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Methodology Article

Influence of Superplasticizer Compatibility on the Setting Time, Strength and Stiffening Characteristics of Concrete

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Abstract: The adverse effects of elevated temperatures on the properties of the fresh concrete include increased water demand, shorter setting time and increased slump loss. Superplasticizer (SP) is important to enhance the workability and setting time of concrete under hot weather, hence, an experimental investigation was conducted to determine the effect of dosage of the mentioned admixture. Concrete mixes with SP dosages of 400, 600, 800, 1000 and 1200 ml/100kg of cement were prepared, together with two control mixes (water/cement ratio were 0.56 and 0.66 respectively). After casting, normal curing was carried out on the concrete samples. Properties such as compressive strength, porosity, water absorption, permeability and initial surface absorption were determined, besides determining the workability and setting time of the fresh concrete. Over dosage of SP were found to deteriorate the properties of concrete with indication of lower compressive strength and higher porosity. However, if the dosage levels are lower than the optimum dosage, increase in admixture dosage might help to enhance the concrete characteristics.

Keywords: Superplasticizer, Compatibility, Strength, Dosage

1. Introduction

Concrete structure is the most common type of structure, and it keeps developing and improving day after day to meet up with the global and environmental requirements, this structure is basically a mixture of cement, water, sand, and coarse aggregate. However, cement considered as the most expensive and significant ingredient in concrete production. Concrete is the major structural material widely consumed in the world, after water. Most of the infrastructure and building construction in the world are using concrete as construction material. An admixture, according to the ASTM C-125-97a standards, is a material other than water, aggregates or hydraulic cement that is used as an ingredient of concrete or mortar, and is added to the batch immediately before or during mixing. A material such as a grinding aid added to cement during its manufacture is termed an additive. Most concrete used contains at least one admixture. The proportion of concrete in which admixtures was used in 1975 in Australia, Germany and Japan was 80, 60 and 80%, respectively [1].

Superplasticizer is a type of water reducers; however, the difference between superplasticizer and water reducer is that superplasticizer will significantly reduce the water required for concrete mixing [2]. Generally, there are four main categories of superplasticizer: sulfonated melamine-formaldehyde condensates, sulfonated naphthalene-formaldehyde condensaes, modified lignosulfonates and others such as sulfonic- acid esters and carbohydrate esters. Effects of superplasticizer are obvious, i.e. to produce concrete with a very high workability or concrete with a very high strength. Mechanism of superplasticizer is through giving the cement particles highly negative charge so that they repel each other due to the same electrostatic charge. By deflocculating the cement particles, more water is provided for concrete mixing [2]. For general usage, dosage of superplasticizer is between 1- 3 l/m^3. However, the dosage can be increased to as high as 5- 20 l/m^3. Since concentration of superplasticizer is different, any comparison of performance should be made on the basis of the amount of solids, and not on the total mass. Effectiveness of a given dosage of superplasticizer depends on the water/cement ratio. Effectiveness increases when w/c decreases. Compatibility with actual cement is one of the most important parameters that needed to be considered, and it is not recommended that the cement and superplasticizer conform the standard separately [2]. There are few advantages obtained when superplasticizer is used: produce high workability concrete with constant cement content and strength, with objective for easy placing and compaction; produce concrete with normal workability, but lower water requirement; production of concrete with combination of high workability and low water content; and designing a normal strength and workability concrete with less cement content [1]. Usage of superplasticizer becomes famous nowadays since it possesses advantages for both fresh and hardened concrete. The utilization of superplasticizer will have positive effects on properties of concrete, both in the fresh and hardened states. In the fresh state, utilization of superplasticizer will normally reduce tendency to bleeding due to the reduction in water/ cement ratio or water content of concrete. However, if water/ cement ratio is maintained, there is tendency that superplasticizer will prolong the time of set of concrete as more water is available to lubricate the mix [3]. In the case of hardened concrete the use of superplasticizer will increase compressive strength by enhancing the effectiveness of compaction to produce denser concrete [3]. Risk of drying shrinkage will be reduced by retaining the concrete in liquid state for longer period of time. In addition, rate of carbonation become slower when water/ cement ratio is decreased with the presence of superplasticizer.

However, different types of superplasticizer will normally have different effects on properties and performance of concrete. As studied the effect of two types of superplasticizers- acrylic polymer (AP) and sulfonated naphthalene (SN) on concrete containing high volume of fly ash. From the investigation, they concluded that AP- based superplasticizer performs significantly better than the SN-based superplasticizer, where it provides higher slump level, lower slump loss and higher water reduction. In addition, concrete containing AP- based superplasticizer gives higher compressive strength and durability performance (in terms of CO_2 and chloride penetration) [4]. Hence, addition of AP-based superplasticizer not only improves the slump loss problem of the concrete, but also it does not cause any reduction in the early strength development of hardened concrete. The influence of a superplasticizer by the name of Mighty 2000 confirmed that slump of fresh concrete can be optionally controlled in all mix- designs if reactive polymer is added [5]. Since workability of low water/cement ratio concrete is difficult to control, addition of reactive polymer can usefully maintain the initial slump of ready mixed concrete. In addition, they claimed that superplasticizer can really produce a good quality concrete by increasing the density of concrete, through significant reduction in water requirement and slump loss.

In order to examine the effect of superplasticizer on concrete containing mineral admixtures and different types of cement, the addition of fly ash and silica fume affects the superplasticized concrete. When superplasticizer is added to fly ash- concrete produced from type III Portland cement, increase in SP dosage (from 2 to 4%) can advantageously be used to obtain high strength concrete (80MPa) for massive concrete structures [6]. However, only marginal advantages were observed when type I Portland cement was used. Furthermore, worse condition was found in concrete with the absence of fly ash. Addition of SP will give no additional strength increase independent of the Portland cement type. Hence, they concluded that cement type and addition of mineral admixture can vitally affect the efficiency of superplasticizer. For concrete containing silica fume, the effect of SP is totally different from those containing fly ash. In the absence of silica fume, compressive strength of SMP superplasticized concrete appears to be higher than those SNP superplasticized concrete, regardless of the cement type used. On the other hand, the presence of silica fume significantly improve the compressive strength of SMP superplasticized concrete at 4% dosage, and no substantial difference is observed when superplasticizer is used at dosage of 2%. Therefore, conclusion was made that superplasticizer significantly improves the strength of high strength concrete with presence of silica fume [6]. Development of strength superplasticizer (OPC) concrete and concrete containing fly ash [7] Found more beneficial effect if superplasticizer is added to lower grade fly ash as compared with higher grade mix. In addition, they observed that continuous curing is essential for strength development of fly ash concrete since they provide lower early strength than plain concrete.

2. Materials Used

Concrete is a composite of cement, aggregate (fine and coarse) and water. Sometimes, chemical or mineral admixtures are added in order to change the characteristics of concrete for certain applications. Since the materials are important in determining the quality of produced concrete, they should be properly selected and chosen before the beginning of the experiment.

2.1. Ordinary Portland Cement

The cement used in this study is a product from Cement Industries of Malaysia Berhad (CIMA), with a brand name blue lion. This type-I cement complies strictly with BS 12: 1991 where it is widely used in general construction, for example buildings, bridges and other precast concrete products. It is available in 50 kg bag.

2.2. Mixing Water

Water is important to ensure continuous hydration process.

Along the experiment, tap water is used for mixing and curing of concrete. The water must be free from reactive elements such as reactive ions and impurities to guarantee the quality of the concrete.

2.3. Fine and Coarse Aggregates

The fine aggregate used in this investigation is river sand. The size range from 150µm, 300 µm, 600 µm, 1.18 mm, 2.36 mm and 5 mm, with the specific gravity and water absorption of 2.46 and 1.5 respectively. Sieve analysis shows that the percentage passing 600µm is 26.76%. Coarse aggregate used in this study is granite with a maximum size of 20mm. Water absorption and specific gravity of the aggregate are 0.614% and 2.66 respectively. In addition, aggregates should be cleaned before mixing to wash away the fine particles that stick on the surface of the aggregate.

2.4. Superplasticizer

The superplasticizer used in this study is Glenium C380. It is a new superplasticizer, which not only suitable for prestressed concrete, but also for other types of concrete. One of its benefits is that it can improve both early and final strength. In addition, slump retention and workability of concrete also enhanced by using Glenium C 380 if compared with traditional superplasticizer.

3. Concrete Mix Proportion

In order to study the effect of superplasticizer on the properties of fresh and hardened concrete, seven mixes are prepared. After design calculation, the concrete of Grade 30 with water/cement required to obtain slump between ranges 60- 180 mm is 0.6. However, as the aggregate used in the experiment is in dry condition, the weight of mixing water had to be increased by the amount required for absorption by the aggregates. Hence, water/ cement ratio becomes 0.66 [7]. On the hand, when superplasticizer is added to the mixes, the slump becomes higher than 180 mm. As a result, 15% of water [2] is reduced until the water/ cement ratio is only 0.56. Therefore, two controls are used in this experiment for comparison purposes. Details of the mixes are given in table 1.

Table 1. *Mix Design Details.*

Sample	Dimension (mm) L×B×H	Concrete Mix with SP (Kg/m^3) to the Grade 30						
		Cement	Fine aggregate	Coarse aggregate	Water	SP	W/C	slump
		kg/m^3	kg/m^3	kg/m^3	kg/m^3	ml/m^3		mm
Control Mix M	150×150×150	340	965	865	190	-	0.56	45
Control Mix M1	150×150×150	340	965	865	225	-	0.66	125
MS1 400ml/100kg	150×150×150	340	965	865	190	1360	0.56	140
MS2 600ml/100kg	150×150×150	340	965	865	190	2040	0.56	155
MS3 800ml/100kg	150×150×150	340	965	865	190	2720	0.56	165
MS4 1000ml/100kg	150×150×150	340	965	865	190	3400	0.56	180
MS5 1200ml/100kg	150×150×150	340	965	865	190	4080	0.56	190

4. Results and Discussions

4.1. Effect of Superplasticizer on Setting Time of Concrete

Results for setting time test of concrete with different dosages of superplasticizer concrete is shown in Table 2. Figure 1 is graphs plotted to present the comparison of setting time of different dosage of superplasticizer with control mix.

Table 2. *Setting Time of Superplasticizer Concrete.*

Concrete Mix	Initial setting time (hours)	Final setting time (hours)
Control M	3:55	5:35
Control M1	4:30	6:10
400ml/100 kg of cement (MS1)	5:10	6:30
600ml/100 kg of cement (MS2)	6:10	7:45
800ml/100 kg of cement (MS3)	7:00	8:30
1000ml/100 kg of cement (MS4)	8:30	9:40
1200ml/100 kg of cement (MS5)	8:45	10:15

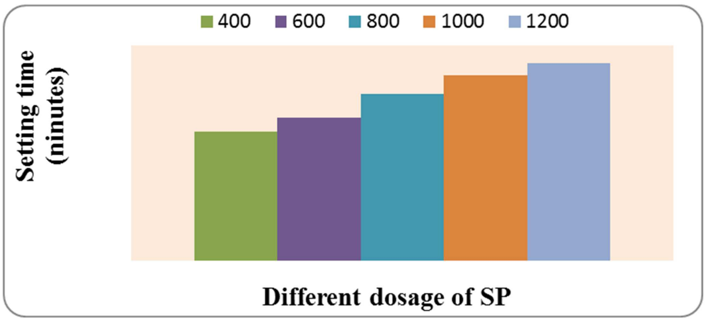

Figure 1. *Column graph for setting time of superplasticizer.*

Concrete with different dosages.

The graphs presented the setting time of earlier concrete containing superplasticizer in comparison to the control mixes. By observing the graphs the setting time is longer when either superplasticizer is added to the concrete. In term of dosage, higher dosage of superplasticizer tends to prolong the setting time. However, different mechanisms are shown by this superplasticizer. However, superplasticizer increases setting time through deflocculation by adsorption of negative charges on the cement particles so that they repel each other due to electrostatic force.

4.2. Effect of Superplasticizer on Compressive Strength

Compressive strength of concrete with different dosage of superplasticizer is shown in Table 3. This test is performed on 1, 3, 7 and 28 days. The values of compressive strength for the different dosage of superplasticizer are then shown as a graph in Figure 2.

Table 3. *Compressive Strength of Superplasticizer Concrete.*

Concrete Mix	Compressive strength in N/mm^2			
	1 day	3 days	7 days	28 days
Control (M) (plain concrete)	15.97	27	36.31	42.22
Control (M1) (plain concrete	12.75	23.23	29.99	35.29
400ml/100 kg of cement (MS1)	16.77	31.16	36.57	42.77
600ml/100 kg of cement (MS2)	20.05	34.18	42.92	44.61
800ml/100 kg of cement (MS3)	20.41	34.38	41.17	46.79
1000ml/100 kg of cement (MS4)	19.78	33.98	40.60	44.21
1200ml/100 kg of cement (MS5)	20.00	32.84	40.70	42.46

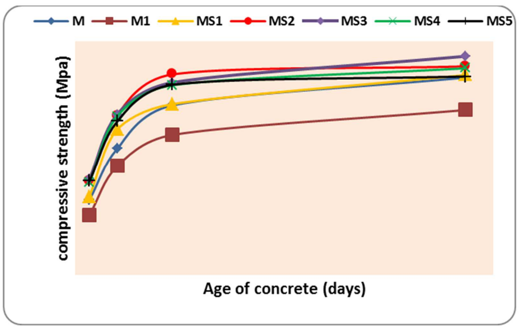

Figure 2. *Compressive strength of concrete with different dosages of SP.*

After conducting the experiment, graph of compressive strength versus age of concrete is plotted. From the graph, continuous strength gain for superplasticizer concrete admixture is observed by the increase in compressive strength with age. At early age (1- 7 days from casting), the rate of strength gain is high since the reaction between the cement particles and water is active. When time goes by, the rate become lower, and hence, the slope of curve for age 7 to 28 days is less steep compared with its early age.

When observe the effect of dosage of the admixture, superplasticizer concrete present different behaviours on the compressive strength of concrete. The increase in dosage will increase the compressive strength for all ages. Since addition of SP will provide more water for concrete mixing, not only the hydration process will not be disturbed, but, it is accelerated by the additional water from deflocculation of cement particles. Hence, increase in dosage will increase the entrapped water and promote hydration of cement.

Though increment in dosage of superplasticizer will enhance the compressive strength, there is still an optimum limit for the usage of admixture. When the dosages go beyond this limit, increase in dosage will only reduce the compressive strength. This phenomenon occur since over dosage of SP will cause bleeding and segregation, which will affect the cohessiveness and uniformity of the concrete. As a result, compressive strength will reduce if the used dosage is beyond the optimum dosage.

4.3. Effect of Superplasticizer on Water Absorption and Porosity

4.3.1. Water Absorption of Superplasticizer Concrete

The results for water absorption from 3 to 28 days on superplasticizer concrete are shown clearly in Table 4. These values are then used to plot the graphs as in Figure 3.

Table 4. *Water Absorption of Superplasticizer Concrete.*

Concrete Mix	Water Absorption of Superplasticizer Concrete (%)		
	3days	7days	28days
Control (Plain Concrete) M	5.13	4.95	4.49
Control (Plain Concrete) M1	5.65	5.34	4.92
400ml/100 kg of cement MS1	5.4	5.26	4.25
600ml/100 kg of cement MS2	5.2	5.16	4.12
800ml/100 kg of cement MS3	4.65	4.38	4.05
1000ml/100 kg of cement MS4	4.88	4.83	4.15
1200ml/100 kg of cement MS5	5.09	5	4.21

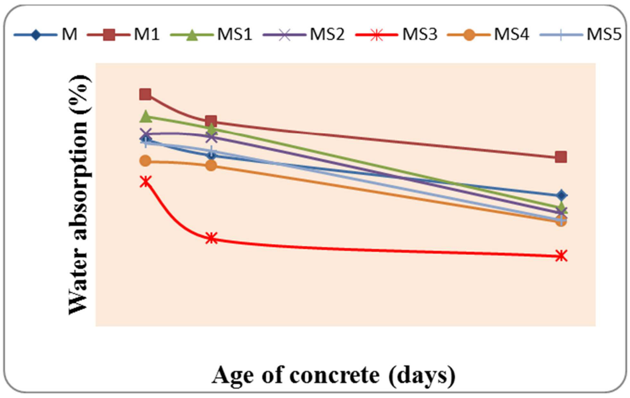

Figure 3. *Water absorption concrete with different dosages of SP.*

Optimum dosage of SP and retarder are found based on the lowest water absorption that they present at the age of 28 days. From the graphs, it can observe that optimum dosage for both of the admixtures is 800 ml/ 100 kg of cement. Dosage with lower or higher than this optimum value will increase the water absorption.

4.3.2. Porosity of Superplasticizer Concrete

The results for porosity from 3 to 28 days on superplasticizer concrete are shown clearly in Table 5. These values are then used to plot the graph as in Figure 4.

Table 5. *Porosity of Superplasticizer Concrete.*

Concrete Mix	Porosity of Superplasticizer Concrete (%)		
	3days	7days	28days
Control (Plain Concrete) M	13.46	11.95	11.54
Control (Plain Concrete) M1	15.48	13.85	13.23
400ml/100 kg of cement MS1	13.2	11.85	11.11
600ml/100 kg of cement MS2	12.36	11.68	10.65
800ml/100 kg of cement MS3	11.45	11.02	10.33
1000ml/100 kg of cement MS4	11.86	11.31	10.7
1200ml/100 kg of cement MS5	12.1	11.53	10.85

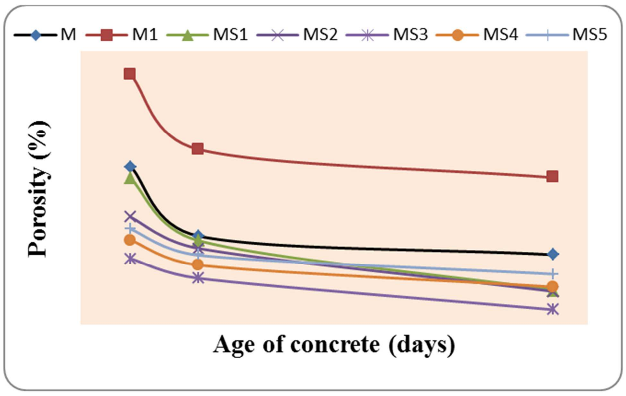

Figure 4. *Porosity of concrete with different dosages of SP.*

From the results, it is clear that both porosity and water absorption reduce with time. The reason for this phenomenon is that pore structure and size decreases when the pores are filled by the hydration product- calcium silicate hydrate. Since hydration process continues as long as there is reaction within the raw materials, further reduction in porosity and water absorption is expected for age of longer than 28 days.

Coming to the effect of dosage, the higher the dosage of superplasticizer, the lower the water absorption and porosity is. The reason for this observation is that increase of dosage will increase water provided for concrete lubrication. As a result, effectiveness of compaction increases due to increase of workability. However, there should be an optimum dosage that produces lowest water absorption and porosity. Further increase of dosage that higher than the optimum dosage not only will give no effect on the water absorption and porosity, but, on the other hand, increase their ability to absorption water due to higher porosity for the occurrence of bleeding and segregation.

4.4. Effect of Superplasticizer on Permeability

The results for permeability for plain concrete and concrete containing different dosage of superplasticizer are shown in Table 6. These values are then used to plot the graph as in Figure 5.

Table 6. *Permeability of Superplasticizer Concrete.*

Concrete Mix	Permeability of Superplasticizer Concrete (10^{-17} m^2)		
	3 days	7 days	28 days
Control (Plain Concrete) M	8.54	5.55	3.92
Control (Plain Concrete) M1	15	9.7	7
400ml/100 kg of cement MS1	9.7	6.1	3
600ml/100 kg of cement MS2	8.1	4.3	2.4
800ml/100 kg of cement MS3	4.6	3.4	2.1
1000ml/100 kg of cement MS4	7	5.2	2.9
1200ml/100 kg of cement MS5	7.8	5.5	3.4

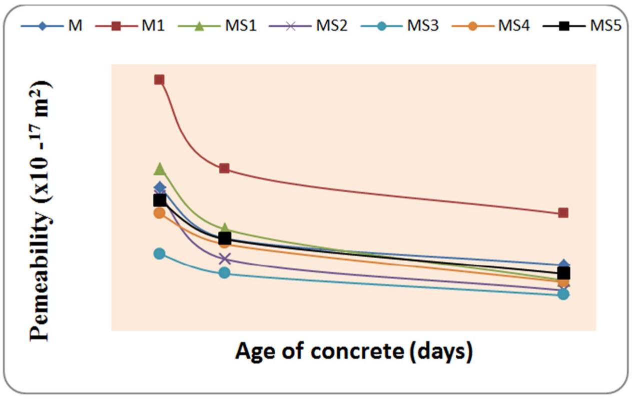

Figure 5. *Permeabilty of concrete with different dosages of SP.*

Permeability is the ease of fluid to flow through the concrete.The graphs show the permeability of concrete against age for different dosages of SP. From the graphs, the trend shown by permeability is similar to those trend obtained from water absorption and porosity, to the pore size and pore distribution of the concrete.

As expected, permeability decreases with age. This situation can be explained by reduction of pore size and pore size distribution due to the filling of hydration products. The longer the hydration process, the smaller the pores within the concretes are. The decrease of pore size will finally obstruct the ease of fluid to flow through it. Hence, mature concrete will have better resistance against aggressive ions and water compared with young concrete, which contain high amount of pores.

As in the case of water absorption and porosity test, increase of SP dosage will first reduce the permeability, as long as the dosage is not above the optimum value. Lowest permeability found in concrete with optimum dosage of SP of 800 ml/ 100kg. When the dosage is beyond this point, no reduction, but increase in permeability was found. The optimum dosage of SP is found based on the lowest permeability that they present at age 28 days. From the graphs, we can observe that optimum dosage for SP is 800 ml/ 100 kg of cement. Dosage with lower or higher than this optimum value will increase the permeability.

4.5. Effect of SP on Initial Surface Absorption (ISAT)

The results for initial surface absorption test are summarized in Table 7. The flow reading presented is at test point 2 hours since the flow is stable at this moment. These values are then used to plot the graph as shown in Figure 6.

Table 7. *Flow of Superplasticizer Concrete at 2 Hours.*

Concrete Mix	Flow of Superplasticizer Concrete Different Age (ml/m^2/s)		
	3 days	7 days	28 days
Control (Plain Concrete) M	0.12063	0.1023	0.0634
Control (Plain Concrete) M1	0.14995	0.11333	0.1001
400ml/100 kg of cement MS1	0.09044	0.07153	0.05763
600ml/100 kg of cement MS2	0.07833	0.06732	0.04361
800ml/100 kg of cement MS3	0.05123	0.04058	0.03315
1000ml/100 kg of cement MS4	0.07321	0.05621	0.04492
1200ml/100 kg of cement MS5	0.0981	0.07167	0.0543

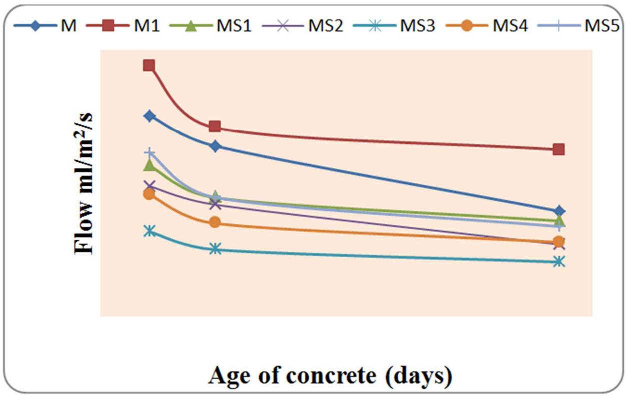

Figure 6. *Flow at 2 hours versus age of concrete for different dosages of SP.*

Since initial surface absorption depends on the voids that exist in the concrete, its trend and development are expected to be similar to the trend obtained from water absorption/ porosity and permeability tests. Within the test period (2 hours), the flow of the distilled water through the concrete samples reduces with time, which indicates that flow at 10 minutes is the fastest and the lowest flow is at 2 hours. In term of age, the same observation was obtained. Flow of the water reduces with age, where the highest flow value occurs at age 3 days, and lowest value derived at age 28 days. The reason for this phenomenon is that porosity of the concrete reduces with age as hydration process proceeds with time. Hence, the ease of the flow become lower and it takes more time for the water to flow though the desired distance.

As the dosage of the SP increases, the flow will reduce. The reason for this observation is because SP helps to accelerate the hydration process by providing more water for concrete lubrication. As a result, flow reduces with increase of dosage. However, if the optimum dosage is exceeded, pores in the concrete will increase due to less cohesiveness resulted from segregation and bleeding. Therefore, over dosage lead to higher flow of the distilled water through the concrete samples.

5. Conclusions

The characteristic behaviour of concrete was studied using different doses of superplasticizer. From the test results, the following conclusions are offered:

a) Setting time is enhanced when superplasticizer is added to the concrete.
b) Compressive strength is improved by superplasticizer for all ages compared with control.
c) Water absorption and porosity reduces when dosage of superplasticizer increases. However, beyond the optimum dosage, water absorption/ porosity increases with increase of superplasticizer dosage.
d) Permeability presents similar trend as water absorption/ porosity does, increase in dosage will increase the permeability, when the dosage exceeds optimum value.
e) Initial surface absorption test indicates that inclusion of superplasticizer able to reduce the flow due to lower porosity. Any dosage that beyond the optimum value, not only cannot improve the pore structure of concrete, on the other hand, increases the flow by producing less dense concrete.

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