Increase on Strengths of Hot Weather Concrete by Self-curing of Wet Porous Aggregat

Meningkatnya Kekuatan Beton Cuaca Panas dengan Perawatan Sendiri Pada Agregat Berpori Basah

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ABSTRACT

Generally, a concrete made in hot weather usually accompanied by a decrease of compressive and tensile strengths. The loss of much combined water in the concrete body is mostly caused by high evaporation of water or moisture during a period of fresh and hardened concrete. An alternative was needed to cope with this problem. Wet porous aggregate which holds much water than wet ordinary aggregate may solve the problem. Porous aggregate of flyash aggregate usually used in a lightweight concrete is generally linked to low strengths of concrete, but when use it in wet (saturation) condition the aggregate could provide favourable strengths of concrete. An absorbed water within the flyash aggregate, different with combined water in mix design to determine W/C ratio, moves out to the cement paste which has already hardened, thereby, continuing the hydration process. This mechanism is called "self curing" and would intensify much products of hydration therefore increasing the strengths. Experiment was done in the room temperature ranged from 20°C to 40°C and with constant at a relative humidity. The results, the self curing occurred within the body of concrete using flyash aggregate, as wet porous aggregate, had provided the higher compressive and tensile strengths compared with concrete using silane flyash and crushed stone aggregates. Even in the high air temperature the self curing gave favourable effect on the compressive and tensile strengths as it contributes a better bond strength around the aggregate of flyash.
Keywords: self curing, hot weather concrete, bond strength, fly ash aggregate, wet porous aggregate

ABSTRAK

Umumnya beton yang dibuat di daerah cuaca panas selalu diikuti dengan penurunan kekuatan tekan dan tarik. Kehilangan banyak air campuran di dalam badan beton lebih banyak disebabkan oleh penguapan air atau uap air selama masa beton segar dan keras. Alternatif lain dibutuhkan untuk menyelesaikan masalah tersebut. Agregat berpori jenuh air yang menyerap lebih banyak air dari pada agregat batu pecah diharapkan dapat menyelesaikan masalah kekurangan air di dalam badan beton. Biasanya agregat flyash berpori yang digunakan untuk beton ringan akan selalu dihubungkan dengan rendahnya kekuatan. Kandungan air yang banyak di dalam agregat flyash, bukan bagian faktor air semen, akan menyebar keluar ke dalam pasta semen keras dan kering untuk melanjutkan proses hidrasi, mekanisme ini disebut "selft-curing" dan akan meningkatkan produk hidrasi yang berarti meningkatkan kekuatan. Eksperimen sudah dilakukan di dalam ruangan bertemperatur antara 20°C-40°C dan dengan kelembaban konstan. Hasilnya, self-curing yang terjadi di dalam badan beton yang menggunakan agregat flyash jenuh air telah memberikan kekuatan tekan dan tarik yang lebih tinggi dibandingkan dengan beton agregat batu pecah dan beton ringan agregat flyash jenuh air tetapi dilapisi zat waterproofing (jenis silanol). Meskipun pada temperatur tinggi self-curing memberikan pengaruh memuaskan terhadap kekuatan tekan dan tarik beton agregat flyash karena adanya kekuatan rekat lebih baik di sekitar permukaan agregat flyash.
Kata-kata Kunci: perawatan sendiri, beton cuaca panas, kekuatan rekat, agregat abu-terbang, agregat berpori jenuh air

INTRODUCTION

The role of moisture content in hardened concrete gives a specific base for designing concrete, particularly, in hot humid climate at tropical countries. If the total combined water does not escape from the body of concrete, in fresh and hardened condition of concrete, and it continues to create much more hydration products, the concrete would have good quality even under a high air temperature. Previous researches resulted that concrete sealed with plastic to prevent the water escapes (Matsufuji et.al, 1988). But this method, in actual operation, would probably be difficult to be applied. An alternative way is needed to cope with this difficulty. Wet porous aggregate which holds much water than wet ordinary aggregate may possibly solve the difficulty.

A phenomenon of water absorbed by porous aggregate moving out into the hardened cement paste when concrete is already dry, will be applied to prove the usefulness of the continued presence of moisture in hardened concrete without treatment be applied on the concrete surface.

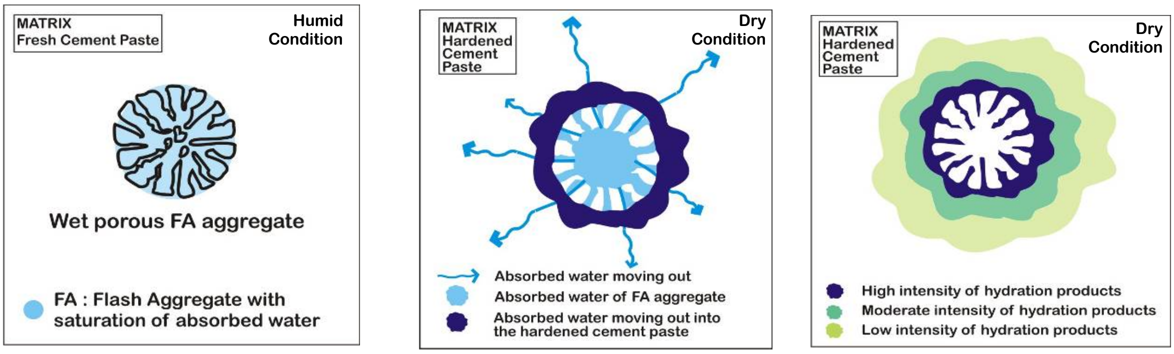
During the process of the movement of water, the whole body will become damp and because of high humidity of air the rate of drying is low. This situation would support a continuation of wet curing within the body of concrete, and it is called "self curing". The existence of the self curing is firstly introduced by Prof.Yasunari Matsufuji. In the previous research (Matsufuji et.al., 1986) has suggested that the situation be clear if temperature and humidity are high. Therefore a better quality in terms of strength and drying shrinkage would be produced in hot humid climate (Sampebulu', 1988).

This experiment will make clear the self curing effect on strengths. Artificial lightweight aggregate of flyash having porous structure was used.

MECHANISM OF SELF CURING PROCES

Porous aggregate used in concrete is generally linked to poor quality of the concrete. However, when use it in wet condition the aggregate could provide favourable effects on the concrete due to the water absorbed by the aggregate. This water moves into the cement paste which has already hardened, thereby continuing the hydration process (Sampebulu',2001). Because of that, improvements in concrete qualities would be obtained such as increase in strengths and decrease in drying shrinkage.

(1) Fresh period | **2) self curing process** | **(3) The process ended**



STATE 1:
The same humidity condition between FA aggregate and fresh cement paste, no movement of absorbed water

STATE 2:
The different humidity condition between FA aggregate and hardened cement paste (dry condition),absorbed water of FA aggregate are moving out into the hardened cement paste to continue hydration process much more at around the surface of aggregate

STATE 3:
The process of moving out of water and hydration has been stopped, the high density of hydration products near the surface creates the layer that has higher bonding between hardened cement paste and the surface of FA aggregate, which is called as bond strength.

Figure 1. The mechanism of self curing

The water movement is caused by the humidity gradient between the aggregate that is high and the cement paste that is low. Since the hydrating reaction which inevitably absorbed water while the concrete is in the fresh and hardened states, the free water (combined water) will decrease until little is late to saturate the solid surfaces of hydrated cement. This is known as “self-desiccation”. This desiccation will occur rapidly in high temperature. As a consequence, the relative humidity attains to the equilibrium condition.

As the paste already filled with water again, the interrupted hydration process would resume the continue for relatively long time. This would create much more hydration products than in such case that absolutely no moisture or water moves to the paste. Thus, with wet porous of aggregate, the absorbed water allows wet curing within the body of concrete to continue, taking part in hydration. The more proper term for naming this process is “self curing”. The mechanism of the self curing is shown in Figure 1. This term will distinguish this curing form another type of curing process that is almost similar, i.e. autogenous curing described by A.M. Neville (Neville, 1982).

The difference of the two type is in their way of water supply and temperature require to continue the curing. In the self curing, the water comes from the aggregate, and this curing could take place in high and low temperature environment. While the autogenous curing is operated otherwise.

The autogenous curing is the curing, in adiabatic condition, utilizing the heat generated by the hydration of ce-ment’s pure compounds. A specimen is sealed in a plastic bag after mixing and then placed in a polyurethane container for 46 hours. It would be expected that the water to function in water curing comes from the free water already escaped as vapour around the container, and from that still existed within the body of specimen. This, of course, differs with the process found in the self curing.

METHODOLOGY

To prove the presence of self curing and its effect on strengths, several procedures, materials and mix proportions were attempted for use in this case.

Materials and Mix Proportions

All mixes used the same materials of cement and fine aggregate. Ordinary Portland cement was used as cement and river sand as fine aggregate. Two types of coarse aggregate were used, i.e. artificial lightweight of Fly Ash (FA) and crushed stone. In this experiment, FA aggregate was used because it, unlike a natural porous aggregate, has more homogeneous pores within the interior to the surface and among each of the pieces.

Two types of FA aggregate were used in this experiment. First type was FA aggregate as wet porous aggregate which holds much water. Second type was of the same FA aggregate but immersed into a silanol agent before mixing was done. As the silanol agent is the type of waterproofing material, initially absorbed water of the silanol-immersed aggregate, in terms of self curing, would not move or no water movement between the aggregate and the cement paste. This aggregate type is called Silane Fly Ash (SFA) aggregate.

Physical characteristics of all types of aggregates used and mix proportions are presented in Table 1 and 2. In the Table 1, the FA aggregate has a high absorptive capacity compared with other types.

Table 1. Physical characteristic of aggregate used

Aggregate	Spesific Gravity		Size (mm)	Absorbed Water (%)	Unit Weight Kg/m^3	Absolute Volume (%)	Fineness Modulus
	Dry	Saturation					
FA	1.35	1.59	15	17.8	0.87	64.4	6.40
Silane FA	1.36	1.39	15	2.22	0.87	64.4	6.40
Crushed Stone	2.88	2.99	20	0.81	1.66	58.6	6.60
River Sand	2.51	2.56	2.5	1.83	1.64	65.2	2.50

Generally, as shown in Figure 2, this FA aggregate has absorbed water about 50% of its total absorption at saturation only in 30 seconds, 70% in one day, and attained to equilibrium in one month. But in this experiment, FA aggregate at time of mixing did not quite attain to the saturation point.

Mix proportions of concrete and mortar are shown in Table 2. Based on the purpose of this experiment, proportions of water and coarse aggregate were made constant so as to allow the effect of self curing in relation with various water-cement ratios. Chemical admixtures were also added into the mixes, air-entrained agent of vinsol type and water-reducing of high flood type.

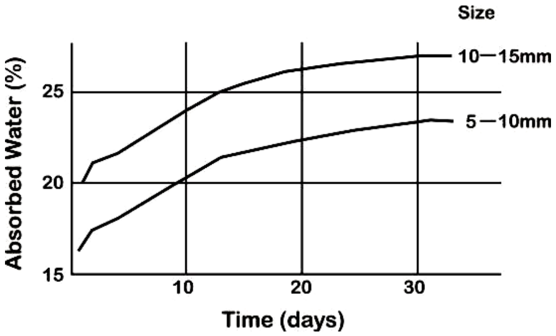


Figure 2. Increase of water absorbed by Fly Ash aggregate with increase in time (Tomosawa, AIJ)

Table 2. Mix proportions

W/C (%)	Slump (cm)	Proportion (l/m^3)				Air Content	Sand Ratio s/a	AE (%.C)
		C	W	S	G			
35		163		257			0.42	
40		143		277			0.43	
45	18	126	180	294	360	4.0	0.45	0.03
50		114		306			0.46	
55		104		316			0.47	

Method of Experiments

The methods used are drawn in Table 3 for strength test. Japanese Standard Specification of SA 1108 method was applied for compressive strength test and purely-pulled method for tensile strength test.

Table 3. Outline of experiment for strength test

Code of Specimen		Temperature of Material (^oC)	Curing Condition and Method	Size of Specimen (cm)	Chemical admixture (%.C)	
Abbc (*)	W/C(%)				AE	Water Reducing
FA	35	normal	Standard Room 20^{o}C: water / dry, RH-70%	compressive Ø 10 x 20	0.03	0.4
	45					-
	55					-
SFA	35					0.4
CA	35		Hot Room 40^{o}C: Fog,RH-100% / Dry,RH-70%	Tensile Ø 7.5 x15		0.4

Note: (*) FA- Flyash aggregate, SFA-Silane Flyash Aggregate
CA- Crushed Stone Aggregate, RH-Relative Humidity

Table 4. Result of fresh concrete

Code of Specimen	Slump (cm)	Air Content (%)	Unit Weight (kg/m^3)
FA-35	20.0	5.5	1.893
FA-45	19.8	7.6	1.831
FA-55	17.3	7.2	1.826
SFA-35	17.5	7.2	1.816
CA-35	20.3	3.1 (4.3)	2.417

RESULT AND DISCUSSION

Properties of fresh concrete are shown in Table 5. The slump test result was about 18 cm for concrete using FA and about 21 cm for concrete using crushed stone aggregate. Except, for W/C 35%, the same of slump of about 21 cm for FA-35 and CA-35.

In general, FA aggregate concrete is characterized by much air content and lighter unit weight, Table 4.

Since FA aggregate as porous aggregate is usually not saturated completely with water thus with a great deal of air still remaining in the aggregate, the use of an ordinary pressure method for measuring the air content of fresh FA aggregate concrete is rather difficult.

Strengths

The characteristics of strengths to be discussed consist of compressive and tensile strengths, and static modulus of elasticity.

Compressive strength

Varying in the amount of absorbed water of aggregates with a constant water-cement ratio (35%), FA concrete attained to higher compressive strength than SFA and CA concrete. The effect of self curing had appeared at 28 days strength in comparison of the result of FA concrete with that of SFA concrete. In dry curing at both 20^{o}C and 40^{o}C curing conditions, the strength of FA concrete was 30-40 kgf/cm2 higher than that of SFA concrete. The strength of FA concrete continuously increased in a range of age from 28 to 91 days but the opposite results found for SFA and CA concrete, see Figure 3.

Since a W/C ratio is constant, it is expected that only one factor causes the increase, namely, the self curing in which the absorbed water of FA aggregate moves into the hardened cement paste and then the hydration process once interrupted would resume to go on. This is the greatest possibility that would take place and could be believed because the W/C ratio is constant. The most clear evidence of self curing effect is that the laterage strength of FA concrete is stronger than crushed stone aggregate concrete. This is contrary to the visual case in which an ordinary concrete is stronger than all types of a lightweight concrete. This usual case appeared in water and fog curing at both 20^{o}C and 40^{o}C in which the CA concrete had 520 kgf/cm^2 at 91 days, Table 5, that was the highest strength in this experiment. This value is lower by about 70-80 kgf/cm^2 for that in drying curing.

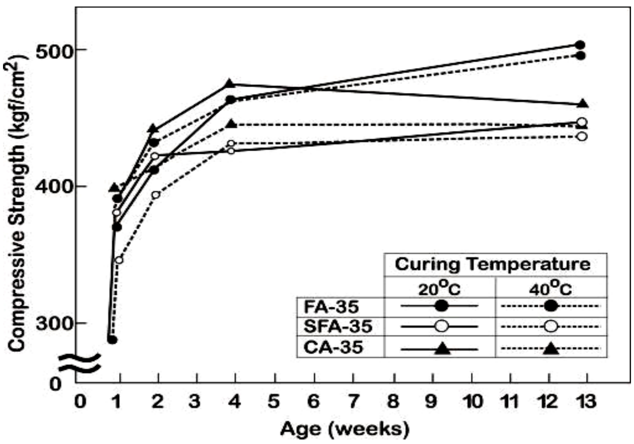


Figure 3. Effect of curing temperature on the compressive strength of flyash, silane flyash and crushed stone aggregate. Dry curing, W/C = 35%.

Table 6 shows the percentage difference in compressive strength from the dry curing to those from the water and the fog curing. Values of crushed stone aggregate concrete in 40^{o}C curing decreased with time increased. At least two factors, shape and absorbed water of aggregate, are responsible for that decreasing. Pockets (voids) are formed easily underneath an angular shape of crushed aggregate, unlike a globular shape of FA aggregate, during the fresh state period when a process of bleeding or sedimentation is taking place (Sampebulu', 2008).

The ratio of W/C 35% and less than 1% of absorbed water of the aggregate are small values. While the bleeding is going on, the water would be trapped within the formed pockets between aggregate and matrix. After the bleeding finishes and the concrete has hardened, the pockets will dry when curing goes on in dry condition. This will leave the pockets dried. As a consequence, the pockets will become a cause of crack as they consist of just air and soft parts. Moreover, the edges of angular aggregate would produce a concentration stress when concrete is subjected to load forces and this then increases the possibility of cracks occurring easily around the pockets.

The effect W/C ratio on strength is clearly seen in Table 6. For both 20^{o}C and 40^{o}C the smaller the W/C ratio the higher the percentage difference of comprehensive strength was found. The density of concrete thus seems to have relation with this. The density will become heavier as the absorbed water moves from FA aggregate. The water would continue to create more hydration products around the aggregate pieces. Therefore, this would improve bond strength between the aggregate and the cement paste.

Table 5. Results of hardened concrete, strength test

Code of Specimen	Curing		Compressive Strength (kgf/cm^2)				28 days static modulus of elasticity (x10^{5}kgf/cm^2)	28 days static Tensile Strength (kgf/cm^2)
	Condition	Method	7 days	16 days	28 days	91 days		
FA-35	20^{o}C	water	348	393	417	468	2.06	-
		Dry	359	401	463	497	2.01	33.5
	40^{o}C	Fog	401	443	451	492	2.13	-
		Dry	389	432	461	490	1.98	33.5
FA-45	20^{o}C	water	235	307	355	371	1.78	-
		Dry	258	340	373	381	1.63	28.1
	40^{o}C	Fog	272	356	375	402	1.86	-
		Dry	276	345	360	375	1.65	26.9
FA-55	20^{o}C	water	187	243	277	309	1.90	-
		Dry	196	251	276	300	1.57	21.5
	40^{o}C	Fog	228	258	283	330	1.87	-
		Dry	218	240	268	295	1.53	23.3
SFA-35	20^{o}C	water	352	404	421	462	2.12	-
		Dry	382	422	424	442	1.89	31.3
	40^{o}C	Fog	382	413	448	447	2.20	-
		Dry	345	392	430	432	1.82	27.9
CA-35	20^{o}C	water	378	423	465	523	3.31	-
		Dry	388	440	572	453	3.28	23.5
	40^{o}C	Fog	410	443	487	524	3.67	-
		Dry	397	411	443	440	3.07	22.0

The development of strength in dry curing was greater for the concrete made with FA aggregate. The different strength ratios of dry curing to the water and fog curing are shown from Figure 4 to 5.

Even at 40^{o}C curing temperature, the strength of FA concrete was greater than that of CA concrete (Figure 4). Various water-cement ratios of FA concrete also resulted in various strengths and particularly a smaller W/C ratio provided a greater strength for dry curing at both 20^{o}C and 40^{o}C (Figure 5).

Table 6. Percentage difference in compressive strength of dry curing to the strength of water and fog curing

Code of Specimen	Curing Condition	Percentage Difference			
		7 days	14 days	28 days	91 days
FA-35	20°C	3.2	2.0	11.0	6.2
	40°C	-3.0	-2.5	2.2	-0.4
FA-45	20°C	9.8	10.7	5.1	2.7
	40°C	1.5	-3.1	-4.0	-6.7
FA-55	20°C	4.8	3.3	-4.0	-3.0
	40°C	-4.4	-7.0	-5.3	-10.6
SFA-35	20°C	8.5	4.5	0.7	-4.3
	40°C	-9.7	-5.1	-4.0	-3.4
CA-35	20°C	2.6	4.0	1.5	-13.4
	40°C	-3.2	-7.2	-9.0	-16.0

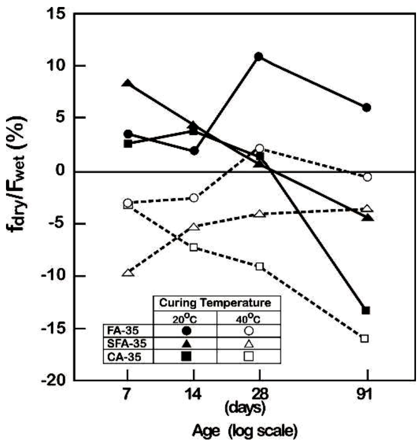


Figure 4. Development of compressive strength in 20°C and 40°C of dry curing compared with the strength in both temperatures of water and fog curing. W/C=35%. Aggregate used: flyash, silane flyash and crushed stone.

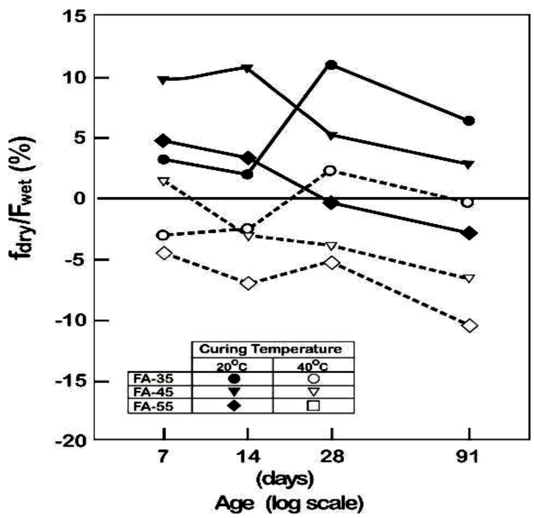


Figure 5. Development of compressive strength in 20°C and 40°C of dry curing compared with the strength in both temperatures of water and fog curing W/C=35%, 45%, 55%.
Aggregate used: flyash

Tensile Strength

Tensile strengths of each type of concrete are shown in Table 5, to prove the self curing effects no testing was done for specimens by water and fog curing.

Various degrees of tensile strength were found for the FA concrete specimens classified in 4 types of W/C ratio. The strengths for W/C 35% was the highest among them. Apparently low total water gives better tensile strengths. Based on purely visual observation of the broken surface of specimens already tested, apparent pieces of FA aggregate were cut in two parts. This indicates that the bond strength around the aggregate worked favourably. The remaining bond layers were seen around the broken FA aggregates. The remarkable indication was that all the apparent aggregates had broken in FA concrete of W/C 35%.

It is obvious that the water once absorbed in FA aggregate has already moved out into the hardened cement paste to maintain the hydration process. And the progress of the process is recognized much more in the cement paste around the FA aggregate (Figure 1). The result of the process, therefore, would improve the bond strength. This has been clearly proven by the case of W/C 35% in which the tensile strength of FA concrete was the highest compared with the concrete of other W/C ratios.

No effect of self curing can be seen in SFA concrete for which the tensile strength by curing at 40°C was lower than that at 20°C due to the self desiccation occurring more rapidly under high temperature (see section 2). Because no surplus water supplies the self desiccated water, use of SFA aggregate would weaken a tensile strength.

A comparison between compressive and tensile strength at the age of 28 days is shown in Figure 6.

Tensile strength of FA concrete ranges from 1/12 to 1/16 of its compressive strength. No different value was found between 20°C and 40°C curing conditions for FA-35 but the value varied for FA-45 and FA-55 in which the value was higher for 40°C.

A multiple reaction of hydration will take place when ambient temperature is high (Idron, 1968). Because of self curing, this chemical reaction to take place between the aggregate and cement paste increases their bond strength.

On the contrary, the value was lower for 40°C curing condition for SFA and CA concrete. Because such aggregate has neither exit nor enough water, the self curing does not work in the both cases. In addition, 40°C of air temperature will cause much rapid water evaporating from the concrete. This condition, high temperature and lack of water in the body, dries the concretes out and as a result their bond strength does not built up.

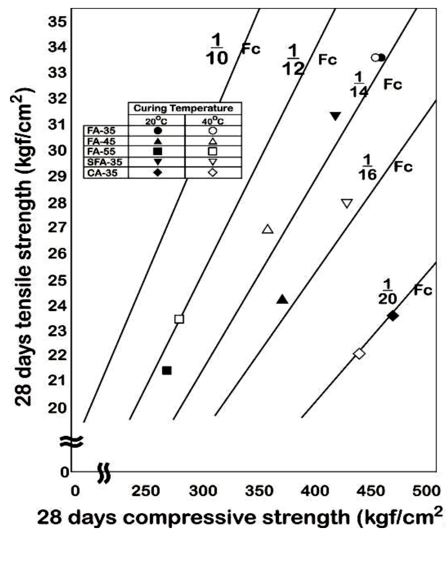


Figure 6. Relation Between Compressive and Tensile Strength at the age of 28 days

In Figure 6, the tensile strength of the CA concrete is about 1/20 of its compressive strength. This belongs to a low value range comparing with the values of FA and SFA concrete. Effect of bond weave around the irregular surface of the crushed stone aggregate is responsible for the low value. Because the aggregate shape is irregular, bleeding water easily collects beneath the pieces of the aggregate. If tensile force is given to such a zone under this circumstance, cracks develop initially in the zone before spreading to other zones in the concrete body.

There are two indications about the magnitude of bond strength between the aggregate and cement paste on the specimen that is broken off by a pulling force. Firstly, if the apparent pieces of the aggregate are broken with mortar matrix around them, this indicates that the bond is strength enough to its ultimate power to hold the aggregate. But, secondly, if the aggregates are not broken this means the bond is weak. By examining the broken surface of the specimens, the first indication appears on all the FA aggregates and the second on all the CA (crushed stone) aggregates and a half of SFA aggregates. The last case of SFA aggregates provides another theory that a globular shape and open pores appeared on aggregate surface are also the factors enhancing the bond strength.

Modulus of Elasticity

Modulus of elasticity to be determined by applying a static method was obtained from 1/3 T_{max} of 28 days strength. In all the concretes shown in Table 5, the elasticities resulted from dry curing were smaller than those from water and fog curing. There is a tendency in FA concrete that the elasticity will decrease with increase in a ratio of water cement.

Comparing between FA and SFA concrete under dry curing condition the elasticity of FA concrete was slightly high. Since the W/C ratio is constant, only the factor that may explain the difference is possible improvement of bond strength between aggregate and matrix through the self curing.

CONCLUSION

The existence of self curing in concrete using flyash aggregate as wet porous aggregate, has provided favourable effects on properties of concrete. Several conclusions are drawn as the significant effects of the self curing.

In moderate and high ambient temperature, flyash aggregate concrete provides higher compressive and tensile strengths compared with silane flyash and crushed stone aggregate concrete. Particularly for tensile strength, the higher temperature gives a favourable effect as it contributes a better bond strength around the flyash aggregate.

There is a tendency that high temperature accompanied by high relative humidity would give a favourable effect on properties of concrete if wet porous aggregate is used. Thus, it should be widely applied in making concrete in hot humid environment.

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