Effects of heating durations on normal concrete residual properties: compressive strength and mass loss

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Fadzli Mohamed Nazri[1*], ShahironShahidan[2], Nur Khaida Baharuddin[1], Salmia Beddu[3] and Badorul Hisyam Abu Bakar[1]

[1]School of Civil Engineering, Engineering Campus, Universiti Sains Malaysia, 14300 Nibong Tebal, Penang, Malaysia.
[2] Jamilus Research Center, Faculty of Civil and Environmental Engineering, Universiti Tun Hussein Onn Malaysia,86400, Pt Raja Johor
[3]Universiti Tenaga Nasional, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor
*Corresponding author: cefmn@usm.my

Abstract. This study investigates the effects of high temperature with five different heating durations on residual properties of 30 MPa normal concrete. Concrete cubes were being heated up to 600°C for 30, 60, 90, 120 and 150 minutes. The temperature will keep constant for 30, 60, 90, 120 and 150 minutes. The standard temperature-time curve ISO 834 is referred to. After heating the specimen were left to cool in the furnace and removed. After cooling down to ambient temperature, the residual mass and residual compressive strength were observed. The obtained result shows that, the compressive strength of concrete decrease as the heating duration increases. This heating duration influence, might affects the loss of free water present and decomposition of hydration products in concrete. As the heating duration increases, the amount of water evaporated also increases led to loss in concrete mass .Conclusively, the percentage of mass and compressive strength loss increased as the heating duration increased.

1. Introduction

The properties of concrete will deteriorated when it was subjected to high temperature. This is due to the changes of physical properties and chemical composition of concrete. Concrete will undergo different type of damages depending on level of temperature. The effects of concrete component to high temperature were reduction in compressive strength, micro-cracking within the concrete microstructure, colour changes consistent with strength reduction, increase in pore structure, and various degree of spalling. There was certain reduction in strength of concrete when it is exposed to high temperature. Based on Ma Q*et al.* [1] residual compressive strength of concrete after being exposed to high temperature occurs in three stages which at room temperature-300°Cthe compressive strength keeps constant. Then at 300-800°C, compressive strength of concrete drop drastically and at more than 800°C temperature, concrete lost its compressive strength.

Prior to technical note by Phaedonos[2] concrete lose its strength up to 30-40% once the temperature hit 300°C. This is because of thermal expansion, internal cracking, and weak adhesion between paste and steel reinforcement within the concrete. At 500-600 °C, more than 70% of concrete strength reduced. In previous research by Haddad& Al-Rousan[3] the mechanical performance of beams after fire was scaled down due to reduction in compressive strength, weak concrete to steel bond and reinforcement steel deteriorated. The load capacity of beam, after heated at 300, 500, and 600°C was reduced to 32%, 79% and 80%.Up to now, previous study by Park *et al.*[4] has established

that post fire curing condition surely enhanced the residual properties of fire-damaged concrete. The mass and concrete density gradually decreases after heating (300°C, 500°C and 700°C). In addition, after post fire curing also recovers the density, mass and also the concrete tensile strength. When concrete exposed to 800°C temperature, there was significant reduction of strength [5]. As the temperature increase, the strength loss become smaller and at 1000°C the value become null [6]. The high temperature surely gave negative effect to the concrete strength [7].

The factors that affect post fire concrete's compressive strength are the rate of heating, the duration of heating, whether the specimen was loaded or not, the type and size of aggregate, the water/cement ratio, and the percentage of cement paste. In general, concrete heated by a building fire always loses some compressive strength and continues to lose it on cooling. Previous research done by Mazza[8] stated that concrete damaged zone comes bigger with longer heating duration. Concrete structures that exposed to high temperature for 60 minutes experienced more damaged compared to concrete that heated for 45 minutes. Bikhiet [9] compared the experimental and theoretical analysis for column heated at constant 600°C temperature with different durations. The findings stated that, for column sample as the period of fire increased from 10 min to 15 or 20 min, the strain of column increased by 45% and 55%, respectively. Both experimental and theoretical analysis reported that as the period of fire increases, the column stiffness decreases. The analysis also showed that with increase in the period of fire (10, 15, 20 min), the corresponding column failure load compared with unheated column decreased by nearly (12%, 15%, 25%) respectively.

2. Experimental programme

2.1. Sample preparation

The normal concrete (NC) with design strength of 30 MPa was prepared. The specimens were in cube (100 x 100 x 100mm). The normal concrete used Ordinary Portland cement, sand, coarse aggregates with maximum size 20mm, water cement ratio of 0.55 and slump value between 150mm to 180 mm. The mix proportion of normal concrete substrate is presented in Table1.

Table 1. NC substrate mix design

Item	Mass (kg/m³)	Remark
OPC	380	Type-1
Coarse Aggregates	1115	Max. 20mm
Fine Aggregates	685	F.M 2.7
Water	205	
W/C ratio	0.55	
Super plasticiser	0.5%	

As the objective is to investigate the effect of heating duration subjected to residual properties of normal concrete, the specimen will be exposed to 600°C temperature for five different durations. The NC was tested for 7 and 28 days strength and then it was heated at 600°C for 30, 60, 90, 120 and 150 minutes. The samples will be heated up using a furnace owns by Concrete Laboratory, University Sains Malaysia. The specification and photo of this furnace were shown in Table 2 and Figure 1.

Figure 1. KC 80/15 furnace

Table 2. KC 80/14 furnace specification.

Model	Temperature max (°C)	Inside dimension (w x d x h)	Litre (L)	External Dimension (w x d x h)	Power (kW)	Weight (kg)	Voltage (V)
KC 80/14	1400	430 x 430 x 430	80	985 x 1066 x 1540	13	280	4003/N

Samples are then placed in the furnace as shown in Figure 3.3. Temperature exposed to the substrate was adopted from previous research by [9-12]. All of this works were preparing their fire damaged substrate by exposing it to 600 °C temperature. The 600 °C also considered as critical temperature for concrete as at this point its strength will lose about 50%. In addition, second phase of C-S-H decomposition occur at this stage and concrete can be consider as thermally damaged [11]. All substrates sample will be placed into furnace for firing. The firing durations specified according to [13]. The temperature will keep constant for 30, 60, 90, 120 and 150 minutes. The standard temperature-time curve ISO 834, also known as the Cellulosic curve / standard nominal fire curve is referred to. After heating the specimen were left to cool in the furnace and removed. The residual mass and residual compressive strength were observed.

2.2. Test method

The Compressive strength test is often considered as the most vital property of concrete. The compressive strength of NC substrate (before and after fire) and UHPFC were determined using 100 x 100 x 100 mm cubes as per BS 1881-116: 1983(Method for determination of compressive strength of concrete cubes)[14].A compression machine with maximum capacity of 3000kN was used to compress the cube specimens at loading rate of 0.30 MPa/s. The cubes of the NC were tested in compression at, 7 days, and 28 days. The sample was demoulded after 24 hours and cured until the age of test in the water tank. Standard curing in water follows until testing. For weight loss assessment, the weight of the concrete cubes was measured before and after exposure to high temperature. The mass loss of the entire investigated specimen is expressed as a percentage of the original mass at the ambient temperature to the mass after exposure to high temperature.

3. Result and discussion

3.1. Compressive strength

According to Kodur, V[15]the compressive strength of concrete can be reduced if it is exposed to high temperature. In this study, the effects of heating durations to normal concrete (NC) compressive strength can be determined. The average compressive strength of normal concrete before and after fire is illustrated in Table 3 and Table 4. The lowest compressive strength recorded is 17.7 MPa. The highest compressive strength achieved is 40.3 MPa, for concrete at 28 days. The concrete's compressive strength decreases as the heating duration increases.

Table 3. Compressive strength of NC after fire (7 days).

Heating Durations (Min)	F1 (N)	F2 (N)	F3 (N)	Average,F (N)	Compressive strength (MPa)
0	320	300	310	310	31.0
30	270	275	280	275	27.5
60	270	240	250	253	25.3
90	230	240	235	235	23.5
120	230	210	215	218	21.8
150	180	170	180	177	17.7

Table 4. Compressive strength of NC after fire (28 days).

Heating Durations (Min)	F1 (N)	F2 (N)	F3 (N)	Average,F (N)	Compressive strength (MPa)
0	410	420	380	403	40.3
30	250	335	300	295	29.5
60	270	300	275	282	28.2
90	210	250	260	240	24.0
120	250	220	235	235	23.5
150	205	240	220	222	22.2

The effect of heating duration on compressive strength of normal concrete at 7 and 28 days ages are shown in Figure 2.

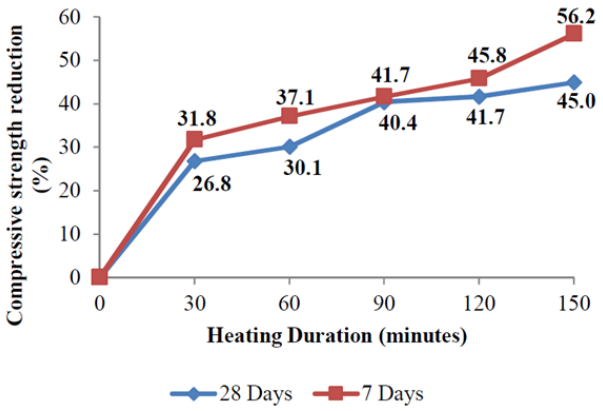

Figure 2. Compressive strength percentage of reduction.

The compressive strength of 7 days ages concrete reduces up to 31.8% after being heated for 30 minutes. Normal concrete loose about 56% of their compressive strength after being exposed to 600 °C temperature in 150 minutes duration. As for 28 days, the compressive strength reduces 26.8%. After being heated for 60, 90 and 120 minutes, the compressive strength values drop to 30.1%, 40.4% and 41.7 %. The reduction of compressive strength is directly proportional with the heating duration. As the heating duration increases, the reductions in compressive strength of concrete become larger. This might be caused by the driving out of moisture and concrete hydration due to high temperature. According to Hager [11] the strength of concrete reduced after being heatedmainly cause of the evaporation of water. There is a sequence of water removal and itdepends on the energy that straps the water and the solid. In short, free waterevaporates first, capillary water next and lastly by the physical bound water. Theprocess of releasing water that is chemically bound with cement hydrates is the last tobe initiated. Longer fire period makes more moisture hydrated and lead to the increase in concrete porosity which makes the concrete becomes weaker.

3.2. Mass loss

For mass loss assessment, the mass of concrete cubes were measured before and after fire. The impact of 600°C temperature with different heating duration on normal concrete is shown in Figure 4.2.

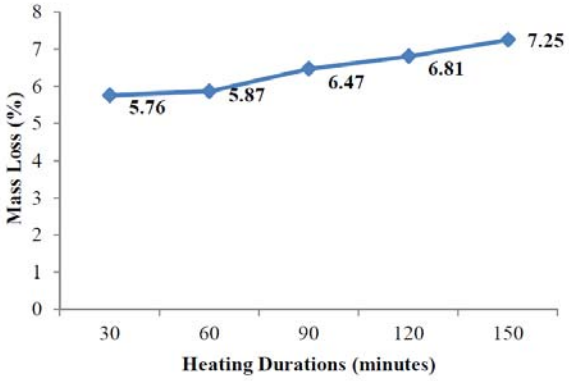

Figure 3. Mass loss of different heating duration.

The mass loss of all samples expressed as a percentage of the original mass at room temperature to the mass of concrete cubes after heated. Figure 3 displays that the longer the heating period, the mass loss of the concrete had the tendency to increase. At first 60 minutes of heating, small percentage of mass loss is observed. When concrete were heated for 90 minutes, its mass reduced about 6.47%. This is due to the loss ofwater content in the concrete. Plus, the concrete shows some spalling, cracking and the piecesof concrete start to breaks away. After being heated up for 120 and 150 minutes sample loss, about 6.81% and 7.25% of its original mass. This heating duration influence, might affects the loss of free water present and decomposition of hydration products in concrete. When concrete is exposed to high temperature, free water in the concrete will firstly be removed through evaporation. As the heating duration increases, the amount of water evaporated also increases. Later, the calcareous aggregates will decomposed, carbon dioxide (CO_2) liberated and altered the mechanical properties of concrete [16] and[1]. Conclusively, the percentage of mass loss increased as the heating duration increased.

The reduction of compressive strength is directly proportional to heating duration. As the heating duration increases, there are more drive out of moisture and concrete hydration [11]. This loss of moisture will lead to reduction in concrete mass too. The evaporation of water and decomposition of hydration product will increase the concrete's porosity. The longer the heating duration make the amount of evaporated water increases, followed by increases in void volume. The expansion in void

volume of concrete will reduce its quality, thus there is reduction in their UPV and rebound number values and mass.

4. Conclusion

The current paper investigates the residual properties of normal concrete exposed to 600°C temperature for five different heating durations. The compressive strength of concrete decrease as the heating duration increases. The lowest compressive strength recorded when sample being heated for 150minuteswhich is 17.7Mpa. At this stage the compressive strength loss about half of it's original value. This heating duration influence, might affects the loss of free water present and decomposition of hydration products in concrete. As the heating duration increases, the amount of water evaporated also increases leads loss in concrete mass. The highest loss of mass recorded when concrete heated for 150 minutes. The lowest percentage of mass loss recorded is5.76%. This occurs when sample heated up to 30 minutes only. Conclusively, the percentage of mass loss increased as the heating duration increased.

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