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RESEARCH ARTICLE-CIVIL ENGINEERING

Investigation of the Change in Mechanical Properties of Concrete Subjected After High-Temperature Effect to Cyclic Lateral Load

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Abstract

The main cause of many physical and chemical events in the world is shown as high temperature. When concrete used as a building material is exposed to high temperatures, its physical and mechanical properties change. The aim of this study is to investigate the change in compressive strength of normal strength concrete exposed to different temperatures for different periods of time when subjected to cyclic loading. For this purpose, 13 reinforced concrete frame specimens and 39 standard cylinder specimens were produced and exposed to 200, 400, 600 and 800 °C high temperatures for 60, 120 and 180 min. Then, the frame test members were allowed to cool on their own and when they reached room temperature, they were removed from the oven and tested under cyclic load. At the end of the cyclic loading tests, 26 concrete core samples were taken from the frame test members and compressive strengths were determined. As a result of the study, it was determined that thermal cracks in normal concrete caused by heat treatment lead to physical and mechanical changes, and these changes are effective in the decrease in strength. In the study, it was found that the decrease in compressive strength was more than 78% in concretes exposed to cyclic lateral loads after high-temperature effect. A comparison of the experimental strength loss curves of concrete with the design curves in the literature was also made.

Keywords High temperature · Exposure duration · Compressive strength · Cyclic load · Design curves

1 Introduction

Concrete is a composite material obtained by mixing aggregate, cement, water, and if necessary, chemical and/or mineral additives in certain proportions, which can be placed in molds of different sizes and shapes and harden when appropriate conditions are provided [1, 2]. Today, in the production of many structures and elements, especially chimney structures, metal treatment plants, furnaces, reinforced concrete structures where high-level radioactive wastes are stored, the use of concrete materials with high strength and durability properties continues intensively due to the developments in technology.

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The high-temperature factor plays an important role in many physical and chemical events that occur on earth. Engineering structures are also adversely affected by the physical and chemical events caused by high temperatures, and many structures are damaged and out of use. High-temperature effects, commonly caused by fire, etc., reduce the strength and durability of concrete materials used in engineering structures. The fire resistance of concrete is affected by factors such as the type of aggregate and cement used in its composition, the temperature and duration of the fire, the dimensions of the building elements and the moisture content of the concrete [3, 4]. In general, aggregates have high fire resistance, but uneven heating and cooling of concrete using water can cause internal pressure in the aggregates, which can cause them to disintegrate. In addition, the grain size of the aggregates used in concrete is also effective on the high-temperature performance of concrete. Shao et al. [5] heated fine, medium and coarse-grained granite specimens at 200, 400, 600 and 800 °C and found that fine grained specimens were less damaged at 800 °C than medium and coarse-grained specimens. The increased crack density was attributed to thermal crack formation during the cooling process for specimens heated at higher temperatures. In addition, it has been determined that aggregate grain size and excessive heterogeneity cause more thermal deformation and deterioration in mechanical properties in concretes composed of coarse aggregates [6]. Another reason for the deformations caused by high temperature on concrete is the expansion of the cement in its composition. Portland cement contains a significant amount of free calcium hydroxide. At 400–450 °C, calcium hydroxide turns into calcium oxide due to water loss. If the concrete is kept in a humid environment after cooling, the formation of calcium hydroxide takes place again. The resulting volume change may cause the concrete to crumble [2, 7–9].

The effects of high temperature on the mechanical properties of concrete have been investigated since the 1940s [10, 11]. In these studies, materials such as cement paste and mortar, concrete samples and high-temperature behavior of reinforced concrete structural elements were investigated [12]. As a result of these studies, the technical basis of many regulations with provisions and recommendations for the determination of concrete strength at high temperature has been established [12]. By using these regulations, the mechanical properties of concrete exposed to high temperatures can be obtained [13–17]. In most of the studies in the literature, the change in mechanical properties of normal and high strength concretes exposed to high temperature has been investigated [18–20]. In some studies, the change in the mechanical properties of normal and high strength concretes exposed to high temperatures was considered depending on the type of cooling [21].

Studies have shown that normal and high strength concretes exposed to high temperatures have loss of strength and deterioration of concrete surfaces. In most of the studies, it has been reported that high-temperature changes the porous structure of concrete and therefore compressive strength may be adversely affected. Vodák [22], based on strength and porosity tests of concrete exposed to temperatures ranging from 25 to 280 °C, suggested that compressive strength decreases with increasing porosity. Similarly, Kodur [23] observed in his study that the compressive strength of concrete exposed to high temperatures ranging from 20 to 800 °C decreased. These changes in the compressive strength of concrete with high temperature are supported by ASCE [24], Kodur [25] and Eurocode [26]. Bazant [27] determined that when concrete is exposed to 400 °C high temperature, most of the chemically bound water is dehydrated and this increases the porosity of the concrete, resulting in a significant loss of strength. Strength losses in concrete exposed to high temperatures have been attributed to thermal crack formation in some studies in the literature. During the heating process, it was determined that sparsely distributed microcracks were formed in the concrete when the temperature reached 200 °C, while the number of microcracks increased continuously at 400 °C [28]. At 400 °C, the maximum width of microcracks was below 2 μm, but in the 550–650 °C range, the crack width increased to 8 μm [29]. On the other hand, some studies in the literature have investigated the effect of heating rate on the thermophysical properties of concrete. Gautam et al., [30] heated two types of Jalore granite rocks to 300 °C at heating rates of 3, 5, 10 and 15 °C/min. In the study, it was determined that thermal cracks develop after the heating rate threshold value between 3 and 5 °C/min, and a heating rate equal to or lower than 5 °C/min should be used to prevent thermal shock damage. In the study, it was determined that the mineral, chemical and elemental composition of granite rock did not change when heated up to 300 °C at different heating rates [30]. On the other hand, microstructural studies have been carried out on the materials used in concrete production in the literature and the physical, chemical and mineralogical changes occurring in concrete have been explained [31–34].

As can be seen from the aforementioned literatures, it has been determined in many studies that high-temperature effect affects the mechanical properties of concrete by causing changes in the physical, chemical and mineralogical properties of aggregate and cement that make up the concrete. However, in most of these studies, the degree of temperature alone or the duration of the effect was considered as a variable parameter. However, in practical engineering, concrete structures can be exposed to different high temperatures for different periods of time. In this context, when the studies in the literature are examined, it can be said that the studies in which both temperature and impact time are considered as variable parameters at the same time are quite limited. In addition to this, the number of studies in the literature on the changes in the mechanical properties of concrete in structures and elements exposed to lateral load effects such as earthquakes after high-temperature effect is also very limited.

In this study, the change in compressive strength of concrete exposed to different temperatures for different periods of time and the change in compressive strength of concrete subjected to cyclic lateral load after high temperature were investigated. The aggregate and cement used in the production of all concrete test specimens were taken with the same physical and mineralogical properties and the effectiveness of lateral load on the strength loss of structures subjected to high-temperature damage was investigated. In this context, the variation of concrete compressive strength as a function of temperature, impact time and cyclic lateral load was investigated, and a comparison was made with some design curves used in the literature. Thus, concrete strength loss curves that can be used in the design of structures exposed to cyclic lateral load effects such as earthquakes after high temperature are shared with the reader.

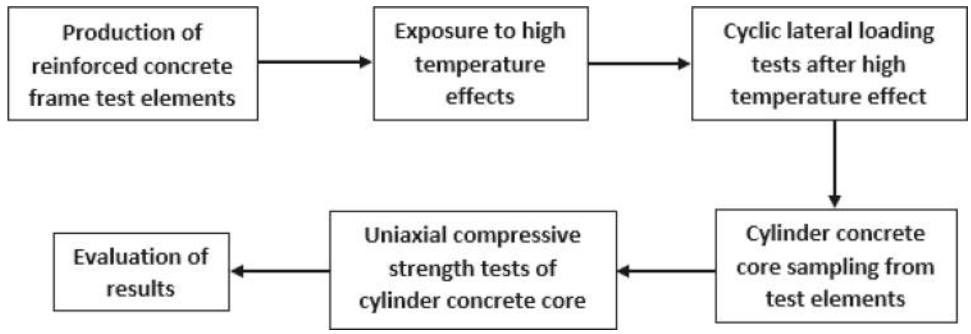

Fig. 1 Experiment matrix flowchart

2 The Aim of Study

The main objective of this research is to investigate the changes in the strength of normal concrete exposed to different elevated temperatures for different periods of time after cyclic lateral loading. In this direction, the compressive strengths of normal concrete exposed to temperatures of 200, 400, 600 and 800 °C for 60, 120 and 180 min; the compressive strengths after cyclic load effect were obtained, and the results were compared. In the study, tests were also performed on samples that were not exposed to high temperatures. The experimental matrix flowchart of the study is shown in Fig. 1.

3 Experimental Study

3.1 Materials

In this study, thirteen reinforced concrete frame test members were produced by obtaining concrete with C25/30 strength class from ready-mixed concrete plant (Fig. 2). Cement and aggregate with the same physical and mineralogical properties were used in all test elements. During the production of reinforced concrete frame test members, concrete was placed in standard cylinder (150 mm × 300 mm) molds in 3 stages, and a total of 39 cylinder concrete specimens were prepared (Fig. 2). The samples were removed from the molds the next day and kept in water at 22 ± 2 °C and 65% relative humidity for 28 days.

3.2 Test Procedure

On the 28th day, the samples were taken out of the water and the temperatures indicated in Table 1 were applied for the indicated times.

The application of the high-temperature effect was done by means of a test furnace (Fig. 3a). The test furnace is trolley-based and the materials to be subjected to heat treatment are loaded into the furnace by means of a moving trolley. The width, length and height of the test furnace are 2000 mm, 1500 mm, and 2000 mm, respectively. There are 2 K type thermocouples in the test furnace with a maximum operating temperature of 1100 °C. One thermocouple is placed to measure the temperature inside the furnace and the other to prevent the furnace internal temperature from reaching an undesirable temperature value.

Fire tests are generally designed either by heating to specified target temperatures through the entire cross section of specimens or by exposing specimens to ISO 834 [35] temperatures for varying periods of time. Therefore, in most of the studies in the literature, only the degree of temperature or the duration of the effect was chosen as the variable parameter. In this study, unlike the studies in the literature, the degree of ambient temperature and the duration of the effect are considered as variable parameters at the same time. In this direction, the targeted ambient temperature was reached within one hour in all of the reinforced concrete frame test elements, and this ambient temperature was kept constant for 60, 120 and 180 min as specified in the test matrix (Fig. 3b). During the application of high temperature, a thermocouple was placed touching the frame specimens in order to monitor the distribution of temperature in the cross section of the reinforced concrete frame test members.

When reinforced concrete structural elements are exposed to a real fire, the ambient temperatures may vary depending on the type of burning material. In addition, changing fire response conditions may also cause structural elements to be exposed to these ambient temperatures for different periods of time. At temperatures of 900 °C and above, concrete material is known to completely lose its properties. The C-S-H gel of concrete decomposes when its temperature reaches 550 °C. When the maximum temperature of the fire environment is below 600 °C, Poon et al. [36] suggested that the original strength can be recovered without the need for repair if appropriate curing conditions are applied. Scanning electron microscopy (SEM) investigations have shown that healing results from a series of rehydration processes that regenerate calcium-silicate-hydrate (C-S-H) [36]. It is known that some of the deformation in concrete is caused by the expansion of the cement and aggregate in its composition. Especially for the expansion of cement, 400–450 °C is the

Fig. 2 Reinforced concrete frame test elements and concrete specimens

critical temperature [2, 7, 8]. Similarly, the elastic modulus of concrete affected by high temperatures decreases as the temperature reaches 121 °C [37]. For these reasons, temperatures of 200, 400, 600 and 800 °C were used as variable parameters in the study.

The concrete specimens exposed to high temperature were allowed to cool on their own and removed from the oven when they reached room temperature. It was observed that some of the reinforced concrete frame specimens and 150 mm x 300 mm standard cylinder concrete specimens removed from the fire test furnace was observed to have disintegration with discoloration. In reinforced concrete frames with a larger surface area compared to standard cylindrical concrete specimens, it was observed that the concrete surfaces first swelled and then flaked during cooling (Fig. 4). It was determined that these spills were more intense especially in reinforced concrete frame test members exposed to 800 °C ambient temperature for 120 and 180 min (Fig. 4), allowing the test elements to cool on their own means that the concrete surface is exposed to the atmospheric environment. CaO, which reacts with CO_2 entering the concrete through the cracks formed on the concrete surfaces due to the effect of high temperature, turns into $CaCO_3$ and causes volume expansion in hardened concrete. It is believed that the volume expansion caused spalling on the surface of the reinforced concrete frame test members and standard cylinder concrete specimens (Fig. 4). In addition, incompatibilities in the thermal expansion anisotropy of aggregates adjacent to each other in the concrete are thought to lead to the breakage of grain boundaries. Since temperature changes during heating and cooling cause expansion and contraction within the aggregate, intragranular cracking is among the main causes of damage. Strength degradation with increasing temperature has always been attributed to thermal cracking caused by inhomogeneous thermal stress and chemical and physical

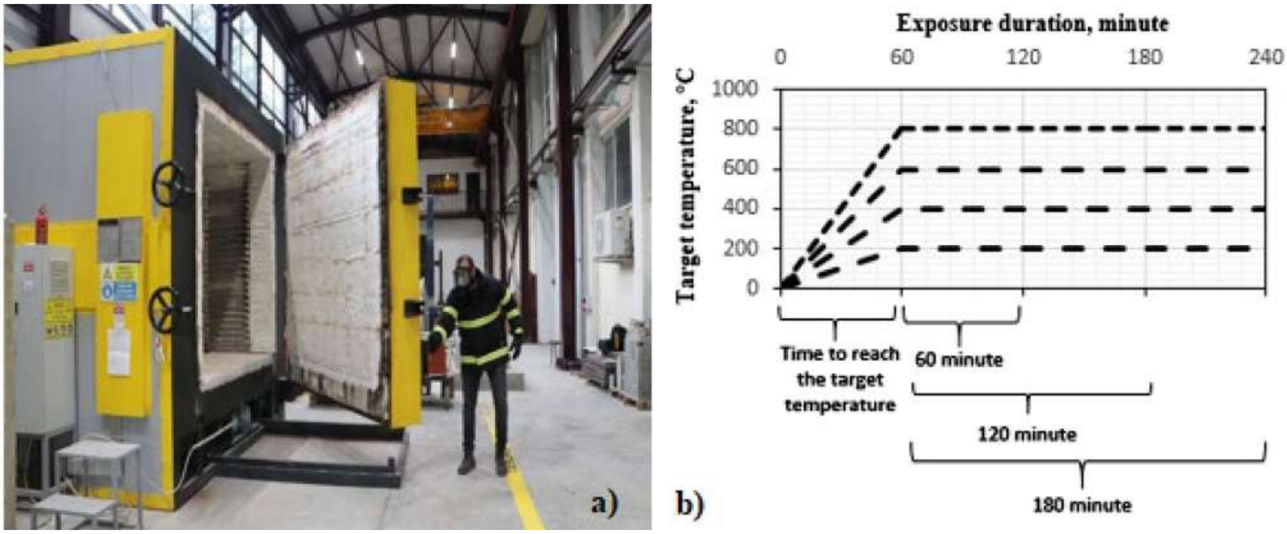

Fig. 3 Test furnace and application of high-temperature effect

Table 1 Application of the high-temperature effect

Group no	Samples name	Temperature level (°C)	Exposure duration (minute)
1	200_60	200	60
	400_60	400	
	600_60	600	
	800_60	800	
2	200_120	200	120
	400_120	400	
	600_120	600	
	800_120	800	
3	200_180	200	180
	400_180	400	
	600_180	600	
	800_180	800	
4	Ref	–	–

reactions (mineral phase transition) during and after thermal treatment [30].

After the reinforced concrete frame test members subjected to high-temperature effect cooled down on their own, a cyclic lateral load effect was applied in the experimental setup shown in Fig. 5. A computer-controlled hydraulic piston with a capacity of 1000 kN was used for pushing and pulling in the application of lateral load. The quasi-static load protocol specified in FEMA 461 [38] was applied for the application of the cyclic lateral load. A horizontal displacement of 0.24 mm was applied during the first 6 cycles of the loading protocol, and this value was increased by 40% in each subsequent cycle (Fig. 6).

Reinforced concrete frame test members subjected to cyclic lateral loads according to the loading protocol shown in Fig. 6 are considered without infill walls in the present study. In this context, the lateral load carrying capacity of reinforced concrete frame test elements subjected to cyclic lateral loading after high-temperature effect may improve if the frames have infill walls and depending on the type of wall material [39].

In order to determine the changes in concrete compressive strength of reinforced concrete frames subjected to cyclic lateral loading after high-temperature effect, three 70 mm × 105 mm core samples were taken from the column body section of each reinforced concrete frame test element that was observed to be undamaged (Fig. 7). The reinforced concrete frame test member exposed to 800 °C high temperature for 180 min could not be cored and the core sample disintegrated during the process.

The ends of the 70 mm x 105 mm core specimens taken from the reinforced concrete frame test members were ground to obtain as flat a surface as possible. The flatness tolerance in the grinding process is less than 0.05 mm. After surface smoothing, the compressive strength of the sulfur-capped specimens was tested and the change in the compressive strength of the concrete with the effect of temperature was examined (Fig. 8). The compressive strength test was carried out by means of a test device in accordance with TS EN 12390-4 [40] standard available at Karadeniz Technical University Building and Materials Laboratory and calibrated by the manufacturer. The compression test is carried out by compressing the concrete specimen by means of a hydraulic oil driven bottom table as shown in Fig. 8. The maximum load capacity of the system is 50 kN, and the loading speed is 0.005 mm/min with an accuracy of 0.01 kN. The test system consists of a loading frame, an axial loading system

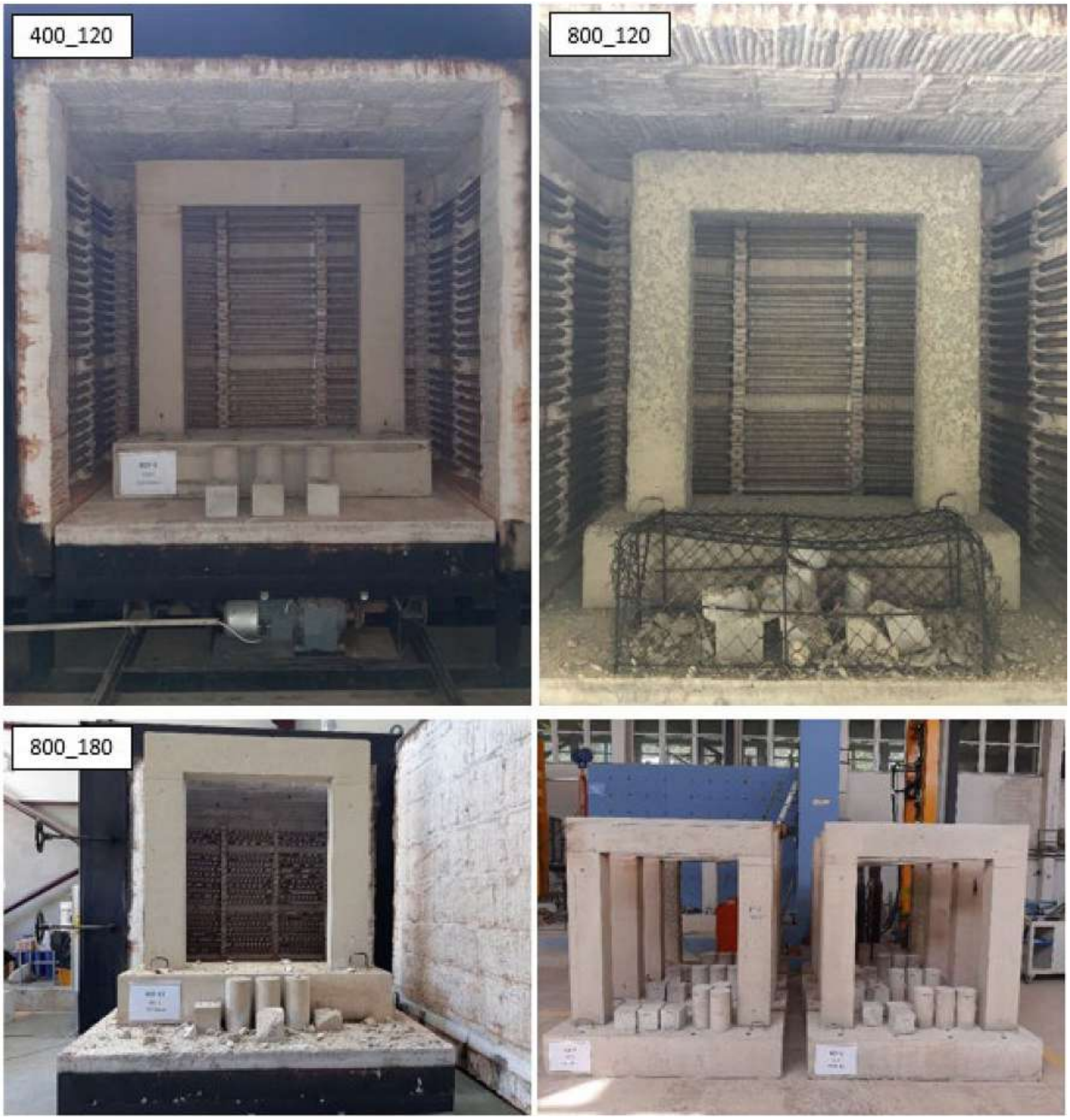

Fig. 4 Concrete specimens subjected to high-temperature effect

and a data acquisition system using hardware and software components. In this study, compressive strength tests of 150 mm x 300 mm standard cylinder concrete specimens exposed to high temperature and 70 mm x 105 mm standard cylinder concrete core specimens taken from reinforced concrete frame members subjected to repeated horizontal loading after high-temperature effect were performed at a constant loading rate of 0.15 MPa/second and compressive strengths were calculated using Eq. 1. 0.15 MPa/second was chosen to keep the loading rate to a minimum when comparing test results.

$$f_{c\theta} = \frac{F}{A_{\mathrm{c}}} \tag{1}$$

where F is the fracture load of the standard cylinder concrete core specimen and A_{c} is the average cross-sectional area (mm^2) of the specimen in the direction perpendicular to the fracture load.

The compressive strengths of all standard cylinder specimens calculated using Eq. 1 were divided by 3 as shown in Eq. 2 to obtain the average compressive strengths.

$$f_{c\theta(\mathrm{ort})} = \frac{f_{c\theta}}{3} \tag{2}$$

In order to eliminate the differences caused by the size effect in the comparison of the compressive strengths of 150 mm × 300 mm standard cylinder specimens exposed

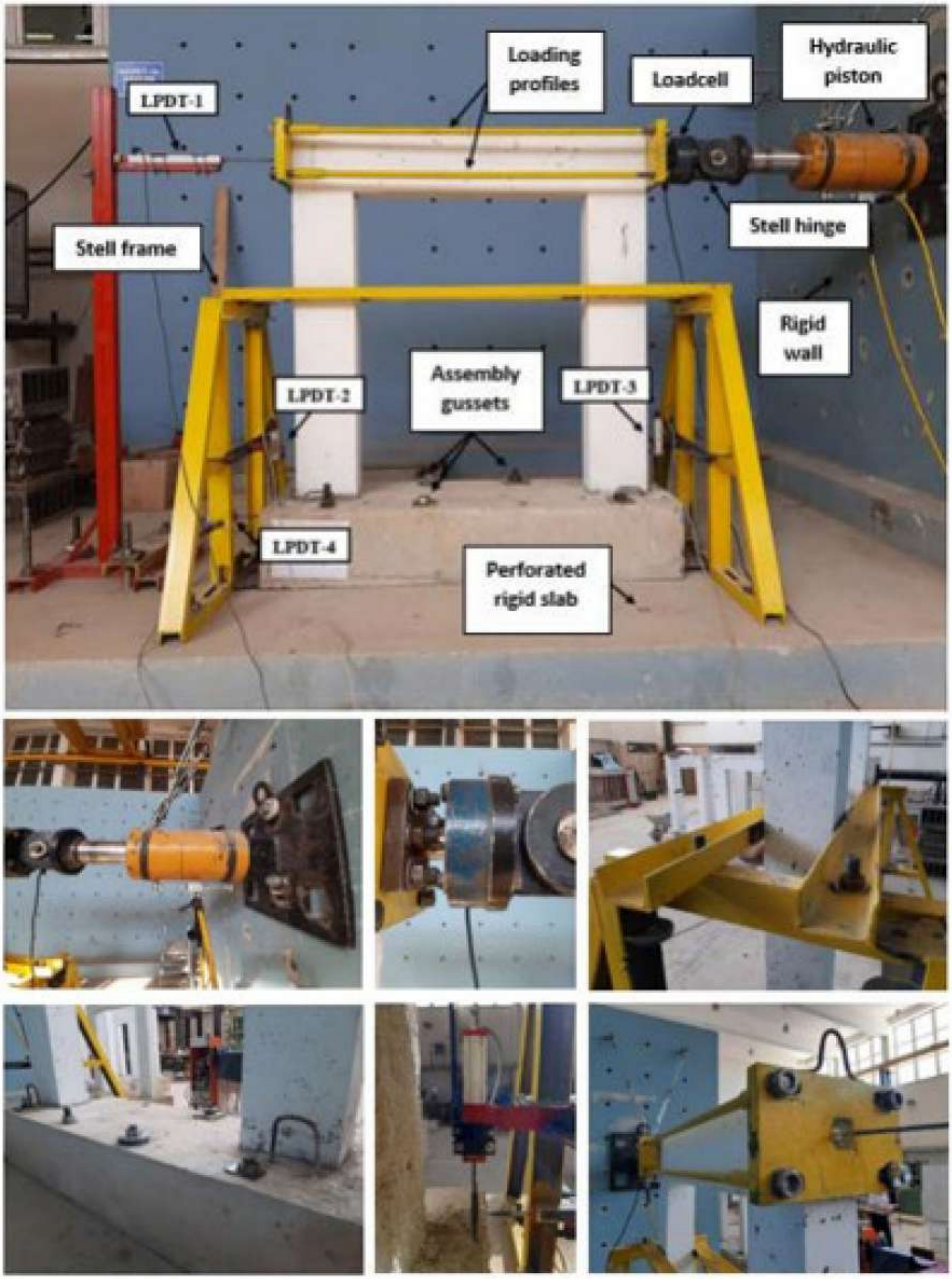

Fig. 5 Application of cyclic lateral load

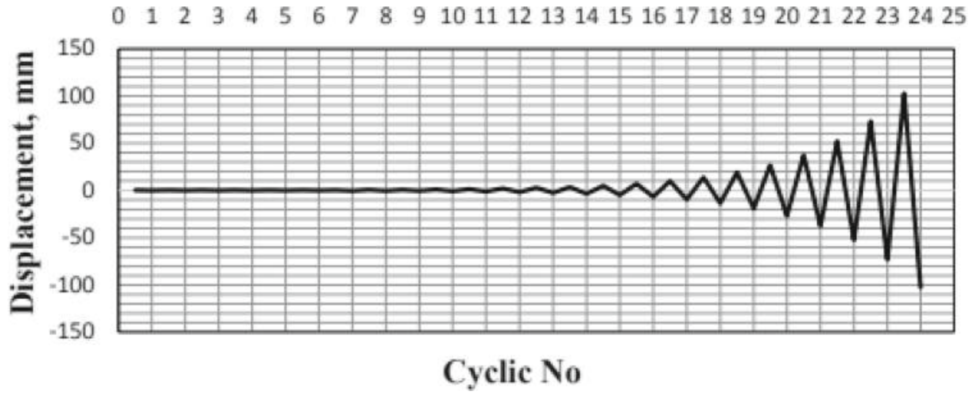

Fig. 6 Cyclic lateral loading protocol

Fig. 7 Core sampling from test elements

to high temperature and 70 mm × 105 mm cylinder concrete core specimens taken from reinforced concrete frame test members subjected to cyclic load effect after high temperature, the compressive strengths of the cylinder concrete core specimens were adjusted by multiplying the size effect correction factor specified in ASTM C42 [41] by 0.96.

4 Findings and Discussion

Uniaxial compressive strength tests were performed on 39 cylinder concrete specimens (YSES) exposed to high temperature and 26 cylinder concrete core specimens (TYYS) taken after cyclic lateral loading tests from reinforced concrete frame test members exposed to high temperature. The average compressive strengths of the concrete specimens are shown in Table 2.

According to Table 2, it was determined that in all groups where the cylinder concrete specimens were exposed to high temperatures for 60, 120 and 180 min, the compressive strength of concrete decreased compared to the reference cylinder concrete specimens that were not exposed to high temperatures. This reduction was 78.63% for sample 800_180, which was exposed to 800 °C high temperature for 180 min. Accordingly, it can be said that the compressive strength of concrete will decrease as the degree and duration of high temperature increases.

It was determined that the compressive strength of cylinder concrete core samples taken after cyclic lateral loading tests from reinforced concrete frame test members exposed to high-temperature effect decreased in all groups compared to the reference cylinder concrete samples that were not exposed to high-temperature effect. This reduction was determined as 65.65% in the 600_180 test element exposed to

Table 2 Comparison of average compressive strength of concrete

Concrete sample names	Failure stress (MPa)		Average ± standard deviation (MPa) $f_{c\theta(\mathrm{ort})}$		Average compressive strength ratio $f_{c\theta(\mathrm{ort})\mathrm{YSES}}/f_{c\theta(\mathrm{ort})\mathrm{TYYS}}$
	YSES	TYYS	YSES	TYYS	YSES/TYYS
200_60	23.28 26.64 24.30	13.68 11.38 –	24.74 ± 1.72	12.53 ± 1.63	1.97
400_60	24.15 22.45 23.24	12.95 12.05 –	23.28 ± 0.85	12.50 ± 0.64	1.86
600_60	19.38 18.14 –	11.41 10.55 –	18.76 ± 0.88	10.98 ± 0.61	1.71
800_60	14.80 15.30 –	11.71 8.69 –	15.05 ± 0.35	10.20 ± 2.14	1.48
200_120	20.67 21.86 –	12.45 12.37 –	21.26 ± 0.85	12.41 ± 0.06	1.71
400_120	14.84 14.08 13.26	11.50 11.74 –	14.06 ± 0.79	11.62 ± 0.17	1.21
600_120	12.25 13.81 –	10.86 6.92 –	13.03 ± 1.10	8.89 ± 2.79	1.47
800_120	–	7.25 5.85 –	–	6.55 ± 0.99	–
200_180	21.35 15.63 18.49	9.21 9.55 –	18.49 ± 2.86	9.38 ± 0.24	1.97
400_180	11.21 13.08 11.20	6.85 8.03 –	11.83 ± 1.08	7.44 ± 0.83	1.59
600_180	8.50 11.73 –	6.20 7.96 –	10.12 ± 2.28	7.08 ± 1.24	1.43
800_180	6.30 6.42 4.23	–	5.65 ± 1.23	–	–
Ref	27.32 24.32 27.69	20.05 18.09 –	26.44 ± 1.85	19.07 ± 1.39	1.39

600 °C high temperature for 180 min. The variation of compressive strength of concrete test specimens with temperature is shown in Fig. 9.

The compressive strength of cylinder concrete specimens exposed to high temperatures of 200, 400, 600 and 800 °C for 60, 120 and 180 min and then cooled on their own is lower than that of reference specimens not exposed to high temperatures (Fig. 9). In addition, the compressive strengths of cylindrical concrete core specimens subjected to cyclic lateral loading effects after high-temperature effect were also lower than the reference specimens that were not exposed to high temperature. However, there was no change in compressive strength between 200 and 400 °C in concretes exposed to cyclic lateral load after high temperature, and the duration of the effect of temperature was 60 min. The decrease in compressive strength of concrete specimens is given in Table 3.

According to Table 3, the decrease in compressive strength is even greater in concretes that are also subjected to cyclic

Table 3 Comparison of decrease in average compressive strength of concrete (%)

Concrete sample names	Average compressive strength (MPa) $f_{c\theta(\text{ort})}$		Effect of high temperature on the decrease in compressive strength (A) $100-\left(\frac{f_{c\theta(\text{ort})\text{YSES}}}{f_{\text{ck}}}*100\right)$	Effect of cyclic lateral load on the decrease in compressive strength (C) $C=B-A$	Ultimate decrease in compressive strength (B) $100-\left(\frac{f_{c\theta(\text{ort})\text{TYYS}}}{f_{\text{ck}}}*100\right)$
	YSES	TYYS			
200_60	24.74	12.53	6.43	46.18	52.61
400_60	23.28	12.50	11.95	40.77	52.72
600_60	18.76	10.98	29.05	29.43	58.47
800_60	15.05	10.20	43.08	18.34	61.42
200_120	21.26	12.41	19.59	33.47	53.06
400_120	14.06	11.62	46.82	9.23	56.05
600_120	13.03	8.89	50.72	15.66	66.38
800_120	–	6.55	–	–	75.23
200_180	18.49	9.38	30.07	34.46	64.52
400_180	11.83	7.44	55.26	16.60	71.86
600_180	10.12	7.08	61.72	11.50	73.22
800_180	5.65	–	78.63	–	–
Ref	26.44 (Specimens not subjected to high-temperature exposure)				
Ref	19.07 (For specimens subjected to cyclic lateral load only)				

Fig. 8 Determination of compressive strength of concrete core samples.

lateral load effect after high temperature. In addition, concrete specimens exposed to 800 °C high temperature for 120 min could not be compression tested because they disintegrated in the test furnace. In addition, compression tests could not be performed on reinforced concrete frames exposed to 800 °C for 180 min due to fragmentation of the specimens during coring.

The reduction in the compressive strength of cylinder concrete specimens varies depending on the degree and duration of high temperature and cyclic lateral load effects. As the degree and duration of high temperature increases, the effectiveness of the cyclic lateral load in reducing the compressive strength of the cylinder concrete specimens decreases (Fig. 10).

The strength loss curves of the concrete used in this study are given in Fig. 11 together with the design curves given in the Codes [14–17].

Accordingly, the Finnish law is considered to be more suitable for concretes exposed to ambient temperatures between 20 and 800 °C for 60 min. If the duration of the high-temperature effect is 120 and 180 min, the appropriate temperature ranges under Finnish law are 500–800 °C and 580–800 °C, respectively.

The CEB design curve was found to be appropriate for the temperature ranges of 250–800 °C, 500–800 °C and 600–800 °C for 60, 120 and 180 min, respectively.

The Eurocode (siliceous aggregate) design curve is considered suitable for concretes exposed to temperatures of 220 °C and above for 60 min, and the Eurocode (calcareous aggregate) design curve is considered suitable for concretes exposed to temperatures of 300 °C and above for 60 min.

After 180 min of exposure to temperatures between 20 and 800 °C, it was determined that Eurocode design curves were not suitable for concretes subjected to cyclic lateral loading.

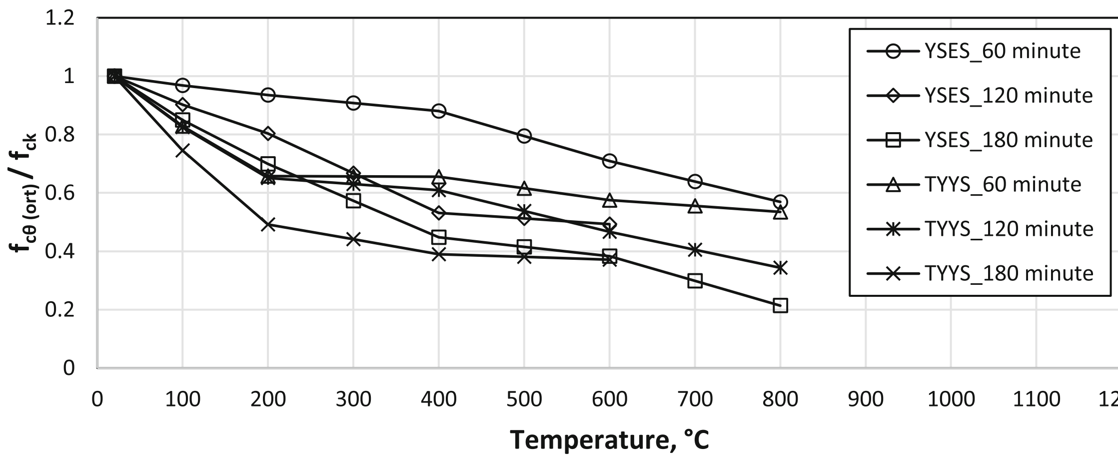

Fig. 9 Variation of compressive strength with temperature. f_{ck}; Compressive strength of reference standard cylinder concrete specimen not exposed to high temperature

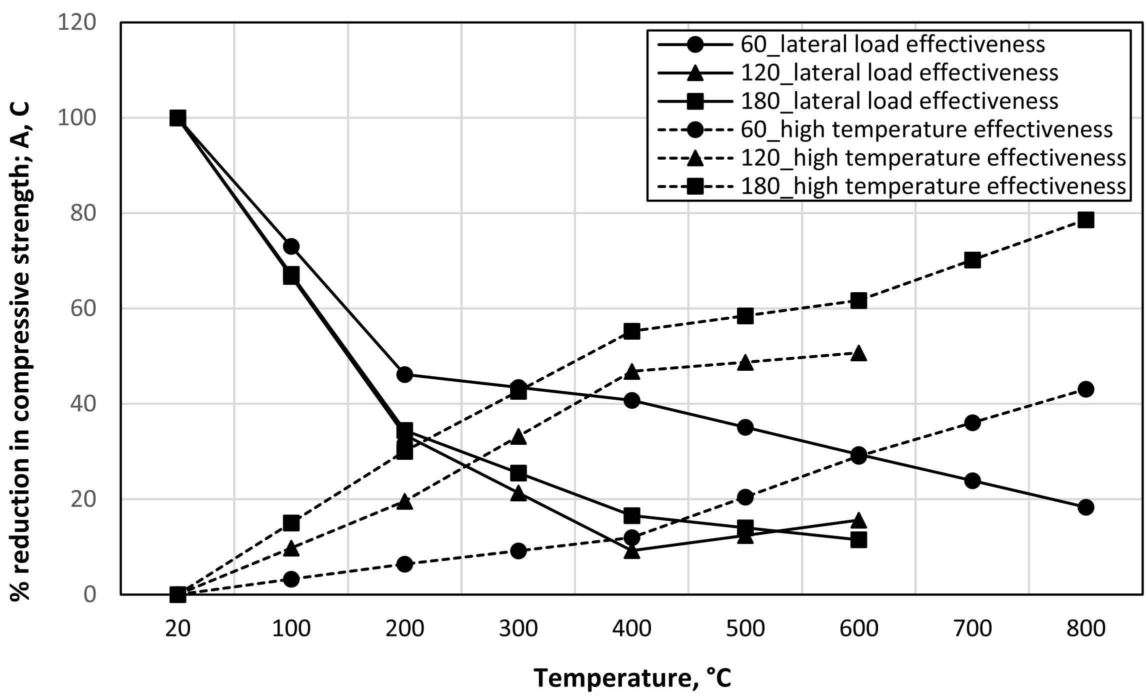

Fig. 10 Variation of the effectiveness of lateral load and high temperature on the decrease in compressive strength with temperature

5 Conclusions

In this study, uniaxial compressive strength tests of normal strength concrete exposed to temperatures of 200, 400, 600 and 800 °C for 60, 120 and 180 min were performed after cyclic lateral loading. In this study, the compressive strength of concrete exposed to different temperatures for different periods of time and the change in compressive strength of concrete subjected to repeated horizontal loading after high-temperature effect were investigated. The results obtained were also compared with reference specimens not exposed to high temperature and evaluated according to different design codes. The main results of this research are summarized as follows.

- The change in the compressive strength of concrete exposed to high temperatures may vary depending on the degree of ambient temperature, the duration of this temperature, the rate of heating and cooling, the grain size and mineralogical properties of the aggregate used in concrete and the chemical properties of cement. Since all the physical and chemical properties and mineralogical structure of the aggregate and cement components in the concrete used in this study are the same, it is thought that the effect

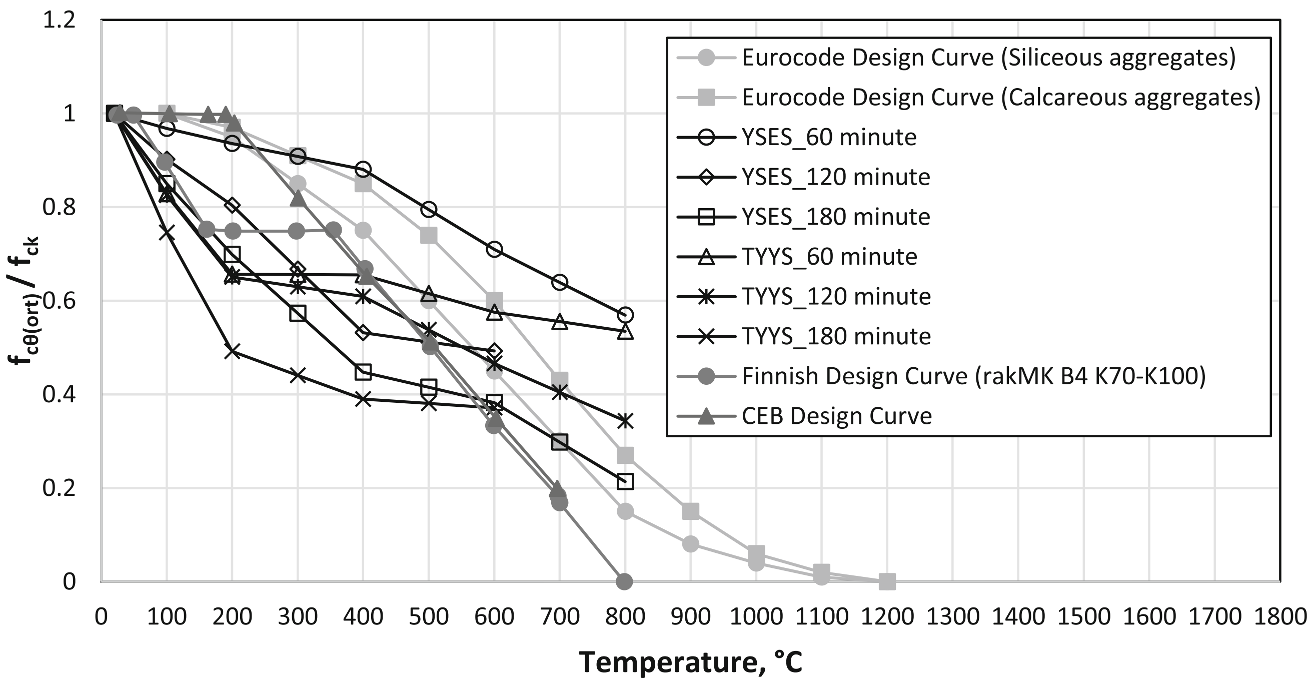

Fig. 11 Comparison of design curves and experimental strength loss curves

of the degree of ambient temperature, the duration of its effect and the change in the heating rate and the lateral load effect are more dominant in the change in the compressive strength of the concrete specimens. It is thought that the damage on the concrete surface in specimens 800_120 and 800_180, where the heating rate was 13 °C/min, was caused by the thermal shock effect.

- The coring process for evaluating the compressive strength of concrete materials used in reinforced concrete structures should be approached with caution in determining the concrete strength class in earthquake damaged structures. Although the average compressive strength of concrete specimens not exposed to high temperature was determined as 26.44 MPa, the average compressive strength of concrete core samples taken from the reference reinforced concrete frame element after cyclic lateral loading was obtained as 19.07 MPa. Although coring is performed from undamaged areas of the concrete, microcracks that occur during the earthquake are decisive in the decrease in compressive strength.
- As stated in similar studies in the literature [30], the width of microcracks in concrete increases with increasing temperature. Similarly, in some studies in the literature [42], it was determined that some of the microcracks tended to close during cooling of heated concrete specimens. The inconsistency of stiffness values in concrete specimens exposed to high temperatures also supports the opening and closing cycle in microcracks [42]. It is known that when the ambient temperature is below 550 °C, the C-S-H gel structure of the cement does not deteriorate and is effective in recovering some of the strength after heating [36]. In this study, it is thought that the main parameter affecting the variation of mechanical properties between standard cylinder concrete specimens is the ambient temperature and the opening and closing cycle of the cracks in the concrete depending on the duration of this ambient temperature.

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