
**Düzce University Journal of Science & Technology**

*Research Article*

# The Investigation on The Effects of Different Temperature Types on Concrete Containing Expanded Perlite Aggregate

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## ABSTRACT

This study was carried out to investigate the effect of high temperature by using fire and oven on the physical and mechanical properties of three different concrete classes that are C16/20, C20/25 and C40/50 also, concrete samples are manufactured as containing expanded perlite aggregate (EPA) and not containing perlite aggregate. The reference temperatures are specified as 22 ºC, 100 ºC, 300 ºC, 500 ºC in the oven and the case of fire. These temperatures are applied to a sample having 100x100x100 $mm^3$ dimensions. The tests made on each concrete type are weight per unit volume, compressive strength, and ultrasonic pulse velocity. Consequently, the test results come out statistically different of the concrete samples affected by high temperature according to if the heat is applied by the oven or fire, the compressive strength of the samples decreases as the high-temperature degree increases in a compressive strength test. Besides that, while the loss of compressive strength of oven samples at 500 ºC comes out approximately 60 %, for samples applied fire is approximately 10%.

***Keywords:*** *High temperature, Fire, Expanded Perlite Aggregate*

# Farklı Sıcaklık Türünün Genleştirilmiş Perlit Agregalı Betonlar Üzerindeki Etkilerinin Araştırılması

## ÖZET

Bu çalışmada, üç farklı beton sınıfında genleştirilmiş perlit katkılı ve katkısız betonlar üretilerek yüksek sıcaklık fırınında ve gerçek yangın durumunda betonun fiziksel ve mekanik özellikleri test edilmiştir. Beton sınıfları sırasıyla C16/20, C20/25 ve C40/50'dır. Fırında ve gerçek yangın durumunda uygulanan sıcaklıklar Ref (22ºC), 100ºC, 300ºC, 500ºC olarak belirlenmişlerdir. Bu sıcaklık değerleri 100x100x100 mm3 ölçülerindeki betonlar üzerinde uygulanmıştır. Her beton türüne birim hacim ağırlık (BHA), ultrases geçiş hızı (UGH) ve basınç dayanımı (BD) deneyleri yapılmıştır. Sonuçta, yüksek sıcaklık fırını ile yangın arasında her bir deney arasında istatiksel olarak fark olduğu, BD'da sıcaklık değeri arttıkça yangın ve yüksek sıcaklık değerini giderek azaldığı tespit edilmiştir. Ayrıca, fırın numunelerinin 500 ºC'deki BD kayıpları ortalama %60 civarındayken, yangın numunelerinin %10 civarında olduğu belirlenmiştir.

***Anahtar Kelimeler:*** *Yüksek sıcaklık, Yangın, Genleştirilmiş Perlit*

Received: 06/07/2018, Revised: 01/08/2018, Accepted: 14/09/2018

# I. INTRODUCTION

Concrete is a material of construction which is formed by using cement, aggregate, water, and chemical admixtures; its properties can be listed as plasticity, having the high compressive strength and having good adherence with steel[1]. When the fire resistance of concrete is discussed, it is essential that to know its thermal conductivity and density [2]. Since, the physical and mechanical properties of concrete such as strength, elasticity and weight per unit volume could be changed by the effect of being exposed to high temperature distinctly other materials of construction [3-5]. Therefore, it is quite important that the strength of construction having concrete after being exposed to fire must be known [6]. Concrete is in the A1 class (fireproof), and under the effect of high temperature the yield point of concrete changes, modulus of elasticity decreases and chemical reactions occur in concrete. As a result of this, the damage formed by the effect of high temperature in concrete does not lead to loss of material [7]. First of all, to find out the effect of high temperature on concrete, that must be considered the effect of high temperature on cement and aggregate that is the most important ingredients of concrete [8]. Since in the concrete mixtures proportion of aggregates is 60-80%, the aggregates affect thermal expansion, thermal conductivity and performance of concrete directly under fire [9]. The mineral composition of aggregates has a direct effect on the behavior of concrete under fire [10]. Arioz's study (2007) concrete is manufactured by using calcareous aggregate, Portland Cement, and stream bed rubble aggregate in different water/cement ratios and be exposed to the high temperature in the range of 200 ºC - 1200 ºC. As a result, it is observed that the type of aggregate and water/cement ratio has not significant effect on the loss of weight when concrete is exposed to high temperature, it is also observed that adding stream bed rubble leads to high amounts of loss of compressive strength [2].

Use of lightweight aggregate to a certain extent instead of aggregates that are used in concrete will lead to better thermal, and sound insulation and the concrete will be lighter. Doğan and Sananer indicated that using pumice, perlite and gas concrete has a detractive influence on While there are studies on effects of high temperature on normal-strength concretes [6, 12, 13] and also high-strength concrete [14, 15], there are not many studies on effects of real fire on both concrete types destructive effect of earthquake by lightening dead load [11]. Also, they indicated that construction materials that are manufactured by using lightweight aggregates increase thermal and sound insulation, besides that, this leads to energy saving approximately in the proportion of 50% [11]. There occur important physical and chemical alterations in cement by the effect of high temperature. For this reason, concrete demonstrates inconsistent behaviors. At 120 ºC water releases from Calcium Silica Hydrate (CSH), at 300 ºC hydrated calcium silica is dehydrated and at 470-530 ºC calcium hydroxide $Ca(OH)_2$ decomposes as a result of this, the concrete will start to shrink. Dehydration of hydrated calcium silica and thermal expansion of aggregates increase the internal stress of concrete at nearly 300ºC and fractures pass from cement phase and surround aggregates. When the temperature goes beyond 500ºC fractures occurs in cement paste, they are more significant than 0.01 mm, they lead to cracks in aggregates, and they can be visible to the naked eye.

Concrete has invisible little spaces in it, although it looks like solid and space less. Spaces in concrete do not differ significantly until 120 ºC. At the temperatures, 25 ºC, 70 ºC, and 120 ºC high-strength concrete has a constant space ratio. While the temperature changes from 300 ºC to 600 ºC, the increment in space ratio for normal-strength concrete is approximately 148%, it is for high-strength concrete is nearly 86%. Normal-strength concrete and high- strength concrete preserves 99% of its weight. Also, normal-strength concrete and high-strength concrete losses 1.4% of its weight by evaporation of water in it at the temperature of 70-120 ºC. The most loss of weight as 7% occurs at 120-300 ºC. The reason for this evaporation of water that is chemically bonded. The weight is decreased since the water is evaporated and volume increases as a result of expansion. Weight per unit volume decreases as weight is decreases and volume increases, however, this decrement can be ignored.

Compressive strength change in concrete affected by high temperature depends on environmental factors such as; the degree of heat, the time of being exposed to heat, cement type, water/cement ratio, type of cooling of concrete. Changes in the compressive strength of concrete are significant in the range of 400-600 ºC [24].

In literature, when investigating the effect of high temperature on behaviors of concretes that are manufactured by various chemical and mineral admixtures, the high temperature is supplied by the help of ovens. In this study, physical and mechanical changes in concrete samples that are prepared by using expanded perlite aggregates (EPA) by the effect of the high temperature applied by the oven and fire.

## II. MATERIAL AND METHODS

There are 24 sample groups for all experiments. For each of these 24 sample groups, three samples are used for all temperature values, and 72 samples are prepared in total. The results of all experiments are calculated using arithmetic mean.

### *A. MATERIALS*

CEM I 42,5R cement supplied from Ankara Baştaş Cement Factory. is used for concrete samples. In Table 1, the physical, chemical and mechanical properties of CEM I 42,5R is given. City water supply as mixing water in Ankara is used.

***Table 1**. Physical, Chemical and Mechanical Properties of CEM I 42,5R*

| **Chemical Composition** | **%** | **Physical Properties** | | **Compressive Strength (MPa)** | | |
|---|---|---|---|---|---|---|
| $SiO_2$ | 18.32 | Specific Gravity (g/cm$^3$) | 3.11 | Day 2 | Day 7 | Day 28 |
| $Al_2O_3$ | 4.51 | Initial Setting Time (min) | 160 | 29.2 | 40.3 | 48.1 |
| $Fe_2O_3$ | 3.07 | Final Setting Time (min) | 210 | | | |
| CaO | 63.75 | Volume Expansion (mm) | 1 | | | |
| MgO | 1.6 | Specific Surface (Blaine) (cm$^2$/g) | 3562 | | | |
| $SO_3$ | 3.17 | | | | | |
| $Na_2O$ | 0.37 | | | | | |
| $K_2O$ | 0.85 | | | | | |
| Loss of Ignition | 4.43 | | | | | |
| Insoluble Residue | 0.88 | | | | | |

The expanded perlite aggregate that is added to the concrete sample is equivalent to 20% of the volume of the concrete sample. EPA is supplied from Çankırı by Akper Perlit, and physical properties, chemical composition and sieve analysis of EPA are given in Table 2.

*Table 2. Physical Properties, Chemical Composition and Sieve Analysis of EPA*

| Physical Properties | | Chemical Composition, % | | Sieve Analysis | |
|---|---|---|---|---|---|
| Material Type | Expanded Perlite | $SiO_2$ | 71-74 | mm | % |
| Color | White | $Al_2O_3$ | 12-14 | +2.00 | 25-30 |
| Density | 55-65 kg/m$^3$ | $K_2O$ | 5-6 | +1.00 | 30-35 |
| Maximum Moisture | 1% | $NA_2O$ | 3-4 | 0.5 | 15-20 |
| Ph | 6-8.5 | MgO | 0,1-0,2 | 0,21 | 15-20 |
| | | CaO | 0,08-0,1 | -0.9 | 20-25 |
| | | $Fe_2O_3$ | 0,5-1 | | |
| | | $TiO_2$ | 0,09-0,012 | | |
| | | Loss of Ignition | 3-4 | | |

Also, fly ash (FA) supplied from Ankara Çayırhan Thermal Power Plant is added a concrete sample. The chemical composition of F class fly ash according to TS EN 197-1, and ASTM C 618 standards are given in Table 3.

***Table 3**. Chemical Properties of FA*

| | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | S+A+F | CaO | MgO | $Na_2O$ | $K_2O$ | $SO_3$ | KK |
|---|---|---|---|---|---|---|---|---|---|---|
| FA (%) | 52,35 | 10,69 | 9,10 | 72,14 | 8,86 | 3,52 | 2,77 | 1,69 | 2,92 | 0,62 |

(0-4), (4-12) and (12-22) mm of sizes for aggregates are used in concrete samples. Saturated surface dry (SSD) density of aggregates is obtained as 2.5, 2.63, 2.68 g/cm$^3$ respectively.

## *B. METHODS*

Four concrete classes are specified (C16/20, C20/25, C30/37 and C40/50 ) to understand the better effect of the high-temperature oven and real fire on expanded perlite aggregate concrete. Compressive strength test, weight per unit volume test and ultrasonic pulse velocity test are applied on samples having 100x100x100 mm$^3$ dimensions. Also, the temperature is applied as 22 ºC (Ref), 100 ºC, 300 ºC and 500 ºC for each concrete sample. Samples are manufactured and tests are conducted at Gazi University, Faculty of Technology, and Civil Engineering Concrete Laboratory. Ingredients of concretes containing EPA and not EPA free in m$^3$ is listed in Table 4 in kg.

***Table 4**. Material Quantity for concrete samples with EPA added and EPA-free ($m^3/kg$)*

| | **C16/20** | | **C20/25** | | **C40/50** | |
|---|---|---|---|---|---|---|
| | **EPA-free** | **EPA added** | **EPA-free** | **EPA added** | **EPA-free** | **EPA added** |
| Cement | 246.7 | 246.7 | 268.1 | 268.1 | 355.8 | 355.8 |
| Water | 185.0 | 185.0 | 185.0 | 185.0 | 185.0 | 185.0 |
| Fly Ash | 24.7 | 24.7 | 26.8 | 26.8 | 35.6 | 35.6 |
| 0-4 | 871.8 | 853.8 | 863.4 | 845.4 | 829.1 | 811.1 |
| 4—12 | 680.6 | 680.6 | 674.0 | 674.0 | 647.2 | 647.2 |
| 12—22 | 390.4 | 390.4 | 386.6 | 386.6 | 371.2 | 371.2 |
| Superplasticizer conc. admixture | 0.25 | 0.25 | 0.27 | 0.27 | 0.36 | 0.36 |
| EPA | -- | 12 | -- | 12 | -- | 12 |

For fire modeling, the industrial oven is used to match of the temperature of the furnace and the temperature of the high-temperature oven is cared. The frusto-conical mechanism is prepared to reach to 500 ºC in a specific time, and the surface of cube sample having a length of 100 mm is arranged as for fit precisely to conical.

Pre-tests are done, and it is determined that the samples reach different temperature values takes how much time. All of the concrete samples wait under the high-temperature effect for an equal time interval to observe the effect of fire on each concrete types. Concrete samples are exposed to fire for a range of time of 3-20 minutes depending on different temperature values.

Weight per unit volume (WUV) are conducted in accordance with TS EN 12390-7, ultrasonic pulse velocity (UPV) test is performed in accordance with TS EN 12504-4 and ASTM C 597 and compressive strength (CS) test is performed in accordance with TS EN 12390-3 at the Gazi University Faculty of Technology Concrete Laboratory.

## III. Results And Discussion

In this study, weight per unit volume (WUV), ultrasonic pulse velocity (UPV) and compressive strength (CS) test are conducted on each concrete sample.

### *A. STATISTICAL EVALUATION*

Repeated measures analysis of variance is done for evaluation of experimental results for two (EPA added and EPA-free) different additive type factor (AF), four different (C16/20, C20/25, C30/37 and C40/50) concrete class factor (CCF), five different (22 ºC-Ref, 100 ºC, 300 ºC and 500 ºC) applied temperature rating factor (TRF), two different (fire and oven) temperature type factor(TTF). Statistical experimental results for WUV, UPV, and CS is given in Table 5.

***Table 5**. Repeated measures analysis of variance for WUV, UPV, and CS*

| | | Degree of Freedom | Sum of Squares (SS) | Mean of Squares (MS) | F-test (F) | Level of Significance (p) α<0,05 |
|---|---|---|---|---|---|---|
| WUV | TTF*CCF*TRF | 45 | 13.47 | 0.299 | 5.013 | 0,000000 |
| UPV | TTF*CCF*TRF | 45 | 5.67 | 0.126 | 2.072 | 0,000368 |
| CS | TTF*CCF*TRF | 45 | 398.84 | 8.863 | 7.446 | 0,000000 |

According to Table 6, repeated measures analysis of variance for WUV, UPV and CS tests results, TTF*CCF*TRF interaction having α<0.05 level of significance has a substantial effect. In other words, depending on different concrete classes for both fire and high-temperature values are different from each other statistically.

*B. WUV TEST RESULTS*

Results of weight per unit volume (WUV) test for three different concrete classes depending on high-temperature oven/fire values given in Figure 1.

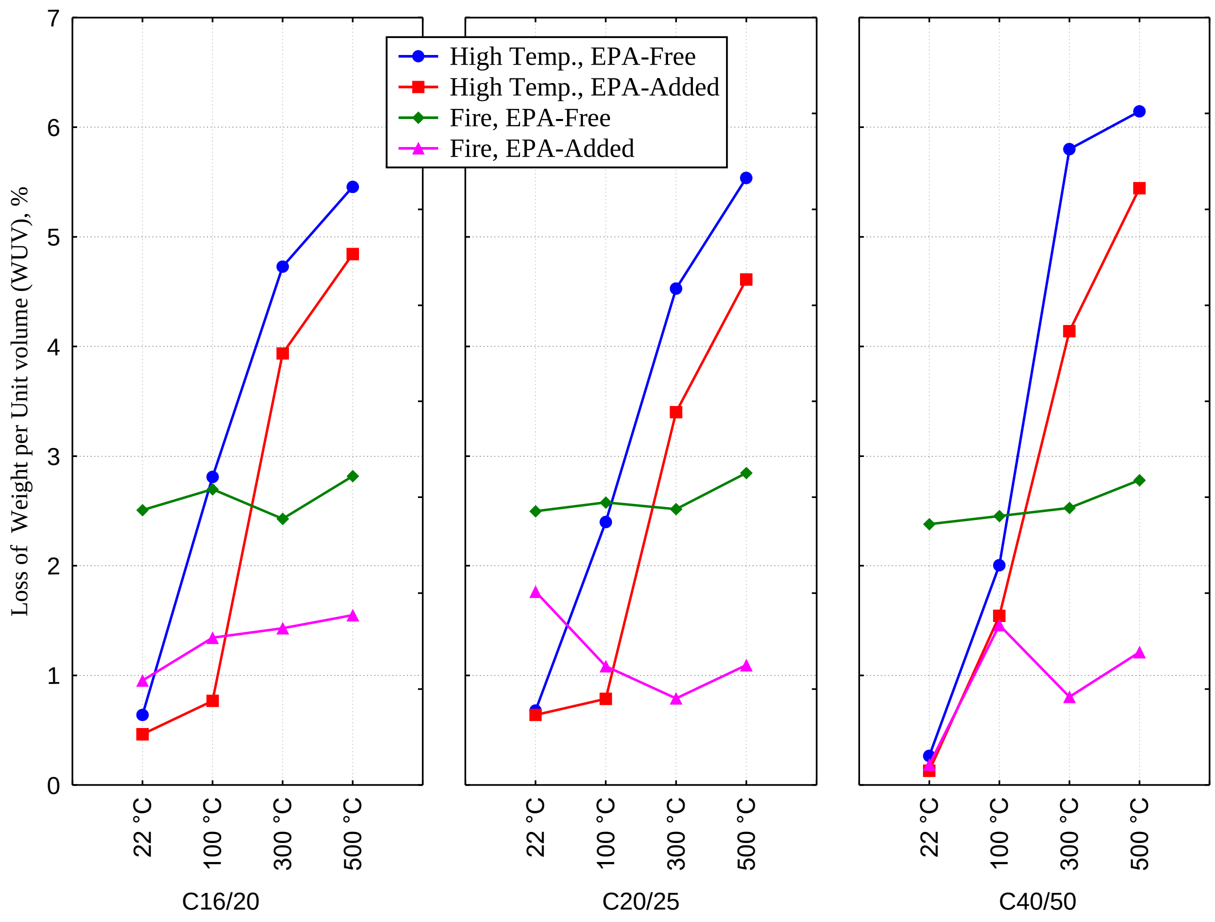


***Figure 1**. Loss of WUV values*

As it can be seen in Fig. 1 EPA free oven samples' loss of WUV decreases as temperature value increases. While EPA free oven samples show the most damage of WUV, by the effect of high temperature, with the value of 6,144% at 500°C for C40/50 samples, for EPA added oven samples show the least loss with the value of 0.267% at 100°C for C40/50. Besides that, while EPA added oven samples shows the most damage of WUV with the value of 5.444% at 500 °C, the least loss of WUV with the value of 0,131% at 22 °C.

While the loss of WUV shows increment for some temperature interval, it shows decrement for some temperature interval for EPA free fire samples. By the effect of high temperature, while EPA free fire samples demonstrate the most loss of WUV with the value of 2,847% at 500°C for C20/25, C40/50 examples show the least decline of WUV with the value of 2,379% at 22°C. For EPA added fire samples the loss of WUV increases for some interval and decreases for some range. For EPA added fire samples the most loss of WUV is for C20/25 samples with the value of 1,764% at 22 °C, the least loss of WUV is for C40/50 samples with the value of 0.187% at 22 °C.

The loss of WUV that is developed by the effect of high temperature, for both EPA free and EPA, added fire samples do not show an apparent increment as the temperature value increases, for some intervals decrement is observed. Also, WUV increment and CS classes are not seen as related factors for fire samples. Since, the loss of WUV that is caused by the effect of high temperature, for EPA added fire and oven samples is smaller than EPA free samples, it can be said that EPA prevents loss of WUV which may be caused by the effect of temperature.

The difference between high temperature and fire can be explained as fire affects only one surface, but in a high-temperature oven, the heat is applied to whole surfaces in a confined space.

### *C. UPV TEST RESULTS*

Results of ultrasonic pulse velocity (UPV) test for three different concrete classes depending on high-temperature oven/fire values are given in Figure 2.

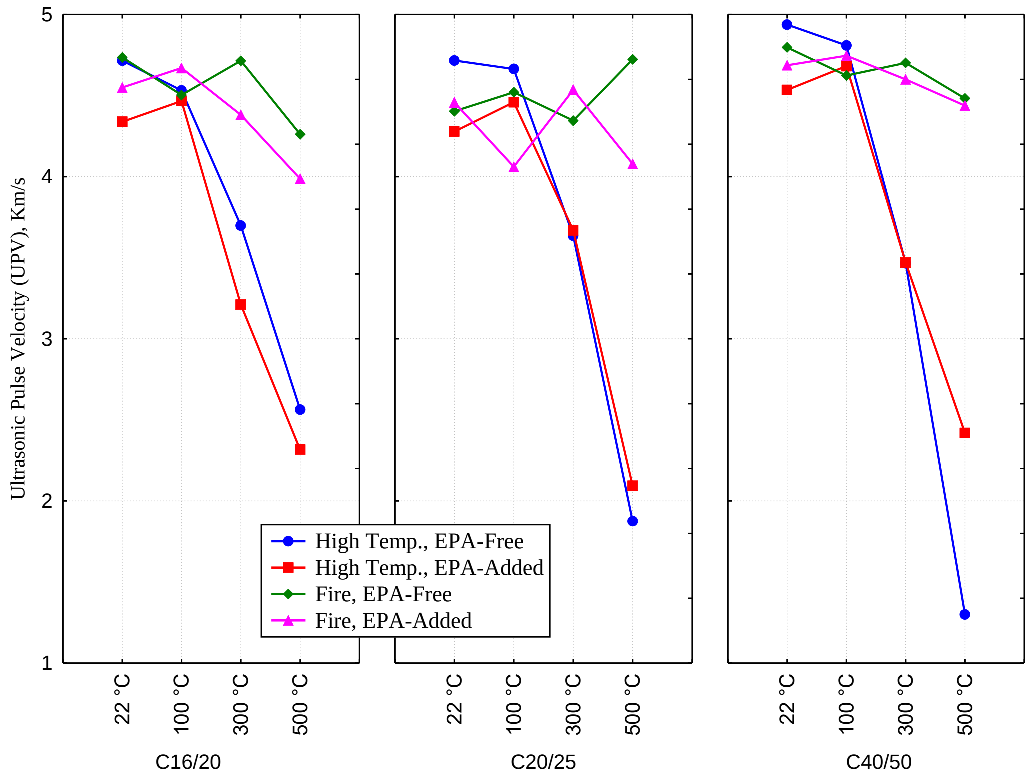


***Figure 2.*** *UPV values*

As it can be seen in Fig. 2 UPV values decrease by the effect of high temperature in EPA free samples. While for EPA free oven samples UPV value is 4.938 km/s at most at 22 °C for C40/50, for EPA added samples UPV value is 1.3 km/s that is at least at 500 °C for C40/50. While, for EPA added oven samples UPV value is 4.682 km/s that is at most at 100 °C for C40/50, for C20/25 samples UPV values is 2,093 km/s that is at least at 500 °C.

For EPA free fire samples UPV values increase for some interval while they decrease for some interval by the effect of high temperature. While for EPA free C40/50 fire samples the UPV value is 4.797 km/s that is at most at 22 ºC, for C16/20 samples the value is 4.262 km/s which is at least at 500 ºC. For EPA added fire samples the UPV value is 4.671 km/s which is at most at 100 ºC for C40/50, while for C16/20 samples it is 3.987 km/s that is at least at 500 ºC.

For both EPA free and EPA added oven samples UPV values decreases uniformly as temperature increases. This situation may be caused by the increment of the spaces in concrete. For both EPA free and EPA added fire samples UPV values show a substantial increase as the temperature increases.

## *D. RESULTS OF COMPRESSIVE STRENGTH TEST*

Results of compressive strength (CS) test for three different concrete classes depending on high-temperature oven/fire values given in Figure 3.

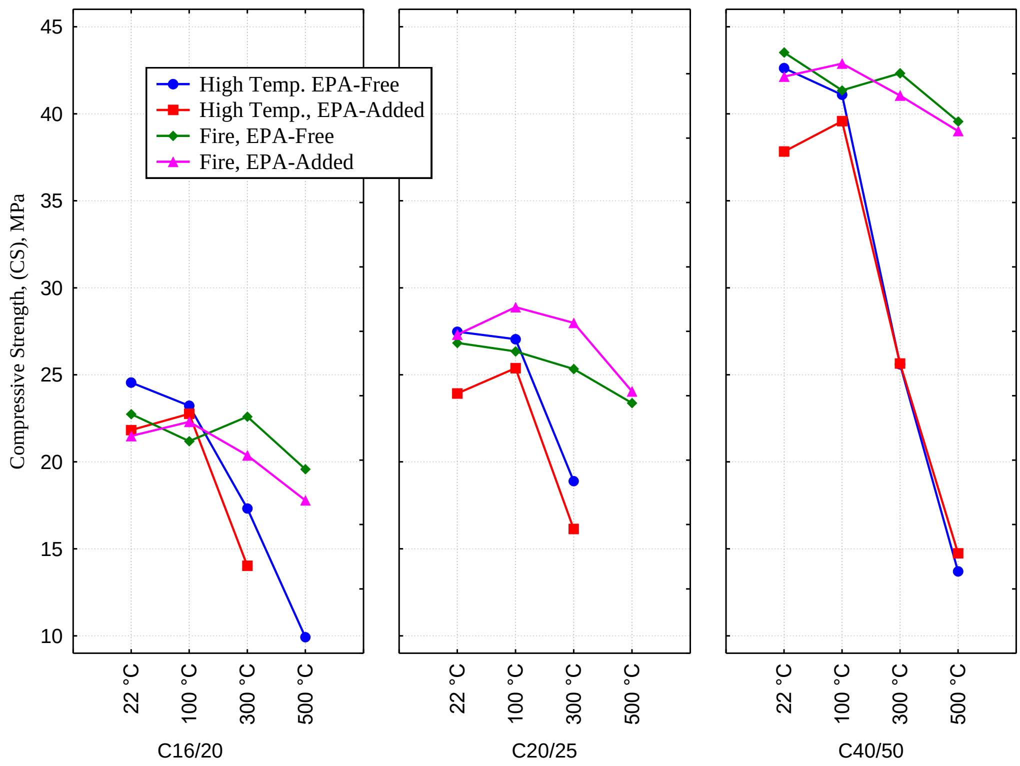


***Figure 3****. CS Test Values*

As it can be seen from Fig. 3, for EPA free oven sample groups CS values show a substantial decrease as the temperature increases.  While for EPA free oven sample groups the most CS value is 42, 62 MPa for a C40/50 class at 22 °C, for C20/25 samples it is 8, 72 MPa, which is the least value, at 500 °C. For EPA added oven samples, CS values decrease uniformly as the temperature increases. For EPA added oven samples the most CS value is 39,874 MPa for a C40/50 class at 100 °C, while the least CS value is 8,057 MPa for a C20/25 class at 500 °C.

The decrement in CS values for EPA free fire samples is more substantial than EPA free oven samples as the temperature increases. For EPA free fire samples the most CS value is 43.52 MPa for a C40/50 class at 22 °C, while it is at least 19.58 MPa for a C16/20 class at 500 °C. While for EPA added fire samples the most CS value is 42.885 MPa for a C40/50 class at 100 °C, it is at least 17.785 MPa for a C16/20 class at 500 °C.  The decrement of CS for both EPA free and EPA added oven samples are quite larger than both EPA free and EPA added fire samples. This situation may be caused by the heat loss during a fire or by the effect of the fire affects only one surface of the sample

## IV. Conclusion

All in all, it is observed that as the temperature increases, the average loss of WUV values also increases. According to the WUV test results, the loss of WUV under high temperature given with oven is greater than the loss WUV under high temperature given with fire. For both EPA free and EPA added oven samples, loss of WUV values increases neatly as the temperature value increases, however for both EPA free and EPA added fire samples, a miserable increment is observed as the temperature increases. The difference between high-temperature oven and fire can be explained as fire affects only one surface for fire or there may be heat abduction around the fire engine or 500 ºC sample may remain incapable under the effect of one surface fire.

For both EPA free and EPA added fire samples UPV values decrease miserably, almost remain constant, as temperature increases. For all samples under high temperature, UPV values of EPA added samples decrease less than UPV values of EPA free samples. This situation shows that the concrete retains its void space against high temperature because of EPA.

According to CS results, for all samples, compressive strength decreases as the concrete class increases. The compressive strength dissipation under the influence of the high temperature for the oven samples is %60 while the compressive strength dissipation under high temperature for fire samples is around %10. No relation is observed in compressive strength dissipation whether the samples have EPA or not. Also, it is observed for all samples that under high temperature, there is no relation between water-cement ratio and compressive strength dissipation.

For similar studies, it can be suggested that the applied temperature may be increased and the loss of heat in fire engine may be prevented.

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