KSÜ Mühendislik Bilimleri Dergisi, 22(3), 2019
Araştırma Makalesi

KSU J Eng Sci, 22(3), 2019
Research Article

Kahramanmaras Sutcu Imam University
Journal of Engineering Sciences

Geliş Tarihi : 14.06.2019
Kabul Tarihi : 09.09.2019

Received Date : 14.06.2019
Accepted Date : 09.09.2019

INVESTIGATION of HIGH TEMPERATURE BEHAVIORS of DIFFERENT CURE APPLIED CONCRETES

FARKLI KÜR UYGULANMIŞ BETONLARIN YÜKSEK SICAKLIK DAVRANIŞLARININ İNCELENMESİ

Kadir GÜÇLÜER

Adıyaman Üniversitesi, Teknik Bilimler MYO İnşaat Bölümü, Adıyaman, Türkiye

*Sorumlu Yazar / Corresponding Author: Kadir GÜÇLÜER, kgucluer@adiyaman.edu.tr

ABSTRACT

Concrete is produced cement-bonded system, which is a composite material formed by the combination of different components. The hydration process of the cement and the hydration products affect the mechanical and technological properties of the concrete. In this sense, the curing process is needed to achieve the targeted mechanical properties. In this study, concrete samples were produced by using additives with different origins called mineral additives. The samples were subjected to pressurized steam curing with the help of autoclave at different temperature and pressure values. After the curing process, the compressive strength of the test samples were investigated. In addition, the cured samples were kept in high temperature furnaces at 450 and 900 ^{0}C for 6 hours and the compressive strength of the samples were examined. As a result of the study, it was found that the autoclave cure caused an increase in the compressive strength of the concrete at 400 ^{0}C. The best high temperature resistance values were determined in the blast furnace slag addition series.

Keywords: Concrete, cure, high temperature, mineral additive.

ÖZET

Beton çimento esaslı sistemde farklı bileşenlerin bir araya gelmesi ile oluşan kompozit malzemedir. Çimentonun hidratasyon süreci ve hidratasyon ürünleri betonun mekanik ve teknolojik özelliklerini etkilemektedir. Bu anlamda hedeflenen mekanik özelliklere ulaşabilmek amacıyla başarılı bir kür işlemine ihtiyaç vardır. Bu çalışmada farklı orijinlerde olan mineral katkılar kullanılarak beton örnekler üretilmiştir. Örneklere otoklav aracılığıyla farklı sıcaklık ve basınç değerlerinde otoklav kürü uygulanmıştır. Kür işleminin ardından deney örnekleri üzerinde basınç dayanımı deneyi gerçekleştirilmiştir. Ayrıca kür işlemi uygulanan numuneler yüksek sıcaklık fırınlarında 450 ve 900 ^{0}C yüksek sıcaklığa maruz bırakıldıktan sonra basınç dayanımı deneyine tabi tutulmuşlardır. Çalışma sonucunda otoklav kürü uygulanmış numunelerin 400 ^{0}C sıcaklıkta basınç dayanımlarında artışa sebep olduğu tespit edilmiştir. En yüksek basınç dayanımı değerleri de yüksek fırın cürufu katkılı serilerde elde edilmiştir.

Anahtar kelimeler: Beton, kür, yüksek sıcaklık, mineral katkı.

INTRODUCTION

There is a global concern on saving energy and reducing carbon dioxide rate by improving the quality of materials and using resources to their maximum limit (Abdullah et al., 2018). Therefore, the recycling of industrial waste products and environmentalist production are very important. Concrete is the most widely using composite construction materials. Concrete production can be made by using industrial waste materials such as fly ash, silica fume and blast furnace slag mineral additives (Duan et al., 2013, Gruyaert et al., 2013, Jiang et al., 2014, Iasaia et al., 2003) . Different additives are used to control technological properties of concrete mixes as well as physical and mechanical properties of hardened concrete. It is important to investigate the effect of these additives on the physical and mechanical properties of concrete in order to achieve the effective performance of concrete and the required properties and durability of hardened concrete (Nagrockiene et al., 2017). Industrial by-products and solid wastes such as mineral additives could be used in concrete as a replacement material to reduce harmful effects of concrete industry on the environment. Therefore strength and durability characteristics of concrete containing mineral additives as partial replacement of cement should be investigated (Uysal&Tanyılıdızı, 2012).

Concrete may be exposed to high temperatures in cases such as the occurrence of fire in concrete structures, in the explosion of jet engines, in factories in the extraction and melting of metals, in some chemical plants where concrete is close to the furnace, and related- nuclear activities (Abaeian et al., 2018). Concrete damage due to high temperature includes weight loss, reductions in strength and modulus of elasticity, and formation of cracks and large pores (Janotka&Mojumdar, 2005). Most researchers believe that the concrete compressive strength increases at around 200 ^{0}C; at about 400 ^{0}C, it begins to decay and 400~800 ^{0}C temperature ranges is the major loss of strength which is 400~600 ^{0}C strength decreases fastest segment (Poon&Shoui, 2004). Esen and Kurt (2017) they stated that they did not observe any change in compressive strength in series up to 400 ^{0}C ın their experimental study (Esen&Kurt, 2017). Similarly, in their study in Morsy et al. (2008), they determined that the compressive strength in the temperature regime up to 200 degrees increased and then decreased (Morsy et al., 2008).

Curing processes applied in concrete technology can be listed as normal curing, low pressure steam curing, high pressure steam curing and membrane winding (Liu et al., 2005). Curing promotes hydration, prevents water loss in concrete, and keep the material saturated or nearly saturated as long as possible or for sufficient time (Mehta&Paulo, 2006). The autoclave is a special steam curing machine with cylindrical shape and steel walls (Mindess et al., 1981). Autoclave curing is often used to accelerate cement hydration and increase the strength development of concrete (Wang&Shie, 2009). However, changes in the application of temperature and pressure in the autoclave cure regime may affect the mechanical properties differently. Chen et al. (2018) found that compressive strength values tend to decrease after increasing autoclave pressure and duration (Chen et al., 2018). Palaou et al. (2012) found that the pressure strength values of concrete test samples decreased with the increase of temperature and pressure values in the autoclave (Palaou et al., 2012). In this study, fly ash, silica fume and blast furnace slag additives were replaced with cement by 15% and concrete samples were produced. The test samples were subjected to a steam pressure of 1,2 and 4 bar for 8 hours in the autoclave. The samples were then exposed to high temperatures at 450 and 900 ^{0}C for 4 hours after the desired temperature was reached to determine the effect of high temperature and curing regime in autoclave.

MATERIAL and METHOD

In the study, Portland cement according to TS EN 197-1 was used as binder. The physical properties of the cement are given in Table 1. Fly ash (FA) was obtained from Çayırhan thermal power plant in Turkey. The chemical properties of fly ash, silica fume (SF), blast furnace slag (BFS) and cement are given Table 2. Total $SiO_2 + Al_2O_3 + Fe_2O_3$ ratio of fly ash is 73.16% and it is compatible with ASTM C 618. No harmful component was found for concrete production in the chemical composition of fly ash, silica fume and blast furnace slag.

Table 1. The Physical Properties of Cement.

Physical Properties		Results
Specific gravity (g/cm^3)		3.09
Settlement	First (min.)	125
Time	Last (min.)	190
Fineness	Specific surface (cm^2/gr)	3420

Table 2. Chemical Components Of Cement And Mineral Additives.

Oxide	CaO	SiO_2	Fe_2O_3	Al_2O_3	MgO	SO_3	K_2O	LOI
Cement	62,63	19,29	4,25	3,88	3,42	2,58	0,34	2,86
FA	10,79	50,43	9,56	13,17	3,74	3,45	1,88	0,86
SF	0,74	94,36	0,70	0,81	1,18	0,20	0,86	0,74
BFS	39,69	40,10	0,92	7,83	4,26	2,11	1,24	0,63

As it is known from the literature, the mineralogical origin of silica fume and blast furnace slag is amorphous (Tokyay, 2016). In the mineralogical structure of fly ash, quartz mineral was observed predominantly. The presence of the anhydrite structure is also remarkable. The concrete mixture values are given in Table 3. The mixing ratios of the test samples to be produced were carried out in accordance with the reference conditions specified in TS 802 (TS 802, 2009). Mineral additives were used by replacing 15% by weight of cement.

Table 3. Mixture Ratios (kg/m³)

Series Name	*Fine Aggregate (0-5 mm)	*Coarse Aggregate (5-12 mm)	*Coarse Aggregate (12-22 mm)	Cement	Fly Ash	Silica Fume	Blast Furnace Slag	Water	Air (%)
WT	668	618	444	371	-	-	-	204	2
SF	668	618	444	315,35	-	55,65	-	204	2
FA	668	618	444	315,35	55,65	-	-	204	2
BFS	668	618	444	315,35	-	-	55,65	204	2

*0-5mm, 5-12 mm and 12-22 mm aggregate specific gravity was found respectively 2,52 - 2,52 – 2,50 g/cm^3

Maximum aggregate grain size was chosen as 22mm. The granulation of the mixture prepared according to the maximum aggregate grain size is formed between the reference curves (Fig. 1).

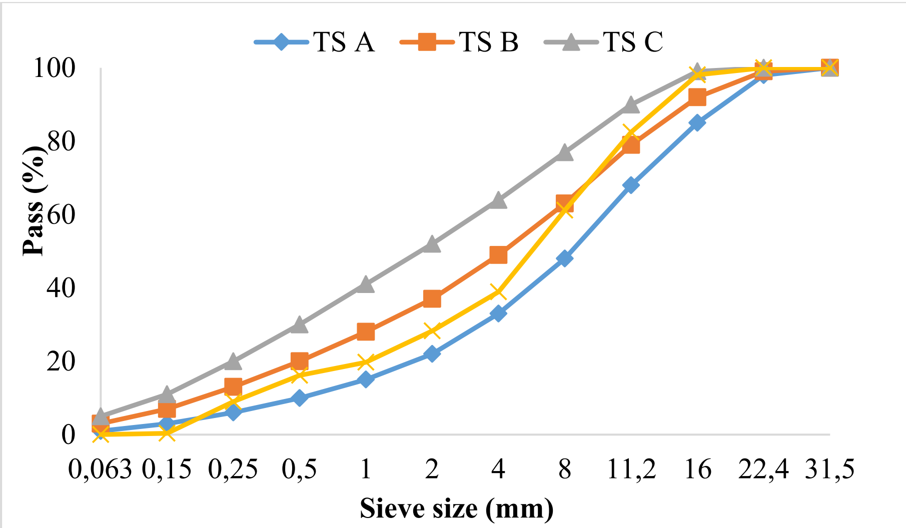

Figure 1. Mixture Granulometry.

The test specimens were cured in an autoclave for 8 hours at 3 different vapor pressures and temperature between 105 - 123 - 145 ^{0}C and 1 - 2 - 4 bar. They were kept in autoclave for 45 minutes at the end of the curing period and 45 minutes heating time until the desired temperature. The applied cure regime is shown in Figure 2. Mineral added test samples were kept in water tank for 7 and 28 days except autoclave cure and standard curing application was performed. The samples were exposed to 450 and 900 ^{0}C in high temperature furnaces (Figure 3). High temperature application was carried out for 4 hours after the desired temperature was reached. The mechanical properties of the samples were compared as a result of different curing processes and high temperature applications.

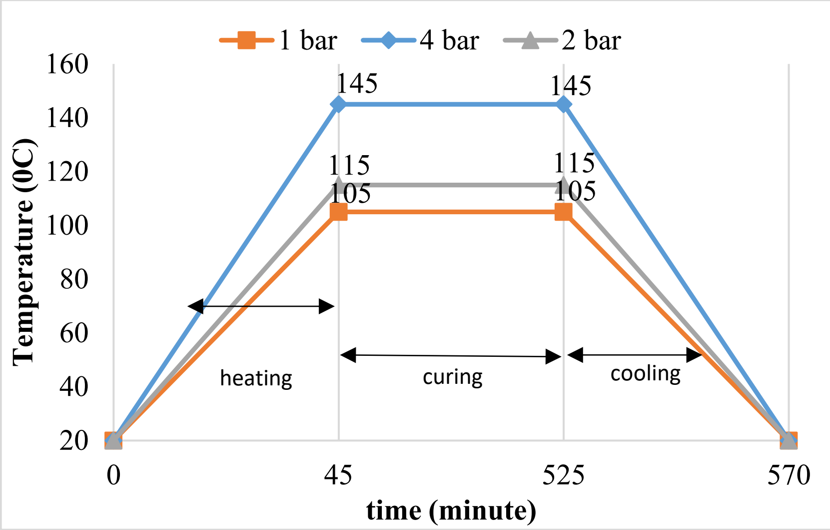

Figure 2. Autoclave Cure Regime.

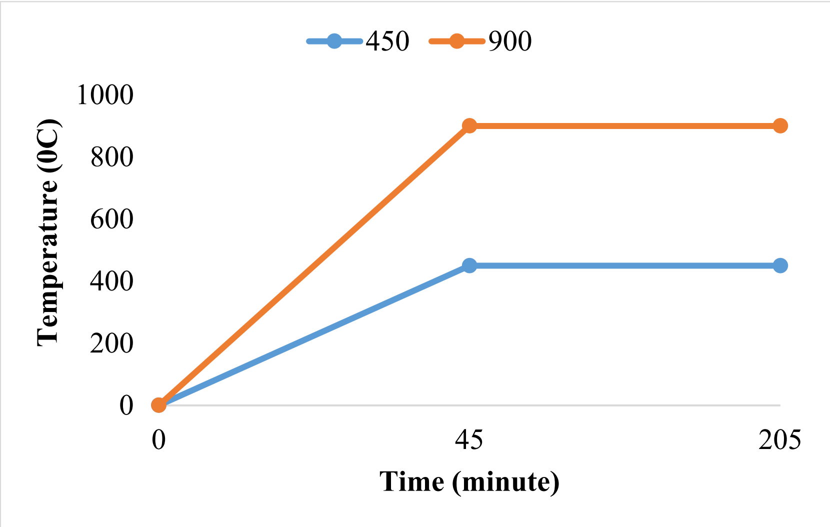

Figure 3. High Temperature Furnace Regime.

In order to determine the mechanical properties, compressive strength tests on autoclave cure and standard curing samples were carried out with reference to TS EN 12390-3 (TS EN 12390-3, 2003). The compressive strength values were calculated with the help of formula (1).

$$f_{ck}=P/A_0 \tag{1}$$

In the equation; f_{ck}, characteristic compressive strength, (N/mm^2), P applied force (N) and A_o surface area (mm^2).

RESULTS and DISCUSSION

The compressive strength findings of the samples produced by silica fume are given in Figure 4. The highest compressive strength values were obtained after 28 days of curing in silica fume additive series. It was determined that the compressive strength values of the samples cured in the autoclave were lower than the standard cured samples. In addition, it was observed that the increase in the pressure value in the autoclave caused a decrease in the compressive strength.

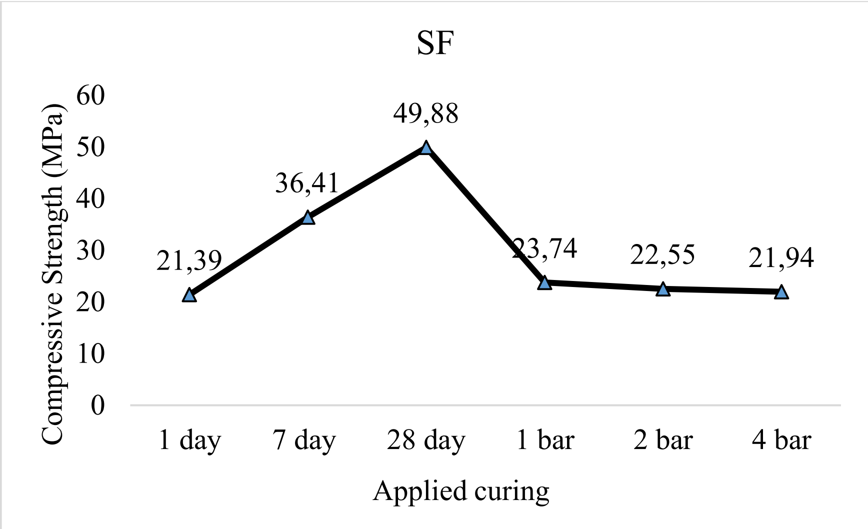

Figure 4. Findings of Compressive Strength of SF Additive Samples.

The compressive strength findings of fly ash added samples are given in Fig. 5. Similar to the silica fume addition series, the highest compressive strength findings in the fly ash additive series were determined in the 28 days standard curing applications. It was determined that the compressive strength of the fly ash additive series decreased with the increase of the pressure value in the autoclave.

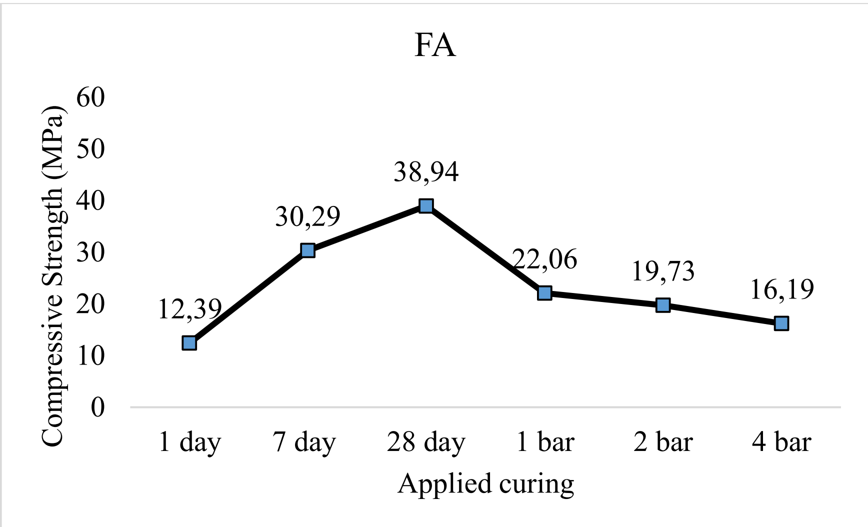

Figure 5. Findings of Compressive Strength of FA Additive Samples

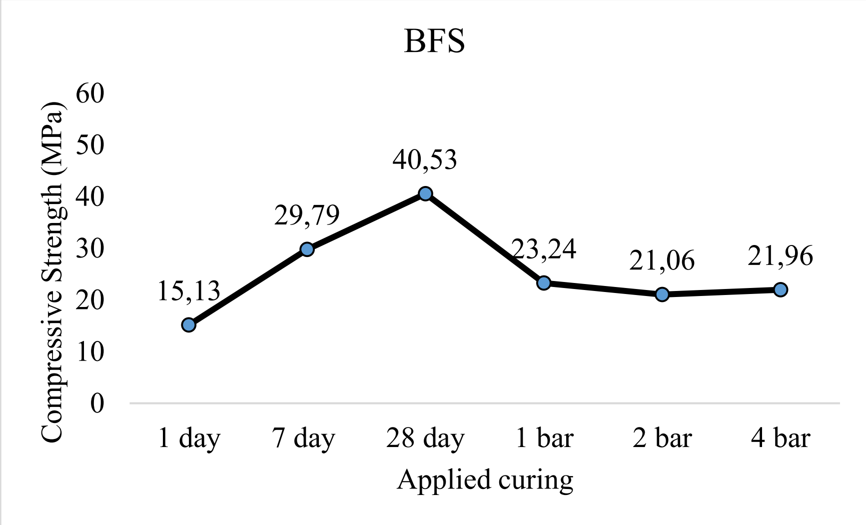

Figure 6. Findings of Compressive Strength of BFS Additive Samples

The findings of the compressive strength of the blast furnace slag added series are given in Figure 6. It was determined that the compressive strength of blast furnace slag addition series decreased with the increase of autoclave pressure value. When the 28-day compressive strength values of the additive samples were compared, the highest value was determined 49.88 MPa in silica fume additive series. This value is determined as 40,53 MPa in BFS series and 38,94 MPa in FA series. The autoclave cure results in an increase in strength compared to the early strength values of the samples. However, increased temperature and pressure in the autoclave cause a decrease in compressive strength. Amorphous mineralogical structure of silica fume and high silica content can be shown as an increase in compressive strength of early and progressive hydration periods. In this sense, it can be said that silica fume has a stronger pozzolanic property than BFS. The anhydrous structure in the mineralogical composition of fly ash can be shown as a cause of decrease in the strength values. As a result of the application of autoclave cure in all series, the compressive strength values were determined lower than 28 day standard curing. Even under high temperature conditions, the reaction between calcium hydroxide and silicate continues, but the rise in temperature will prevent sufficient moisture from being met. The loss of moisture will cause cracks and low strength in the structure (Frıedlaender&Camarda, 1972, Shi&Hu, 2003). This can be illustrated as leading to decreased strength in the autoclave cure application.

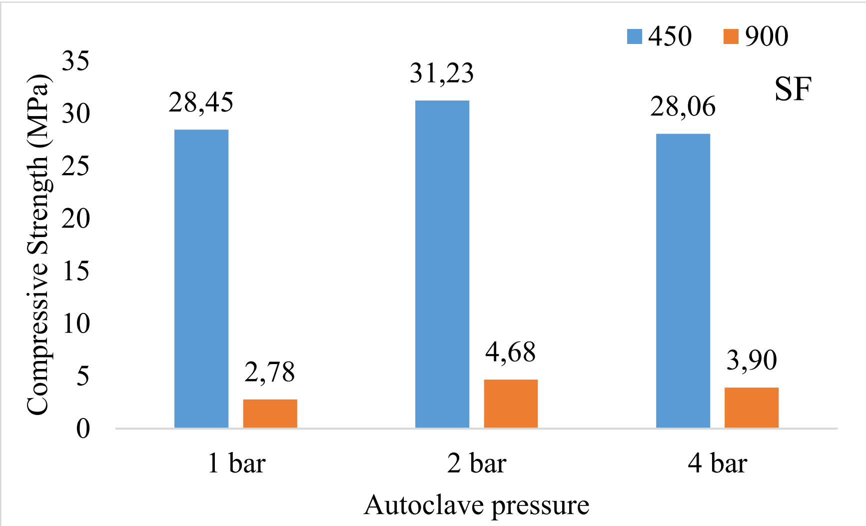

Figure 7. Strength Findings of High Temperature Applied Samples with SF.

The compressive strength data of the samples cured in autoclave with high temperature applied silica fume is given in Figure 7. The compressive strength values of the SF series increase at 450 degrees. After the application of 900 ^{0}C temperature, it has been determined that there is a significant decrease in the compressive strength.

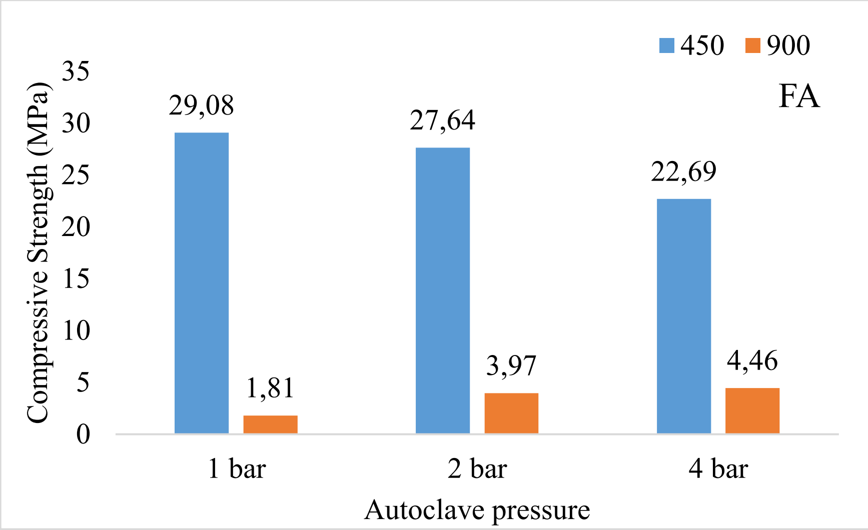

Figure 8. Strength Findings of High Temperature Applied Samples with FA.

Figure 8 shows the measured compressive strength of the samples produced by fly ash after high temperature application. It was determined that the compressive strength of the samples increased after 450 ^{0}C temperature application. After the application of 900 ^{0}C temperature, a significant decrease was observed in the compressive strength. Figure 9 shows the compressive strength results obtained after high temperature application of the BFS series.

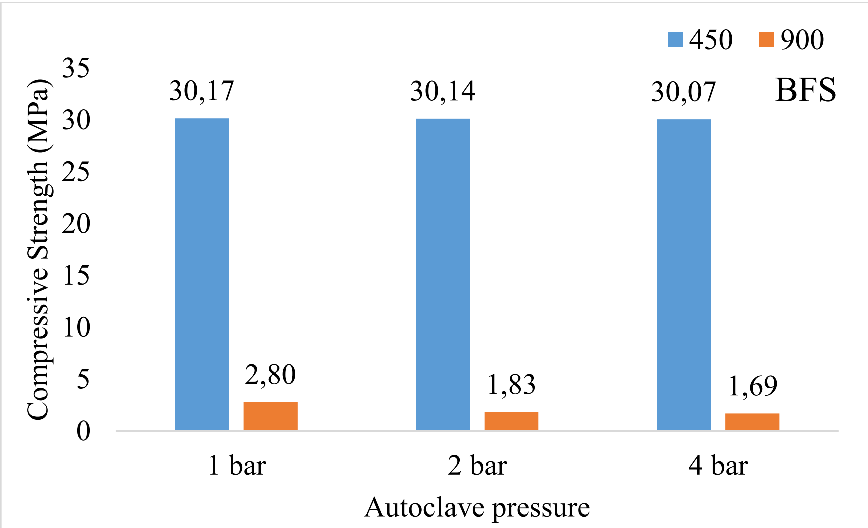

Figure 9. Strength Findings of High Temperature Applied Samples with BFS.

Similar to the series of silica fume and fly ash additions, an increase in strengths of 450 ^{0}C was found in the series with BFS additives. Significant decreases in compressive strengths were determined at 900 ^{0}C. In all series, ıt was determined that autoclave cure positively influenced the high temperature compressive strength of 450 ^{0}C and an increase in compressive strength values.

Obviously, the blended cement mortars of mixes showed an increase in compressive strength at 400 ^{0}C. This increase may be due to the hydration of unhydrated BFS, FA and SF particles which were activated as a result of temperature rise. This increase may be due to further hydration of unhydrated cement grains as a result of steam effect under the condition of the so-called internal autoclaving formed in cement paste (Nimityongskul&Daladar, 1995). In addition, at 400 ^{0}C, autoclave cured samples may have more intense CSH structure. This condensation is caused by the expansion of the structure by increasing the temperature, the partial removal of the water from the medium, and thus the strengthening of the secondary cohesive bonds (Uysal, 2004).

CONCLUSION

As a result of the experimental study;
- It has been determined that autoclave cure improves early compressive strength of concrete.
- Puzolanic activity capacity of silica fume was higher than blast furnace slag and fly ash.
- Chemical structure of fly ash, degree of combustion and physical properties directly affect the concrete compressive strength.
- The autoclave cure positively affected the compressive strength of the concretes subjected to high temperature application of 400 ^{0}C.
- The highest compressive strength loss occurred after 900 ^{0}C high temperature application.
- If the resistance of mineral additives to high temperature is listed; best resistance to blast furnace slag followed by silica fume and finally fly ash.

REFERENCES

Abaeian, R., Behbahani, H.P., Moslem, J.S. (2018). Effects of high temperatures on mechanical behavior of high strength concrete reinforced with high performance synthetic macro polypropylene (HPP) fibres. *Construction and Building Materials,* 165, 631–638.

Abdullah, W., Abdulkadir M., Muhammed M. (2018). Effect of high temperature on mechanical properties of rubberized concrete using recycled tire rubber as fine aggregate replacement. *Engineering and Technology Journal*, Vol. 36, Part A, No. 8.

Chen, T., Gao, X., Ren, M. (2018). Effects of autoclave curing and fly ash on mechanical properties of ultra-high performance concrete. *Construction and Building Materials*, 158, 864–872.

Duan, P., Shui, Z., Chen, W., Shen, C. (2013). Effects of metakaolin, silica fume and slag on pore structure, interfacial transition zone and compressive strength of concrete. *Construction and Building Materials*, 44,1-6.

Esen, Y., Kurt, A. (2017). Effect of high temperature in concrete for different mineral additives and rates. *KSCE Journal of Civil Engineering*, 22(4), 1288-1294.

Frıedlaender, W.V., Camarda, F.V. (1972). Influence of superheated steam on the autoclave-cure strengths of cement and concrete composıtıons. *American Concrete Institute Publishing*, Volume 32, 99-116.

Gruyaert, E., Maes, M., De Belie, N. (2013). Performance of BFS concrete: k-value concept versus equivalent performance concept. *Construction and Building Materials*, 47, 441-455.

Isaia, G.C., Gastaldini, A.L.G., Moraes, R. (2003). Physical and pozzolanic action of mineral additions on the mechanical strength of high-performance concrete. *Cement and Concrete Composites*, 25, 69-76.

Janotka I, Mojumdar S.C. (2005). Thermal analysis at the evaluation of concrete damage by high temperatures. *J. Therm. Anal Calorim*, 81, 197–203.

Jiang, C., Yang, Y., Wang, Y., Zhou, Y., Ma, C. (2014). Autogenus shrinkage of high-performance concrete containing mineral admixtures under different curing conditions. *Construction and Building Materials*, 61, 260-269.

Ka, M. Mehta, J., Paulo, M. (2006). *Concrete Microstructure, Properties, and Materials*. Mc Graw Hill Education.

Liu, B., Xie, Y., Li, J. (2005). Influence of steam curing on the compressive strength of concrete containing supplementary cementing materials. *Cement and Concrete Research*, 35(5), 994–998.

Mindess, S., Young, J.F., Darwin, D. (1981). *Concrete*. Prentice Hall, New Jersey.

Morsy, M.S., Rashad, A.M., Shebl, S.S. (2008). Effect of elevated temperature on compressive strength of blended cement mortar. *Building Research Journal*, Volume 56, 2-3.

Nagrockiene, D., Girskas, G., Skripkuanas, G. (2017). Properties of concrete modified with mineral additives. *Construction and Building Materials,* 135, 37–42.

Nimityongskul, P. and Daladar, T. U. (1995). Coconut husk ash corn cob ash and peanut shell ash as cement replacement. *Journal Of Ferrocement*, Vol. 25, No. 1, 35-44.

Palou, M., Zıvıca, V., Bagel, L., Ifka, T. (2012). Influence of hydrothermal curing on g-oıl well cement properties. *Building Research Journal*, 60, 223-230.

Poon C.S, Shui Z.H, Lam L. (2004). Compressive behaviour of fiber reinforced high-performance concrete subjected to elevated temperatures. *Cement Concrete Research*, 34, 2215-22.

Shi, C., Hu, S. (2003). Cementitious properties of ladle slag fines under autoclave curing conditions. *Cement and Concrete Research*, 33(11), 1851–1856.

TS 802, Beton Karışım Tasarımı Hesap Esasları, Türk Standartları Enstitüsü, Ankara, 2009.

TS EN 12390-3 (2003). Beton-Sertleşmiş Beton Deneyleri-Bölüm 3: Deney Numunelerinde Basınç Dayanımının Tayini, Türk Standartları Enstitüsü, Ankara.

Tokyay, M. (2016). *Cement and Concrete Mineral Admixtures*. CRC Press, New York.

Uysal, A. (2004). Yüksek sıcaklığın beton üzergindekgi etkileri. İTÜ Fen Bilimleri Enstitüsü, Yüksek Lisans Tezi, İstanbul.

Uysal, M., Tanyildizi, H. (2012). Estimation of compressive strength of self compacting concrete containing polypropylene fiber and mineral additives exposed to high temperature using artificial neural network. *Construction and Building Materials,* 27, 404–414.

Wang, H., Shie, J. (2009). Effect of autoclave curing on the compressive strength and elastic modulus of lightweight aggregate concrete. *Journal of ASTM International*, Vol. 6, No. 6: 1-4.

ORCID

Kadir GÜÇLÜER *http://orcid.org/0000-0001-7617-198X*