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Effect of Delay Curing Start on Durability and Mechanical Properties of High and Normal Strength Concrete

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Abstract: The effect of delayed curing start on durability and mechanical properties of High Strength Concrete (HSC) and Normal Strength Concrete (NSC) was studied. In this study, curing start was delayed for (0, 1, 3, 7, 28) days for samples cured by immersion in water and cast with (HSC) or (NSC). Compressive strength, flexure strength, splitting tensile strength, static elastic modulus, poisson's ratio, carbonation, shrinkage, sulfate resistance and freeze-thaw resistance of concrete were measured. Scanning Electron Microscopy (SEM) as well X-Ray Diffractometer (XRD) were used to evaluate the microstructure of concrete under diverse curing circumstances. The results show that the delay in starting the curing of (HSC) and (NSC) leads to a decrease in the durability and mechanical properties of both types (especially, (HSC)) and reduces the degree of cement hydration and the amount of hydration products and increases the mean diameter of the pores. The biggest effect is delayed curing on the first day.

Key words: Delay curing start, mechanical properties, durability, HSC, NSC, XRD

INTRODUCTION

Concrete material is the mainstay of construction materials and construction and the development of this material reflects an evolution of the engineering thinkingand in order for concrete to reach its present context as a structural and architectural material in the first place has undergone a number of stages in terms of manufacturing, construction and even curing and methods. In previous years, concrete had compressive strength higher than 45 MPa was current in limited sites. While, the (HSC) uses have expanded in the present-day and (HSC) is today used in numerous sites of the globe. Because of a request for higher strength concrete and recent developments in technology of material the growth has been possible. HSC has been helpfully used for high structures, columns, bridges, shear walls of multistory structures, prestressed and precast members and tunnels (Yogendran *et al*., 1987).

In order to get the good concrete it is necessary to cure it after the casting process and that by providing the appropriate perimeter during the early stages of casting. The curing expression is called the method used to stimulate cement hydration and includes control of the temperature and movement of moisture from and to the concrete. More accurately the aim of the curing is to maintain as much as possible to keep the concrete saturated or close to the saturation state until filling the blanks that were originally filled with water in the dough tender cement with the required quantity of hydration products (Obla *et al*., 2005). The curing of concrete is considered to be a true and continuous process of important things affecting mechanical properties and durability of concrete. Many concrete constructions are not cured in the early days after casting to ensure that the required properties are obtained where the curing is started later than the day of casting for a holiday after the day casting or relying on building guards who do not perform the curing properly or to waste the contractors or not to provide sufficient quantities of water or any other factors. On the other hand, there are many studies on the importance of curing and its methods that preceded this study. Study by Paya *et al*. (2000) on the compressive strength growth of concrete with SF cured at 40 and 20°C indicated that there was an important improvement of compressive strength for concrete with SF at early stage. Maltais and Marchand (1997) found that the mechanical properties of concrete with SF could be enhanced by vapor curing at little pressure associated to normal curing. Kosmatka *et al*. (2002) stated that vapor curing could quicken cement hydration and silica fume hydration and be helpful to the early compressive strength improvement. The goal of this study is to study the effect of delay curing start on the durability, mechanical properties and microstructure of HSC and NSC.

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MATERIALS AND METHODS

Experimental program

Properties of materials: Ordinary Portland cement whcih complies with the requirement by Anonymous (1984a, b) was used. Silica Fume (SF) used was German production bought from local markets. The physical properties and chemical composition of silica fume and cement are given in Table 1. Sand utilized was normal sand with a modulus of fineness of 3.04, planned in zone 2 depending on (Anonymous, 1984a, b). In Table 2, its grading is listed. The gravel utilized was broken gravel. The maximum coarse aggregate size was 14 mmand its grading is shown in Table 3. To produce high strength concrete with SF a "Glenium 54" was utilized. The amount for (Glenium 54) as stated by the manufacturer is 0.25-1.25 L/50 kg of cement. The amount utilized by the current study was 0.95 L/50 kg of cement). (Glenium 54) manufactured by (BASF) company. In Table 4, the mix proportion of NSC and HSC are listed.

NSC and HSC mixing process: Depending on ASTM (2005) NSC was mixed. 20% of the water was put in the mixer with gravel was utilized. Afterward a little seconds, 20% of the water was put with sand. After that, the mixer was worked for little instants. The residual water and cement were then put. The NSC was mixed for three and a half minutes then by three and a half minutes. Break, then by two and a half minutes. Depending on Anonymous (1997), HSC was mixed. The mixing process of HSC is listed shown as.

Mix cement with silica fume in dry state. Mix half amount of gravel with half amount of sand. Add all the cement and silica fume. Add residual of fine aggregate and coarse aggregate. Add all water. Mix for 3 min. Mix the Glenium 54. Mix for 3 min.

Test process: Mixing and sample preparation were achieved at room temperature (23±2°C). The samples were divided into five groups as follows:

- Specimens cured in water submerged immediately after the model was raised
- Specimens cured in water submerged after 1 day delay
- Specimens cured in water submerged after 3 days delay
- Specimens cured in water submerged after 7 days delay
- Specimens cured in air

Table 1: Physical properties and chemical composition of SF and cement

Label	Cement	Silica fume
Specific surface area (m^2/kg)	309.00	25000.00
Density (g/cm^3)	3.23	0.48
SiO_2	18.90	95.68
Al_2O_3	5.40	0.50
Fe_2O_3	3.60	-
CaO	60.35	1.30
MgO	3.05	0.43
SO_3	1.67	0.31
Loss	3.09	1.55

Table 2: The grading of sand

Sieve size (mm)	Cumulative passing (%)
4.75	95
2.36	81
1.18	60
0.60	39
0.30	15
0.15	6

Table 3: The grading of gravel

Sieve size (mm)	Cumulative passing (%)
20	100
14	100
10	55
5	4

Table 4: Mix proportion of NSC and HSC.

Parameter	NSC	HSC
Cement (kg/m^3)	351	442
Silica fume (kg/m^3)	-	78
Glenium 54 (L/m^3)	-	8.4
Gravel (kg/m^3)	906	1067
Water (kg/m^3)	200	130
w/cm ratio	0.57	0.25
Sand (kg/m^3)	861	739

Depending on Anonymous (2000), the compressive strength of concrete cube (f_{cu}) was tested. A cube of 100×100×100 mm was utilized for measuring the compressive strength of HSC and 150×150×150 mm of NSC. The average values of three samples was accepted from HSC and NSC and the samples were tested at 28 days. The splitting tensile strength of HSC and NSC was measured depending on Anonymous (2004), two cylinders of 100×200 mm were used and tested at 28 days. 100×100×400 mm concrete prisms were tested depending on ASTM C-78 (2002) procedure to calculate the flexural strength. They were tested at 28 daysand the average values of two sample's results was accepted for each test. The modulus of elasticity was measured according to Anonymous (2002). The results were the average values of two cylinders 300×150 mm at 28 days. According to Anonymous (2003), the Poisson's ratio was tested. The result of poisson's ratio for each HSC and NSC were the average values of two cylinders (300×150 mm) at 28 days. Depending on Anonymous

(2003) the resistance of freeze-thaw for each HSC and NSC aged 28 days was measured. Three samples were tested for each type of concrete. The variations in the weight was determined every 25 cycles of freeze-thaw and the average was stated. Depending on Anonymous (2003), the damage standards was that weight loss exceeds 5%.

Concrete Shrinkage under diverse curing circumstances was tested utilizing a three prism samples with the measurements of 400×100×100 mm. An extensometer of accuracy (0.002 mm) was utilized to test the shrinkage of concrete. At the age of 3 days, one couple of demec discs was fixed at mid length of each specimens to observer the shrinkage of concrete and the initial reading was taken. Reading were recorded in 1, 3, 7, 14, 21, 28, 45, 60, 90 and 180 days after the finish of curing. The shrinkage strain was calculated whcih was similar to that described by Fathifazl *et al*. (2011). Average of shrinkage strain at diverse times were determined from test of the three samples. Depending on GB 50082-2009, the carbonation of HSC and NSC was calculated. Prism samples (100×100×400 mm, two for each groups) were demolded after curing until 28 days, after that dried at a temperature of 65°C for 48 h. The depth of carbonation was tested by breaking 65 mm depth from the surface, spraying the cross-section with a 0.01 phenolphthalein solutionand assessing the carbonation depth from the resulting variation in color after reaching limited times. To calculate the effect of delay curing start on the resistance of sulfate of HSC and NSC, cube samples (100×100×100 mm) and (150×150×150 mm) were used to test the compressive strength before and after immersion in the sodium sulfate solution. The compressive strength of the samples was calculated before they were immersed in a 0.05 sodium sulfate solution in a water for 90 and 180 days. After this action, the compressive strength was tested. The resistance of sulfate was calculated by the compressive strength difference of samples immersed in the sodium sulfate solution or water at the same period. The pH of the sodium sulfate solution should be kept within a range of 6-8 and the sodium sulfate solution temperature was kept at 23 ±2°C. A (SEM) was utilized to get the microstructure of specimens under diverse curing circumstances. For well understanding of the change, the specimens under diverse curing circumstances were tested by XRD.

RESULTS AND DISCUSSION

The test results were discussed considering the compressive strength, flexure strength, splitting tensile strength, poisson's ratio, static elastic modulus, carbonation, shrinkage, freeze-thaw resistance, sulfate resistance of concrete, (XRD) and (SEM). Greatest of the data has been converted to graphical form for ease of understanding.

Table 5: Compressive strength of HSC and NSC

Start curing delay time (days)	f_{cu} of HSC (MPa)	f_{cu} of NSC (MPa)	Comp. str. decrease rate of HSC (%)	Comp. str. decrease rate of NSC (%)
0	71.4	35.5	-	-
1	63.8	32.4	10.6	8.7
3	61.3	31.8	14.2	10.3
7	57.8	30.7	19.0	13.6
28	55.5	29.9	22.3	15.8

Table 6: Splitting tensile strength of HSC and NSC

HSC start curing delay time (days)	Splitting tensile strength of HSC (MPa)	Splitting tensile strength of NSC (MPa)	Splitting tensile strength decrease rate of HSC (%)	Splitting tensile strength decrease rate of NSC (%)
0	6.1	2.80	-	-
1	5.3	2.54	12.8	9.2
3	5.0	2.47	17.0	11.6
7	4.8	2.31	21.3	17.2
28	4.6	2.23	25.4	20.2

Table 7: Flexure strength of HSC and NSC

Start curing delay time (days)	Flexure strength of HSC (MPa)	Flexure strength of NSC (MPa)	Flexure strength decrease rate of HSC (%)	Flexure strength decrease rate of NSC (%)
0	8.5	3.40	-	-
1	7.5	3.10	11.4	8.4
3	7.1	2.97	16.1	12.6
7	6.7	2.82	21.3	17.2
28	6.5	2.74	23.7	19.2

Table 8: Static elastic modulus of HSC and NSC

Start curing delay time (days)	Static elastic modulus of HSC (MPa)	Static elastic modulus of NSC (MPa)	Static elastic modulus decrease rate of HSC (%)	Static elastic modulus decrease rate of NSC (%)
0	32.45	24.83	-	-
1	30.99	24.11	4.5	2.9
3	30.37	23.44	6.4	5.6
7	29.56	23.01	8.9	7.3
28	29.20	22.77	10.0	8.3

Table 9: Poisson's ratio of HSC and NSC

Start curing delay time (days)	Poisson's ratio of HSC	Poisson's ratio of NSC	Poisson's ratio decrease rate of HSC (%)	Poisson's ratio decrease rate of NSC (%)
0	0.240	0.210	-	-
1	0.233	0.206	2.8	1.8
3	0.231	0.204	3.4	2.5
7	0.229	0.203	4.3	3.0
28	0.228	0.202	5.0	3.5

Mechanical properties: Table 5-9 and Fig. 1-5 shows the results of mechanical properties of HSC and NSC specimens at the age of 28 days under different curing circumstances.

From Table 5-9 and Fig. 1-5, it can be noted that delaying the start of curing reduces all the mechanical properties of concrete without exception. It

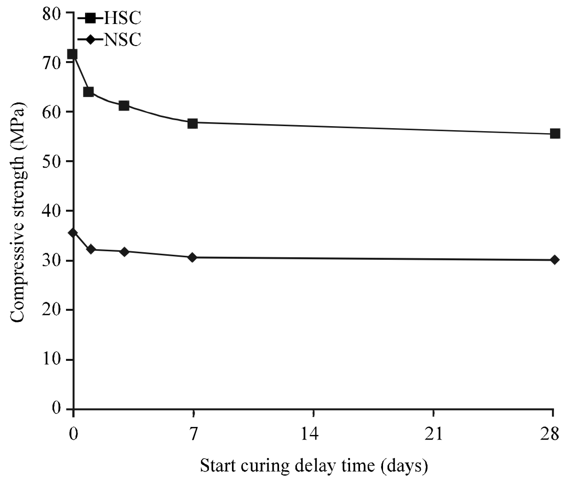

Fig. 1: Effect of delay curing start on compressive strength of HSC and NSC

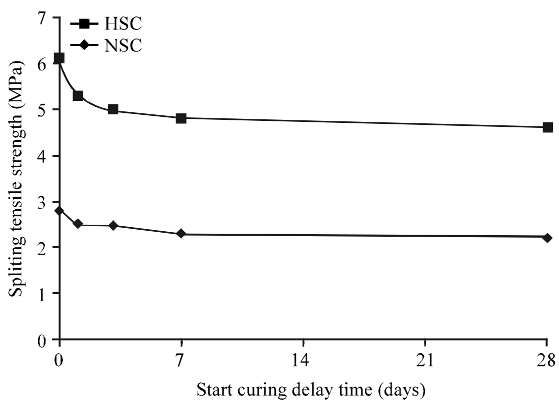

Fig. 2: Effect of delay curing start on splitting tensile strength of HSC and NSC

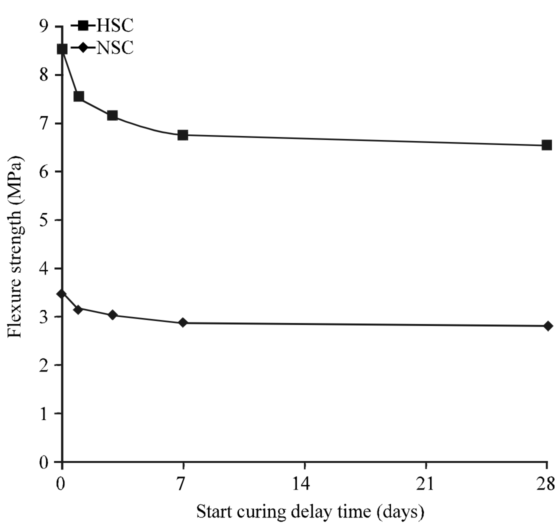

Fig. 3: Effect of delay curing start on flexure strength of HSC and NSC

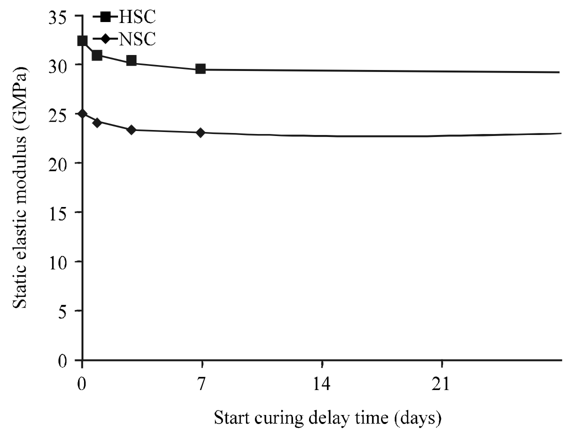

Fig. 4: Effect of delay curing start on static elastic modulus of HSC and NSC

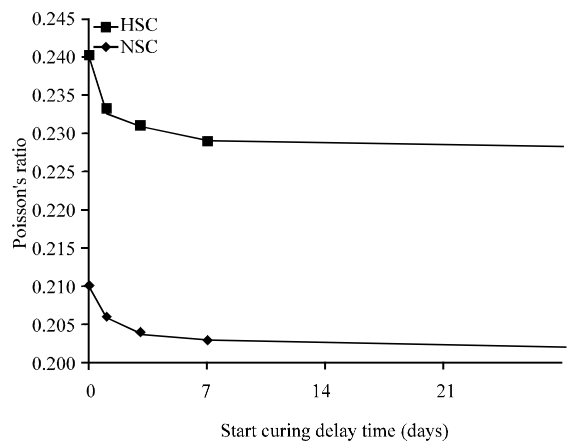

Fig. 5: Effect of Delay Curing Start on Poisson's ratio of HSC and NSC

was noted that at the delay of the start of curing for 28 days, the compressive strength of the high strength concrete decreased by 22.3% and the normal strength concrete by 15.8% compared with the compressive strength of the concrete there was no delay at the start of curing. The experimental results showed that the splitting tensile strength was more mechanical property affected by the delay of the start of the curing where it decreased by 25.4% for the HSC and 20.2% for the NSC compared with the splitting tensile strength of the concrete which did not delay at the start of curing and it is to form micro cracks in concrete due to delayed curing start. It was also, observed that the poisson's ratio less mechanical property affected by the delay of the start of curing because it is the ratio of transverse strain to the longitudinal strain and both strains increase when delay curing start, so, the rate of decrease is a few. It can also be seen that the decrease in static elastic modulus was low

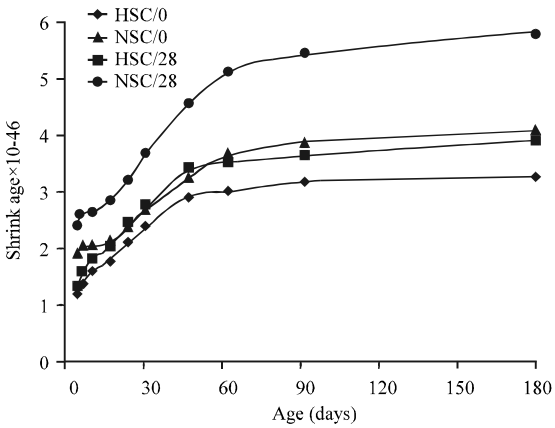

Fig. 6: Effect of delay curing start on shrinkage of HSC and NSC

where it was about 10 and 8.3% for the HSC and for the NSC, respectively, due to the fact that the static elastic modulus of the concrete depends on the modulus of elasticity of cement paste and aggregates. The delay in the start of curing reduces only the modulus of elasticity of the cement paste, so, the decrease rate of the static elastic modulus of the concrete is low. It is also, noted that HSC is more affected by delaying the start of curing than NSC because it contains a large amount of cement, silica fume and low water-cementitious materials ratio (w/cm) whcih makes curing very critical and the capillary pores very thin and close after a little time from the chemical reaction of cement with water. The experimental results indicate that curing is important in early age and less important in later ages. It was observed that the rate of decrease in mechanical properties due to delay of starting curing for 28 days is the approximately same as the decrease rate to delay the start of curing for 7 days. This means that the 7 days curing is sufficient for both types of concrete. The greatest effect of delaying the start of curing is on the 1st day because the capillary pores in the cement paste at this time are large and connected and are not filled with the hydration products after the time begins to close and the hydration products begin to solidify forming a strong casing around the un-hydrated cement. Therefore, when the water comes from the curing process it is ineffective and unhelpful as it cannot reach to the un-hydrated cement.

Shrinkage: Figure 6 displays the shrinkage growth for the four groups of concrete cured under diverse conditions ((HSC/0) high strength concrete without delay curing start, (HSC/28) high strength concrete without curing (air curing), (NSC/0) normal strength concrete without delay curing start and (NSC/28) normal strength

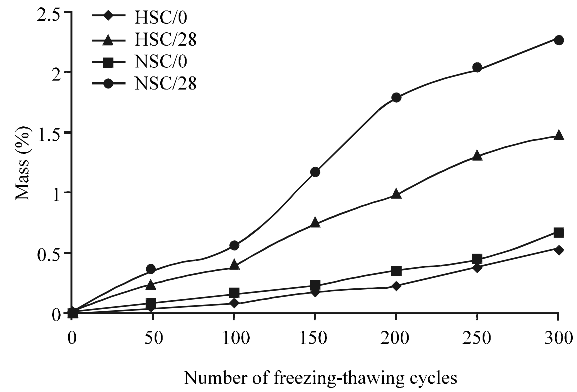

Fig. 7: Effect of delay curing start on freeze-thaw resistance of HSC and NSC

concrete without curing (air curing)) in 180 days. The experimental results indicate that greater rates of shrinkage are noted after day 1 even day 45 for both HSC and NSC and the rate of shrinkage increases gradually after day 45 even day 180. From Fig. 6, it can be noted that the shrinkage of NSC is greater than that of HSC throughout the test period, the shrinkage of (NSC/0) is 3.85×10^{-4} at day 90 and 4.05×10^{-4} at day 180 while for (HSC/0), those are 3.15×10^{-4} and 3.23×10^{-4}, respectively. It is also observed that the shrinkage of normal strength concrete is more affected by delaying the start of curing than the shrinkage of HSC because NSC contains a high water-cement ratio (w/c). Higher w/c ratios lead to greater porosity and thus to greater exposure of capillary water to the environment leading to a greater drying shrinkage. Also, the addition of silica fume as a cement replacement has been reported to decrease the drying shrinkage of concrete (Neville, 1996). The shrinkage measured in this research includes drying shrinkage, chemical shrinkage and autogenous shrinkage.

Resistance of freeze-thaw: The difference of the mass of HSC and NSC cured under diverse circumstances and exposed to 300 cycles of freeze-thaw is exposed in Fig. 7. It can be noted that the reduction of mass of all samples increase with cycles of freeze-thaw. Though, the reduction of mass for four concrete groups after 300 cycles of freeze-thaw are no higher than 0.05 depending on Anonymous (2003). It is noted that the loss of mass for NSC is higher than those for HSC at the cycles of freeze-thaw. The mass loss contents for High Strength Concrete (HSC/0) is 0.53% at 300 freeze-thaw cycles while those for Normal Strength Concrete (NSC/0) is 1.46% at the same cycles. It is also, noted that the resistance of freeze-thaw of normal strength concrete is more affected

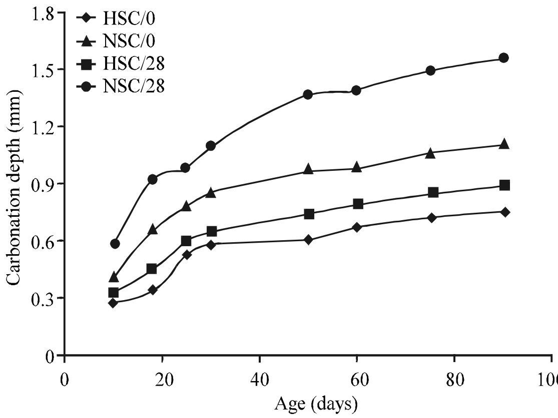

Fig. 8: Effect of delay curing start on carbonization of HSC and NSC

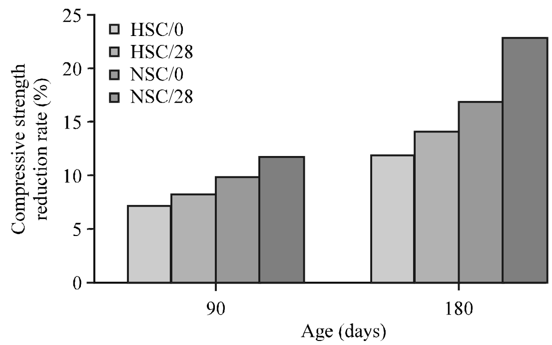

Fig. 9: Effect of delay curing start on sulfate resistance of HSC and NSC

by delaying the start of curing than the resistance of freeze-thaw of HSC because NSC contains a greater porosity paste.

Carbonization: The results of carbonization of HSC and NSC cured under diverse circumstances is shown in Fig. 8 whcih displays that the depth of carbonation of four groups of concrete become deep as the time increases and the depth of carbonation of NSC is more than that of HSC during the test period. With reference to Fig. 8, the carbonation depth of Normal Strength Concrete (NSC/0) is 1.05 mm at day 75 and 1.10 mm at day 90 while for High Strength Concrete (HSC/0), that are 0.72 and 0.75 mm, respectively. This can be credited to the portland cement in the concrete partly replaced by SF. That is known to improve carbonation (Litvan and Meyer, 1986; Cakyr and Akoz, 2008) while the influence of delay curing start on carbonization of HSC can also be slight.

Sulfate resistance: Figure 9 shows the resistance of sulfate results of HSC and NSC under diverse curing circumstances. From Fig. 9, it can be noted that the compressive strength of HSC and NSC decrease after it is immersed in the 0.05 sodium sulfate solution and the reducing rate of compressive strength increases with age. The reducing rate of compressive strength for high Strength Concrete (HSC/0) is 7.2% at day 90 and 12% at day 180 for Normal Strength Concrete (NSC/0), that is 9.72 and 16.8%, respectively. It can be observed that the reducing rate of compressive strength of NSC is greater than that of HSC specimens at the same time when they are immersed in the 0.05 sodium sulfate solution. In general, the effect of the sulfate solution on the HSC is lesser than that on the NSC because high strength concrete contains on SF.

Microstructure:X-ray diffractometer analysis of concrete cured under diverse circumstances is exposed in Fig. 10. The diffraction peak intensity in the X-ray diffractometer is utilized to estimate the content of hydration products under diverse curing circumstances. From Fig. 10, it can be noted that the hydration products of the same concrete under diverse curing circumstances are essentially like and the rate of hydration and degree of concrete (HSC/0, NSC/0) are higher than those of concrete (HSC/28, NSC/28). Figure 11 is Scanning Electron Microscopy (SEM) pictures of HSC and NSC. From Fig. 11, the high strength concrete cement paste is higher closed and compact than the one noted in the normal strength concrete cement paste and the size of hydration products in high strength concrete cement paste is smaller than that of the normal strength concrete cement paste.

From Fig. 10, it can also be observed that the diffraction peak intensity of $Ca(OH)_2$ in NSC is greater than that in HSC. This because the pozzolanic activity of the SF. The pozzolanic reaction of SF requirements to consume an amount of $Ca(OH)_2$ in the concrete. It is acknowledged that increase of pore size can reduction the concrete strength. The pore diameter of NSC is greater compared to that of HSC. Thus, the mechanical properties such as splitting tensile strength, compressive strength, elastic modulus and flexure strength of NSC are lesser than those of HSC. In general, the durability and mechanical properties of concrete are controlled by its pores. Harmful elements in either gaseous or liquid form can simply passage into concrete through pores whcih can reduce the durability of concrete. The passage of harmful elements and the change of water to ice get simplest as the pore diameter increases. Thus, the resistance of carbonization, resistance of sulfate and resistance of freeze-thaw of NSC are lesser than those of HSC.

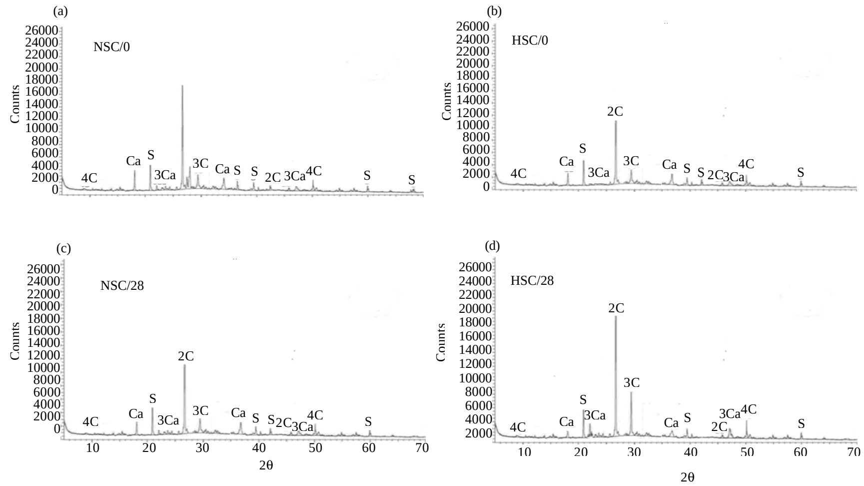

Fig. 10: XRD Analyses of high and normal strength concrete

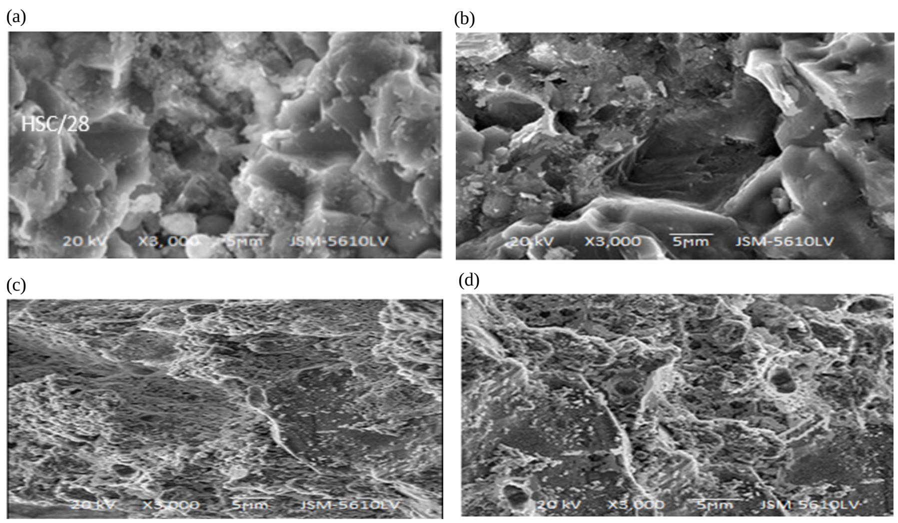

Fig. 11: a-d) Scanning Electron Microscopy (SEM) pictures of high and normal strength concrete

CONCLUSION

Depending on the experimental results for the tested specimens, the following remark opinions can be concluded.

The experimental results indicate that the delay in starting the curing of high and normal strength concrete leads to a decrease in the durability and mechanical properties of both types (especially, HSC).

The splitting tensile strength was more mechanical property affected by the delay of the start of curing where it decreased by 25.4% for the HSC and 20.2% for the NSC compared with the splitting tensile strength of the concrete which did not delay at the start of curing while the poisson's ratio less mechanical property affected by the delay of the start of curing.

The curing is important in early age and less important in later ages and the 7 days curing is sufficient for both types of concrete and the biggest effect is delayed curing on the first day.

The experimental results display that higher rates of shrinkage are noted after day 1 even day 45 for both types of concrete and the rate of shrinkage increases gradually after day 45 even day 180. The shrinkage of normal strength concrete is more affected by delaying the start of curing than the shrinkage of HSC.

The reduction of mass for NSC is higher than those for HSC at the cycles of freeze-thaw. The loss of mass contents for High Strength Concrete (HSC/0) is 0.53% at 300 freeze-thaw cycles while those for normal Strength Concrete (NSC/0) is 1.46% at the same cycles.

The depth of carbonation of NSC is more than that of HSC throughout the test period and the effect of delay curing start on carbonization of HSC can also be slight.

The compressive strength of HSC and NSC decrease after it is immersed in the 0.05 sodium sulfate solution and the reducing rate of compressive strength increases with age. The influence of the sulfate solution on the HSC is lesser than that on the NSC.

The HSC cement paste is higher closed and compact than the one noted in the NSC cement pasteand the size of hydration products in high strength concrete cement paste is smaller than that of the normal strength concrete cement paste. The diffraction peak intensity of $Ca(OH)_2$ in NSC is greater than that in HSC. This because the pozzolanic activity of the SF. The delay in starting the curing of HSC and NSC leads to a reduces the degree of cement hydration and the amount of hydration products and increases the mean diameter of the pores.

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