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Effect Of Time On Compressive Strength Of Concrete Subjected To High Temperature

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Abstract:
Concrete is a construction material which is mainly used for its capacity to resist compression forces. However, when it is exposed to adverse condition of fire, the compressive strength degraded. Therefore, the study aimed at investigating the effect of time on compressive strength of concrete subjected to high temperature. Mix ratio of 1:2:4 and water cement ratio of 0.55 was used for the production of the test concrete cubes. Twenty-four concrete specimens were produced with three specimens for each time of 0, 1, 2, 3, 4, 5, 6, and 7 hours of fire exposure respectively. The test concrete cubes was produced by mixing the required weight of cement, aggregate and water, after which it was poured into an oiled mould of size 150mmx150mmx150mm and compacted in three layers of 50mm each by ramming using steel rod. The test cubes were demoulded after 24 hours, weight and immersed in a curing tank filled with water for 28days at room temperature. After 28 days the test cubes were removed, weight and air dried. The test cubes was fired using kiln and after which they were crushed, to determine their compressive strength, using crushing machine. The compressive strength were assessed before and after fired. The results show that for any time of fire exposure, there is reduction in the concrete strength ranging between 22.22 to 1.64 N/mm^2 and increase in temperature ranging between 20^{o}c to 1315^{o}c. It is also found that the percentage loss of compressive strength increases as the time of exposure increases; while one hour of exposure gave the least strength reduction of 20.21% and seven hours of exposure gave the highest strength reduction of 92.62%. The study concluded that one hour fire exposure time on the concrete has better fire resistance than other time of exposure.

Keyword:*Fire, kiln, Percentage Strength Reduction, Cement, Aggregate.*

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I. Introduction

Concrete, the most widely used structural material is produced using cement, sand, gravel and water. (Naik and Moriconi, 2008), and it is thought to be a well understood construction material, in the light of recent extreme events, including accidents, arsons and terrorism, attention has refocused on the performance of concrete in the vague of fire (Aqeel andSikar, 2016). Concrete is known for its good fire performance due its low thermal conductivity and due to the fact that is incombustible and does not exhale toxic gases when exposed to high temperatures (Mehta and Monteiro, 2017). The heterogeneous nature of the concrete and the uncertainties associated with the nature of the fire and its corresponding thermal loading make the interaction between material and loading very complex (Fletcher et al., 2007]. The exposure to temperature like fire causes severe damage on concrete structures (Khoury, 2000). This concerns both the physical and chemical changes taking place in the cement matrix, as well as the phenomena involved in mass movement (gases and liquids). The effects of the various changes taking place in heated concrete are the alterations of its physical, thermal, and mechanical properties The analysis is complicated due to the fact that cement concrete is a composite consisting of two substantially different constituents: cement paste and aggregates (Hager, 2013).

The heating of cement paste results in drying. Water gradually evaporates from the material. The mechanical properties of cement paste are strongly affected by chemical bonds and cohesion forces between sheets of calcium silicate hydrate (C-S-H) gel. It is assumed that approximately 50% of cement paste strength comes from cohesion forces (important C-S-H gel sheet area); therefore, the evaporation of water between C-S-H gel sheets strongly affects the mechanical properties of the cement paste (Feldman and Sereda, 1968).

Aggregates occupy 70–80% of the volume of concrete and thus heavily influence its thermal behaviour. The term “thermal stability of aggregates” is employed. Considering concrete behaviour at high temperature, a suitable aggregate would be one with a low thermal strains coefficient as well a strains coefficient as well as negligible residual strains. Mineralogical composition determines aggregate thermal strains, since all minerals differ in their thermal expansion properties. The type of minerals governs the chemical and physical changes that take place during heating. For example: quartz aggregates and sands change at 574°C (Khoury, 1992). The carbonate stones limestone and dolomite) are stable up to 600°C. At higher temperature, carbonate aggregate decomposes into CaO and CO2 (700°C). Additionally, the CaO formed during decarbonation may hydrate when cooling, with a consequent 44% expansion (Hager, 2013)

The properties of materials used in preparing concrete play an important role on the performance of concrete during its lifetime. Concrete generally provides adequate fire resistance for most applications. However, the strength and durability properties of concrete are significantly affected when subjected to elevated temperature. Terrorist attack, accidental fire breakout and different type of explosions produce a rapid change of temperature for a short period. (Mohamed et al., 2014). Concrete behaviour under high temperature levels is known to be quite complex, since different types of physical and chemical changes take place in the main concrete constituents, i.e. cement paste, aggregates and pore water. Furthermore, the heterogeneous concrete nature leads to different thermal expansions and shrinkage between aggregates and cement paste. All these phenomena are responsible for the strong deterioration of concrete, which can be easily tracked analyzing the mechanical properties with the increase of the temperature exposure. Moreover, the rise of concrete deterioration and the accumulation of thermal deformations are influenced by many other effects which include moisture loss, heating and cooling rates, time exposure, maximum temperature achieved, possible external applied load, etc. **(**Aqeel and Sikar, 2016).

Degradation of mechanical properties and durability of concrete structures occur when they are subjected to fire situations, depending on the characteristics of the material, fire duration and the ways of fire extinguishing. Mechanical properties such as compressive strength, tensile strength and elasticity modulus are some examples of typically altered characteristics in concrete during high temperature exposure (Jaqueline et al., 2019). High temperature exposure leads to a reduction of residual strength of both normal and high strength concretes. There is a minor change in the residual compressive strength up to about 200 °C and a rapid drop after 350 °C. About 40% is left after 600 °C (Noumowe et al., 1996).

From previous studies considering exposure time of concrete subjected to high temperature for one hour(1hr) conducted by Rajeev et al (2018), have reported from their study on the effect of fire on compressive strength of concrete and concluded that if water cement ratio in any of concrete mix increases, the percentage loss in compressive strength decreases i.e. if water cement ratio is more in concrete mix the water adsorbed in concrete reduces the loss due to fire; and also that the percentage loss in compressive strength of concrete also decreases when the grade of concrete improves. Also, Elizzi et al, (1987), have reported from their study on the influence of different temperatures on the compressive strength and density of concrete and the test results showed that the compressive strength decreased 10% from the original strength up to 400 **º**Cand at 600 **º**Cthe strength reduction was 50% from the original. Considering exposure time of concrete subjected to high temperature for two hours(1hrs) conducted by Lateef et al, (2019), have reported from their work on the effects of fire on the strength of reinforced concrete structural members and found that in cubes, the loss in strength varies from 37.73% to 56.04% for water cooling and air cooling respectively. Also, Morsy et al, (2008), have conducted a study on the effect of fire on microstructure and mechanical properties of blended cement pastes containing metakaolin and silica fume and found out that the compressive strengths of control, M0, M1 and M2 cement pastes increase with temperature up to 200 oC then decrease up to 800 oC.According to Feng (2005), concluded that long-duration fire or high-temperature results in a serious loss of concrete properties, even lead to structural damage or building failure. Naus, (2006), mention that the properties of concrete change with respect to time and the environment to which it is exposed, an assessment of the effects of concrete aging is also important in performing safety evaluations.

There is a lot of studies conducted on the effect of varying temperature on concrete subjected to high temperature but limited studies on the effect of varying exposure time on concrete subjected to high temperature. Therefore, this study aim to investigate the effect of time on compressive strength of concrete subjected to high temperature.

II. Material And Methods

Materials

The materials used in the production of the concrete include Ordinary Portland Cement (OPC), fine aggregate, coarse aggregate and water.

Cement

The brand of Dangote Portland cement Grade 42.5N was procured from a reputable supplier and used in this study. In conformity to ordinary Portland cement as specified in Bs 12:1978, the following tests were carried out on the cement: consistency and setting time of cement and the results is presented on table 1.

Plate 1.0 Determination of setting time and consistency of cement using Vicat Apparatus

Plate 2. Aggregate sieve analysis using manual method

Aggregate

The aggregate (fine and coarse) was procured from a reputable supplier and used in this study. In conformity to aggregate as specified in Bs 812: part 2: 1975, the particle size distribution (using sieve analysis) and specific gravity tests were carried out on the aggregate and the results are presented on table 2.

Water

Pipe borne water fit for drinking was used throughout the study for mixing the concrete materials.

Production of concrete cubes

Mix ratio of 1:2:4 and 0.55 water cement ratio (w/c) was used for the production of the test concrete cubes. Twenty-four concrete specimens were produced with three specimens for each time of 0, 1, 2, 3, 4, 5, 6, and 7 hours respectively. The test concrete cubes was produced by mixing the required weight of cement, aggregate and water, after which it was poured into an oiled mould of size 150mmx150mmx150mm and compacted in three layers of 50mm each by rammering using steel rod. The test cubes were demoulded after 24 hours, weight and immersed in a curing tank filled with water for 28days at room temperature. After 28 days the test cubes were removed, weight and air dried. Test cubes were made from fresh concrete in compliance with BS 1881-108:1983.

Plate 3.0 Produced concrete cube specimens before firing.

Plate 4.0 Melted component of cube specimen

Firing and crushing of concrete cubes

The test cubes was fired using kiln, with fire sourced from kerosene burner, of Abubakar Tafawa Balewa University Bauchi (ATBU), Industrial Design Department and also crushed in ATBU Structural Laboratory, Civil Engineering Department.


Plate 5.0 Kiln used for firing of cubes.Plate 6.0 Crushing machine with crushed cube.

III. Result and Disscussion

The results are presented on Table 1-3 and Figure 1-2, and discuss below.

Table 1: Results for test on cement

Items	Mean Value	Bs 12:1978 Specificatiion
Normal consistency (%)	28.63	26-33
Initial Setting Time (Min)	87.23	Minimum of 45 minutes
Final Setting Time (Min)	153.40	Maximum of 10 hours

The results from Table 1 show that the normal consistency; initial and final sitting time of the cement are conformed to the British standard specification of Bs 12:1978. This qualified the cement to be used in concrete production. Table 2 show that the aggregate (fine and coarse) are classified based on Universal Soil Classification System(USCS) as well graded sand and well graded gravel; while the specific gravity of both the sand and gravel are determined as 2.42 and 2.63 respectively, and 5mm and 20mm maximum size of both the sand and gravel.

Table 2: Results for test on aggregate

Characteristics	Sand	Gravel
USCS	SW	GW
Specific Gravity	2.42	2.63
Maximum Size	5mm	20mm

Table 3: Compressive strength of concrete before and after fire

Time (hr)	Average Compressive Strength (N/mm^2)	percent loss in compressive Strength (%)	Temperature reached (^{O}C)
0	22.22	0.00	0.00
1	17.73	20.21	600.17
2	9.06	59.23	810.30
3	8.66	61.03	900.10
4	5.28	76.24	936.68
5	2.57	88.43	1038.00
6	2.31	89.60	1220.00
7	1.64	92.62	1315.00

Table 3 and Figure 1-2, shows that an increase in time of exposure on the concrete to high temperature there is decrease in the compressive strength ranging between 22.22 to 1.64 N/mm^2 and increase in percentage loss in compressive strength ranging between 20.21 to 92.62%. This result agrees with the report by Mahdi, (2010).

At 0-1hr exposure time the compressive strength is 19.73N/mm^2 and strength reduction of 20.21% while temperature rises from 0-600.17^{o}C. The strength reduction may be attributed to the physical, chemical and thermal changes that have taken place in the concrete as mention by (Aqeel and Sikar,2016; Dipak and Jyoti, 2022). Sujit and Ganesh (2019) reported that decomposition of calcium silicate hydrate (CSH), which is responsible for strength gain in concrete, occurred for concrete fired at 1hr with temperature reached between 500-1300^{o}C. The temperature reached of 600.17^{o}C at 1hr exposure time in this present study indicated that the concrete begins to deteriorate or damaged as reported by Kowaski, (2010), that concrete which reached the temperature of approximately 500-600oC should be treated as damaged. Rajeev et al (2018), reported the strength reduction of 19.57% using concrete grade of M20 with water-cement ratio(w/c) of 0.50 fired at 1hr. 0.50w/c gave lower percentage loss of compressive strength as compared with other lower w/c(0.40 and 0.45) investigated. The strength reduction of 20.21% at 1hr fire exposure revealed in this present study, confirmed the report by Rajeev et al (2018). Elizzi et al (1987), reported strength reduction of 50% from fired concrete at 1hr exposure time with temperature at 600^{o}C.

At 0-2hrs exposure time the compressive strength is 9.06N/mm^2 and strength reduction of 59.23% while temperature rises from 0-810.30^{o}C. The sharp strength reduction of 9.06N/mm^2 may be attributed to the further deteriorating of the cement matrix of the fired concrete. Morsya et al (2008), reported that at 2hrs fire exposure time the strength reduction increases up to 800^{o}C and over 600^{o}C strength losses are mainly caused by calcium carbonate dissociation and subsequent CO2 escape from CaCO3.

At 0-3hrs exposure time the compressive strength is 8.66N/mm^2 and strength reduction of 61.03% while temperature rises from 0-900.10^{o}C. At 0-4hrs exposure time the compressive strength is 5.28N/mm^2 and strength reduction of 76.24% while temperature rises from 0-936.68^{o}C. At 0-5hrs exposure time the compressive strength is 2.57N/mm^2 and strength reduction of 88.43% while temperature rises from 0-1038^{o}C. At 0-6hrs exposure time the compressive strength is 2.31N/mm^2 and strength reduction of 89.6% while temperature rises from 0-1220^{o}C. From 2-6hrs fire exposure time the continues strength reduction may be attributed to further decomposition of calcium silicate hydrate (CSH), since their temperature is still within the range of 500-1300^{o}C, which is in line with the report by Sujit and Ganesh (2019).

At 0-7hrs fire exposure time the compressive strength is 1.64N/mm^2 and strength reduction of 92.62% while temperature rises from 0-1315^{o}C. Weakening of the concrete's compressive strength continues with increase in time until at 7hrs the concrete begins to melt. This result agrees with the report by Schneider et al., (1981), that above 1300°C to 1400°C concrete exists in the form of a melt.

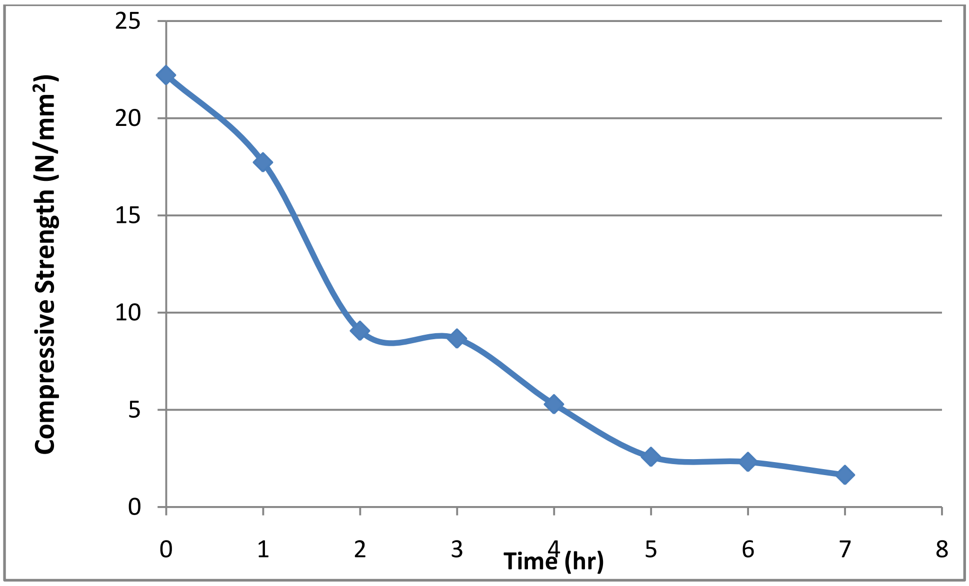

Fig 1: Variation of Compressive Strength with Exposure Time

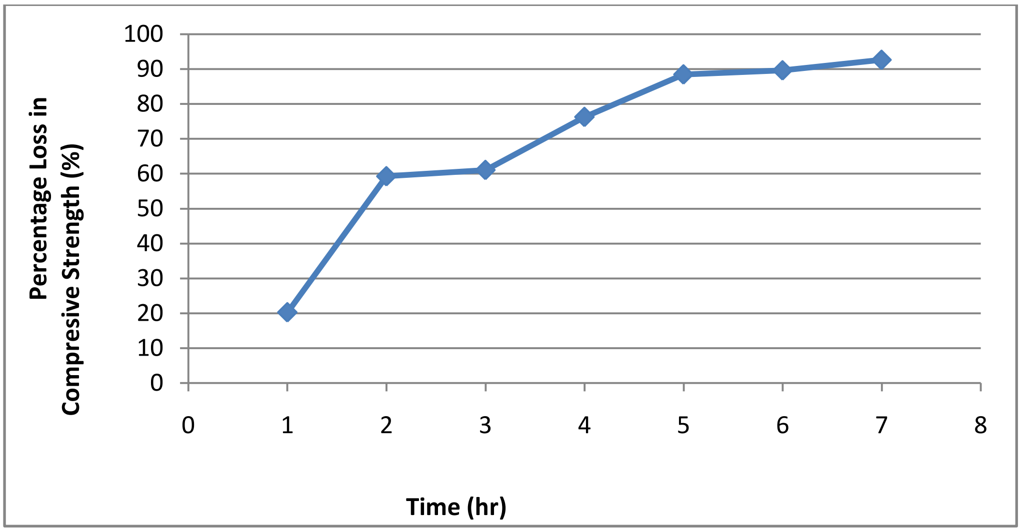

Fig 2: Variation of Percentage loss of Compressive Strength with Exposure Time

IV. Conclusion

The following conclusion was drawn from the study as follows: there is decrease in the compressive strength ranging between 22.22 to 1.64 N/mm2 with increase in time of exposure on the concrete to high temperature; and one hour of exposure has the highest compressive strength of 17.73 N/mm2 while seven hours of exposure has least compressive strength of 7.38 N/mm2. Also, with increase in fire exposure time there is increase in percentage loss of compressive strength ranging between 20.21 to 92.62%.; and one hour of exposure time gave the least strength reduction of 20.21% while seven hours of exposure time gave the highest strength reduction of 92.62%. Therefore, one hour fire exposure time on the concrete have better fire resistance than other time of exposure.

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