max)                              |
| Absorption          | 0.74%        |                                          |
| Fineness modulus    | 2.96         |                                          |

### Table 3. Grading of the used coarse aggregate (gravel).

| Sieve size (mm) | % Passing by weight | Limits of the Iraqi specification No.45/1993 |
|-----------------|---------------------|---------------------------------------------|
| 12.5            | 100                 | 100                                         |
| 9.5             | 95                  | 85-100                                      |
| 4.75            | 11                  | 0-25                                        |
| 2.36            | 0.7                 | 0-5                                         |

### Table 4. Physical and chemical characteristics of the used coarse aggregate (gravel).

| Physical properties | Test result | Limit of Iraqi Specification No.45/1993 |
|---------------------|-------------|----------------------------------------|
| Specific gravity    | 2.60        | -                                      |
| Sulfate content (SO₃)% | 0.07%      | 0.1% (max)                             |
| Absorption          | 0.76%       | -                                      |
2.4 Water
Tap water which used in this work for both mixing then curing of concrete.

2.5 Steel bars
A deformed steel bar of a diameter 12 mm was used in this research. The tension test of bars gave the characteristics listed in Table 5, all values shown is the average of three specimens. The result of testing was done according to the ASTM A615-2009 [9] and ASTM A 496-2007 [10].

| Diameter (mm) | Surface texture | Area (mm²) | Average of yield tensile stress (MPa) | Average of ultimate tensile strength (MPa) | Elongation at ultimate stress (%) |
|---------------|-----------------|------------|--------------------------------------|------------------------------------------|---------------------------------|
| 12            | deformed        | 113        | 610                                  | 722                                      | 11.01                           |

3. Mix design and proportions of concrete
The concrete mix was designed according to BS 5328: Part 2: 2013 [11] to obtain a concrete mix with a (28days) target compressive strength of 40MPa and an initial slump of about (60 mm). The concrete mix proportions are summarized in Table 6.

| Mix ratios       | w/c   | Cement | Sand | Gravel | Water | Average compressive strength $f_{cu}$ MPa |
|------------------|-------|--------|------|--------|-------|------------------------------------------|
| 1:1.55:2.38      | 0.40  | 420    | 650  | 1000   | 200   | 40.2                                      |

$f_{cu} =$ Compressive strength for standard cube (150 mm)

3.1 Mixing procedure
The mixing procedure was done in a concrete mixer with a capacity of 0.1 m³. The concrete was mixed according to ASTM C192-2007 [12]. The coarse aggregate was added to the mixer, and about 20% of the mixing water was used. Fine aggregate was added with about 21% of the mixing water. Then the cement and water were added.

4. Testing of control specimens
The mechanical characteristics of hardened concrete at age 60 days were adopted using three groups of specimens to get compressive strength, splitting tensile strength, modulus of rupture, and modulus of elasticity, at ambient, 400, and 700°C as illustrated in Table 7.

| Test type                  | Number and type of specimen | Specimen dimension (mm) |
|----------------------------|-----------------------------|-------------------------|
| Compressive strength       | 9 Cubes                     | 150                     |
| Splitting tensile strength | 9 Cylinders                 | 150×300                 |
| Modulus of rupture         | 9 Prisms                    | 100×100×400             |
| Modulus of Elasticity      | 9 Cylinders                 | 150×300                 |

Three control specimens for each of the following circumstances exposure: ambient, 400, and 700°C.

4.1 Compressive strength ($f_{cu}$)
The compression test was done according to BS-1881; Part 116-2003 [13], where 150 mm cubes have been used to find the compressive strengths of the beams using a hydraulic universal digit. Compression testing device (Liya-Digital Elect 2000) of 2000 kN capacity at a loading rate of 6.8 kN/sec. An average of 3 specimens was used to get the mean compressive strength; after that, this strength was converted to
cylinder compressive strength ($f_c'$) by using the factor 0.81 (BS EN 206:2013) [11]. Table 8 shows the unburned compressive strength results.

| $f_{cu}$ (MPa) | 40.2 |
|----------------|-------|
| $f_c' = 0.81 \times f_{cu}$ (MPa) | 32.6 |

4.2 Splitting tensile strength ($f_{st}$)
The splitting tensile strength was done according to ASTM-C496/C496M-2011 [14]. Cylinders of 150×300 mm were loaded up to failure using a digit. Testing machine (Liya-Digital Elect. 2000) of 2000kN capacity with rate loading of 2.10 kN /sec. The mean of 3 cylinders was adopted to obtain splitting tensile strength. The following formula finds the splitting tensile strength:

$$f_{ct} = \frac{2P}{\pi DL}$$ (1)

Where: $f_{ct}$ = splitting tensile strength of concrete (MPa), $P$ = load at failure (N); $D$ = diameter of cylinders (mm), $L$ = height of cylinders (mm).

The experimental data are compared with theoretical results adopted using the ACI 318M-2014 code equation:

$$f_{ct} = 0.56\sqrt{f_c'}$$ (2)

See Table 9.

| $f_{c'}$ (MPa) | Splitting tensile strength fct (MPa) |
|----------------|------------------------------------|
| Experimental | ACI expression |
| 32.6 | 3.48 | 3.2 |

4.3 Modulus of rupture ($f_r$)
Using flexural strength testing machine, prismatic specimens of 100×100×400 mm were tested under two-points loading for modulus of rupture according to ASTM C78-2010 [15], using 200 kN capacity Liya testing device at a loading rate of 0.05 kN/sec. The average of 3 prisms was adopted to obtain the mean modulus of rupture. The modulus of rupture was found as follows:

$$f_r = \frac{PL}{bd^2}$$ (3)

Where: $f_r$ = modulus of rupture (MPa); $P$ = load at failure (N); $L$ = length of span between supports center to center (mm); $b$ = width of cross section of prism (mm); $d$ = of cross section of prism (mm).

The experimental data are compared with theoretical results adopted according to the ACI 318M-2014 code equation, see Table 10.

$$f_r = 0.62\sqrt{f_c'}$$ (4)

| Modulus of rupture $f_r$ (MPa) | Experimental | ACI expression |
|-------------------------------|--------------|----------------|
|                               | 3.9          | 3.54           |

Table 8. Unburned compressive strength test results.

Table 9. Unburned splitting tensile strength results.

Table 10. Unburned modulus of rupture values.
4.4 Modulus of elasticity, \((E_c)\)

The static elasticity modulus of concrete \((E_c)\) Measurements were done according to ASTM C469-2002 [16] using three concrete cylinders of 150 × 300 mm. The modulus of elasticity is found from stress strain curve using a stress-strain curve compress meter gauge of 200 mm length and 0.0010 mm accuracy. The load was applied with a constant rate of 40% of the ultimate load. Chord modulus of elasticity is calculated using the following formula:

Where: \(E_c = \) modulus of elasticity of concrete (MPa)

\[
E_c = \frac{(S_2-S_1)}{(\varepsilon_2-0.00005)}
\]

\(S_2 = \) stress corresponding to 40 percent of ultimate load (MPa); \(S_1 = \) stress corresponding to long. strain \(5\times10^{-5} \) (MPa), \(\varepsilon_2 = \) longitudinal strain resulting from stress \(S_2\). The experimental data are compared with theoretical results adopted using ACI 318M-2014 code [17] equation, see Table 11.

\[
E_c = 4700 \sqrt{f_{c}'}
\]

### Table 11. Unburned modulus of elasticity results.

| \(f_{c}'\) (MPa) | Modulus of elasticity \(E_c\) (MPa) |
|-----------------|-----------------|
| 32.6            | 26860           |
|                 | 26835           |

5. Exposing to fire flame test

The burning process has been completed in a furnace was manufactured by using 4 mm thick steel plate just like box shape to burn one or more specimens in each time, as shown in Figure 1, the inner clear space was 0.8 m height by 2.0 meter width and 3.50 meter length, equipped with 20 fire flame from the methane sources (nozzles) and 8 compressed air nozzles all positioned at the lower furnace level near the base to keep enough space underneath the rafter to reach the fire flame from the methane sources (nozzle) to the all burned rafters to simulate underneath fire disaster of simply supported rafter. The rate of transition period to reach the above target temperature was approximately similar to the rate of ASTM E-119 [18].

![](image.png)

**Figure 1.** Furnace and burning process.

6. Post-fire test results

6.1 Compressive strength of concrete \((f'c)\)

Poon et al., 2001 [19] reported three methods are available for testing to find the residual compressive strength of the concrete at high temperatures: stressed test, unstressed test, and unstressed residual strength test. The first two methods prefer to find concrete strength during high temperatures, while the last is excellent for determining the residual properties after exposure to high temperatures. It was observed that the third method gives less strength and is, therefore, more appropriate for obtaining limiting values.

The residual compressive strength results after exposure to 400 and 700°C temperatures are given in Table 12 and Figure 2. Test results are compared with the reduced calculated values using equations.
proposed by Aslani [20]. It is clear that there is a good agreement between the experimental results and the values given by the proposed equations. The difference varies between (6%) at 400°C to (2%) at 700°C. Figure. 2 exhibits, when the temperature reached above 400°C the compressive strength decreases rapidly.

**Table 12.** Effect of fire flame on compressive strength.

| Temperature (°C) | $f'_c$ * (MPa) | Average residual strength (%) | Residual strength [20] (%) |
|------------------|----------------|------------------------------|---------------------------|
| ambient          | 32.6           | 100                          | 100                       |
| 400              | 25             | 77                           | 85.3                      |
| 700              | 12.6           | 39                           | 41.4                      |

* Average of three specimens, was converted to cylinder compressive strength ($f'_c$) by using the factor 0.81.

**Figure 2.** Burning temperature versus compressive strength ($f'_c$).

6.2 *Splitting tensile strength ($f_{ct}$)*

The residual splitting tensile strength results after exposure to 400 and 700°C temperatures are given in Table 13 and Figures 3 and 4. Test results are compared with Chang [21]. It can be noticed that the values of splitting tensile strength decrease as the temperature increased, approximately, the reduction rate was the same at 400 and 700°C, and it was found to be more sensitive to high-temperature exposure than the compressive strength.

Test results are compared in Table 13 with the reduced calculated values using equations proposed by Chang [21]. The difference varies between (3.3%) at 400°C to (3.5%) at 700°C.

**Table 13.** Effect of fire flame on splitting tensile strength.

| Temperature (°C) | splitting tensile strength $f_{ct}$ (MPa) | Average residual splitting tensile strength $f_{ct}$ (%) | Residual splitting tensile strength $f_{ct}$ [21] (%) |
|------------------|------------------------------------------|-------------------------------------------------------|-------------------------------------------------|
| ambient          | 3.48                                     | 100                                                   | 100                                             |
| 400              | 2.15                                     | 61.8                                                  | 58.1                                            |
| 700              | 1.00                                     | 28.7                                                  | 25.1                                            |
6.3 Modulus of rupture ($f_r$)

The residual flexural strength results after exposure to 400 and 700°C temperatures are given in Table 14 and Fig. 5. It can be noticed that the values of flexural strength decrease as the temperature increased, above 400°C. The rate of reduction was slightly higher, and it was found to be more sensitive to high-temperature exposure than the compressive strength. Table 14 also shows the decrease in concrete density with increasing temperature.

### Table 14. Effect of fire flame on flexural strength and density.

| Temperature (°C) | Modulus of rupture ($f_r$) (MPa) | Average residual flexural strength (%) | Density of concrete (kg/m³) |
|-----------------|---------------------------------|---------------------------------------|----------------------------|
| ambient         | 3.9                             | 100                                   | 2263                       |
| 400             | 2.6                             | 66.7                                  | 2172                       |
| 700             | 1.2                             | 30.8                                  | 1969                       |

Figure 5. Burning temperature versus flexural strength ($f_r$).

6.4 Modulus of elasticity ($E_c$)

Test results are summarized in Table 15. This table reveals the residual ratio of $E_c$ for concrete strength compared to its unburned specimen. Figure 6 illustrates the relationship between the residual elastic modulus and the fire flame temperatures. It can be observed that, as the burning temperature increased,
the values of modulus of elasticity decrease. The amount of reduction is about 25 and 52% for the specimens exposed to 400 and 700°C, respectively, compared to the reference specimen (at ambient temperature). The reduction calculations for modulus of elasticity depending on the equations proposed by Aslani [20] are given in Table 15 with that of the experimental work. It is clear that there is a good agreement between them. The difference varies between 3.6 to 6.6%. The residual modulus of elasticity results after exposure to 400 and 700°C temperatures are given in Table 15 and Fig. 6. Test results are compared with Aslani [20].

Table 15. Effect of fire on the modulus of elasticity of concrete.

| Temperature (°C) | Ec (MPa) | Average residual Ec(%) | Residual Ec (%) |
|-----------------|----------|-------------------------|-----------------|
| ambient         | 26860    | 100                     | 100             |
| 400             | 20153    | 75                      | 78.6            |
| 700             | 13100    | 48                      | 41.4            |

Figure 6. Burning temperature versus modulus of elasticity (Ec).

6.5 Properties of steel bars
Abramowicz and Kowalski [22] revealed that the value of steel yield strength and the steel modulus of elasticity drops significantly when a temperature increase occurs. However, after the fire, reinforcing steel usually recovers a majority of its material properties when the structure is cooled down. Due to these notifications, the real deterioration happens when the reinforcement in some structural elements can become useless due to the failure of bar anchorage after the exposure to fire.

Outinen and Mäkeläinen [23] distinguished between two methods of test are used to find tensile of steel at elevated temperatures; transient-state and steady-state test methods. In the transient-state tests, the test specimen is under a constant load and under a constant temperature rise. The heating rate in the transient-state tests is 20°C /min. The temperature and strain are measured during the test. While, in steady-state tests, the specimen was burned up to a definite temperature. Then a tensile test was done after it is cooled down. The steady-state tests can be done either as strain- or as load-controlled. The steady-state test is more convenient to carry out than the transient-state test, and therefore that method is more much used than the transient-state method. So, the second test method was adopted in this research. Accordingly, two types of steel reinforcement burning situations were performed. Directly exposed to high temperatures (400 and 700°C) and others were covered by concrete layer (15 mm) (Figure 7). The effect of burning on the properties of steel reinforcement bars is summarized in Table 16. At a temperature of 400°C, burning did not affect the mechanical properties of the steel reinforcement bars, but this effect was observed at burning temperature 700°C. The percentages of residual yield tensile
stress and ultimate tensile strength are shown in Table.16. The modulus of elasticity was almost not affected by burning and cooling processes. This was confirmed by a number of researchers like reference [24].

![Figure 7. Control samples of steel reinforcement Ø 12 mm.](image)

**Table 16.** Effect of fire flame on the characteristics of steel bars- Ø 12 mm (steady-state tests).

| Bar No. | Temperature (°C) | Yield tensile stress fy (MPa) | Residual yield tensile stress fy (%) | Ultimate tensile strength fu | Residual ultimate tensile strength fu (%) |
|---------|------------------|------------------------------|-------------------------------------|-----------------------------|------------------------------------------|
| 1       | Ambient          | 610                          | 100                                 | 722                         | 100                                      |
| 2       | Covered by concrete and burned up to 400°C | 589                          | 96.6                                | 679                         | 94                                       |
| 3       | Directly exposed to 400°C | 570                          | 93.4                                | 657                         | 91                                       |
| 4       | Covered by concrete and burned up to 700°C | 527                          | 86.4                                | 585                         | 81                                       |
| 5       | Directly exposed to 700°C | 496                          | 81.3                                | 549                         | 76                                       |

**7. Conclusions**

- The residual average percentage of compressive strength of concrete after burning at 400 and 700°C for 1 hour and cooling gradually was 85.3 and 41.4% respectively.
- The residual average percentage of splitting tensile strength after burning at 400 and 700°C for the same exposures was 58.1 and 25.1%, respectively, that the splitting tensile strength is more effective by fire than compression strength.
- The residual average percentage of modulus of elasticity of concrete after burning at 400 and 700°C for the same exposures was 75 and 48%, respectively.
- The residual average percentage of flexural strength of concrete after burning at 400 and 700°C for the same exposures was 66.7 and 30.8%, respectively.
- The residual average percentage of yield tensile stress (Ø 12 mm) after burning at 400 and 700°C for 1 hours and gradually cooled was 96.6 and 86.4%, respectively for bars covered by concrete...
and 93.4 and 81.3%, respectively for uncovered bars, while the residual average percentage of ultimate tensile strength (Ø 12 mm) for the same burning and cooling situations was 94 and 81%, for bars covered by concrete and 91 and 76% for uncovered bars, respectively.

References
[1] Bažant, Z.P. and Chern, J.C., 1987. Stress-induced thermal and shrinkage strains in concrete. Journal of engineering mechanics, 113(10), pp.1493-1511.
[2] Park, S.J., Yim, H.J. and Kwak, H.G., 2014. Nonlinear resonance vibration method to estimate the damage level on heat-exposed concrete. Fire Safety Journal, 69, pp.36-42.
[3] Bilow, D.N. and Kamara, M.E., 2008. Fire and concrete structures. In Structures Congress 2008: Crossing Borders (pp. 1-10).
[4] Fletcher, I.A., Welch, S., Torero, J.L., Carvel, R.O. and Usmani, A., 2007. Behaviour of concrete structures in fire. Thermal science, 11(2), pp.37-52.
[5] Kodur, V.K.R. and Bisby, L.A., 2005. Evaluation of fire endurance of concrete slabs reinforced with fiber-reinforced polymer bars. Journal of structural engineering, 131(1), pp.34-43.
[6] Wróblewski, R. and Stuwiiski, B., 2020. Ultrasonic assessment of the concrete residual strength after a real fire exposure. Buildings, 10(9), p.154.
[7] Iraqi specification No.5.,1993 Portland Cement", Central agency for standardization and quality control. Planning council, Baghdad, Iraq. translated from Arabic edition.
[8] Iraqi specification No.45., 1884. Aggregate from natural sources for concrete. Central agency for standardization and quality control, Planning council, Baghdad, Iraq, translated from Arabic edition.
[9] ASTM Designation A615., 2009. Standard specification for testing method and definitions for mechanical testing of steel products. Annual book of ASTM Standards, American society for testing and material, Philadelphia, Pennsylvania. Section 1, Vol. 1.01, pp. 248-287.
[10] ASTM A496, 2007. Standard specification for steel wire, deformed, for concrete reinforcement. Annual book of ASTM standard, Vol. 01.05, pp.425-429.
[11] BS EN 206, 2013. Applies to concrete for structures cast in situ, precast structures, and precast products for building and civil engineering.
[12] ASTM C192, 2007. Standard practice of making and curing concrete test specimens in the laboratory. West Conshohocken, Pennsylvania, pp. 1-8.
[13] BS 1881: Part 116, 2003. Methods for determination of compressive strength of concrete cubes.
[14] ASTM C496/ C496M, 2011. Standard test for splitting tensile strength of cylindrical concrete specimens. Annual book of ASTM Standards, Vol.04.02 concrete and aggregates, West Conshohocken, PA, United State. 2011.
[15] ASTM C78, 2010. Standard test method for flexural strength of concrete (using simple beam with third-point loading). Annual book of ASTM Standards, Vol.04.02 concrete and aggregates, West Conshohocken, PA, United State.
[16] ASTM C469, 2002. Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression. Annual book of ASTM Standards, Vol.04.02 concrete and aggregates, West Conshohocken, PA, United State.
[17] ACI Committee 318, 2014. Building code requirements for structural concrete, (ACI 318M-14) and commentary (318R-14). American Concrete Institute, Farmington Hills, Michigan, USA.
[18] ASTM, E119, 2016. "ASTM E119-16a." In Standard Test Methods for Fire Tests of Building Construction and Materials,” ASTM International, West Conshohocken, PA, 21.
[19] Poon, C.S., Azhar, S., Anson, M. and Wong, Y.L., 2001. Comparison of the strength and durability performance of normal-and high-strength pozzolanic concretes at elevated temperatures. Cement and concrete research, 31(9), pp.1291-1300.
[20] Aslani, F., 2013. Prestressed concrete thermal behaviour. Magazine of Concrete Research, 65(3), pp.158-171.
[21] Chang, Y.F., Chen, Y.H., Sheu, M.S. and Yao, G.C., 2006. Residual stress-strain relationship for concrete after exposure to high temperatures. Cement and concrete research, 36(10), pp.1999-2005.
[22] Abramowicz, M. and Kowalski, R., 2007, May. Residual mechanical material properties for the reassessment of reinforced concrete structures after fire. In 9th International Conference on Modern Building Materials, Structures and Techniques, Vilnius, Lithuania.

[23] Outinen, J. and Mäkeläinen, P., 2004. Mechanical properties of structural steel at elevated temperatures and after cooling down. Fire and Materials, 28(2-4), pp.237-251.