

PROPERTIES OF FLOWING CONCRETE AND SELF-COMPACTING CONCRETE WITH HIGH-PERFORMANCE SUPERPLASTICISER

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ABSTRACT: *Flowing concrete (FC) and Self-Compacting concrete (SCC) are currently produced with sufficient amount of superplasticiser. However, it must be emphasized that flowing concrete need not to have the self-compacting capability. FC can also produced by having excess amount of water in the mix without any superplasticiser. Such a mix is prone to high bleeding and segregation. This paper discusses the results of an experimental investigation into the properties of flowing concrete and self-compacting concrete mixes having varying dosage of high-performance superplasticer. The properties investigated are workability, bleeding capacity, segregation potential, compressive and tensile strengths, and drying shrinkage. Flowing concrete had 465 kg/m³ of cement whereas the self-compacting concrete consisted of 350 and 135 kg/m³ of cement and fly ash, respectively. The workability was assessed using slump flow and box-differential height tests. The bleeding capacity for the flowing concrete was higher than that for the self-compacting concrete. The strength of both concrete types was found to increase when vibration was employed at the time of moulding of test specimens and the effect of vibration in strength was significant at later ages. Drying shrinkage was influenced by the mix compositions and superplasticiser dosage.*

KEYWORDS: Superplasticiser; Flowing concrete; Self-compacting concrete; Bleeding; Shrinkage

INTRODUCTION

The increase in the complexity of construction, intricate reinforcement details of modern day concrete structures and lack of trained construction workers have demanded a solution to the increasing problem related to uncompacted concrete. Apart from reducing the strengths of concrete, the lack of compaction influences the permeability of concrete, which in turn reduces the durability of concrete structures. A common world-wide durability problem in reinforced concrete structures such as steel reinforcement corrosion is due to the permeability of cover concrete to corrosion-inducing agents, namely carbon dioxide and chlorides.

The development of a special type of concrete, namely self-compacted concrete provides an opportunity to the contractors and altered the options open to the construction industry. The world-wide interest in the development of self-compacting concrete highlights the importance of this new type of concrete to modern day construction. The advances in admixture technology are no doubt helping the concrete producers to achieve their target with ease. Apart from increasing the quality of concrete structures produced, the use of self-compacting concrete reduces the construction cost, through minimizing the compaction effort and reducing the construction time. Gibbs (1) reported the prospects for self-compacting concrete.

The self-compacting concrete differs from conventional concrete in the following three characteristic features, namely, appropriate flowability, non-segregation, and no blocking

tendency. An increase in the flowability of concrete is known to increase the risk of segregation. Therefore, it is essential to have proper mix design.

Flowing concrete on the other hand is not necessarily self-compacting concrete but self-compacting concrete is a special type of flowing concrete. This paper is to reports the results of an investigation into the properties of flowing and self-compacting concretes. The parameters used in this study are dosage level of high-performance superplasticiser (Glenium 51) and effect of compaction. Since the conventional testing methods are not applicable to flowing concrete alternative test methods are needed to assess the properties of the freshly mixed self-compacting concrete and flowing concrete.

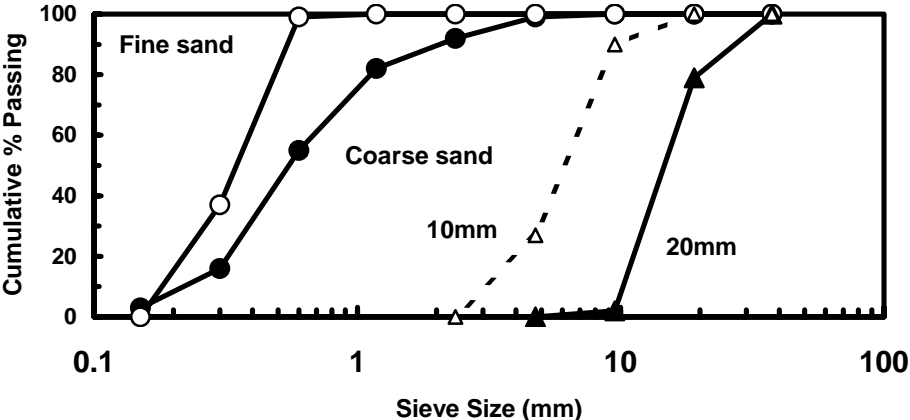


Figure 1: Particle Size Distribution for the fine and coarse aggregates

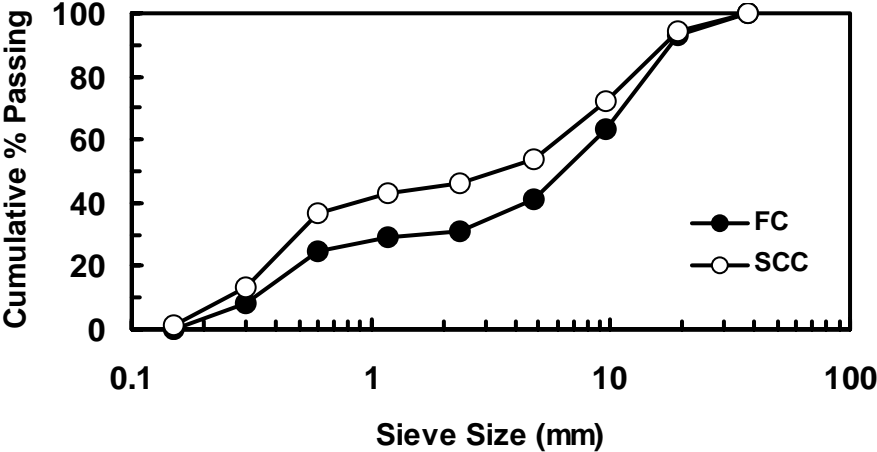


Figure 2: Particle Size distribution for combined aggregate in flowing concrete and self-compacting concrete mixes

EXPERIMENTAL DETAILS

Materials

General purpose Portland cement and low-calcium fly ash were used as binder materials in making the concrete mixes. Crushed river gravel having a maximum size of 20mm and 10mm were used in equal weight proportion combination as coarse aggregate. Napean river coarse sand and Botany fine sand were used as fine aggregate. Figure 1 shows the particle size

distribution for the fine and coarse aggregate. Figure 2 shows the combined grading curves for the aggregate mixes used for production of flowing and self-compacting concrete mixtures. The coarse and fine sands were mixed by equal weight basis.

The fine aggregate content was 32% and 47.6% of the total aggregate by weight in the flowing and self-compacting concrete mixes, respectively. The increase in the fine aggregate content increased the cohesiveness of the self-compacting concrete. The fine particle fraction below 0.30mm was 8% and 13% in the flowing concrete and the self-compacting concrete, respectively. High-performance superplasticiser (Glenium 51) was used the concrete mixes.

Table 1: Mix compositions for Flowing-Concrete and Self-Compacting Concrete

| Mix | Cement | Fly Ash | Water | Coarse aggregate | Fine aggregate | Super - Plasticiser |
|-----|--------|---------|-------|------------------|----------------|---------------------|
| FC | 465 | 0 | 195 | 1155 | 545 | Variable |
| SCC | 350 | 134 | 175 | 934 | 852 | Variable |

Mix compositions and mixing of concrete

Based on the preliminary investigation, the mix compositions as shown in Table 1 were selected to produce flowing concrete and self-compacting concrete mixes. The flowing concrete mix contained cement alone, whereas cement and fly ash were used in combination in the self-compacting concrete. The following mixing sequence was adopted for all concrete mixes produced. The coarse and fine aggregates were first placed in a free fall laboratory-size motorized concrete mixer. While the dry mixing is progress, a part of the mixing water, just sufficient to wet the aggregates, was added. Then, the cement and fly ash (if needed) were added, followed by 80% of the mixing water. The ingredients were wet-mixed for 2 minutes and finally the balance water mixed with superplasticiser was added. The wet-mixing was continued for 30 seconds and then the mixing was halted for 2 minutes. Finally, the mixing was continued for another two minutes.

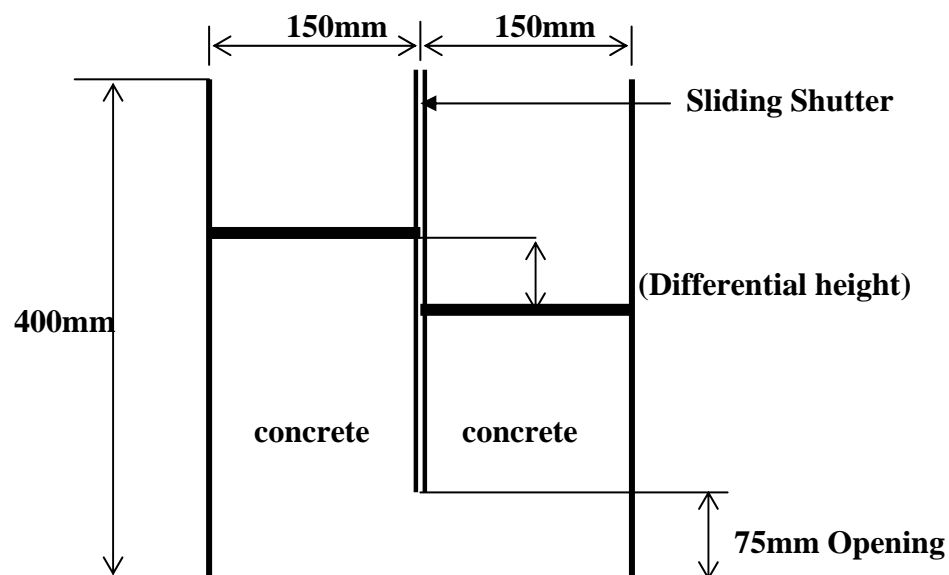


Figure 3: Box differential height apparatus for self-compacting concrete

Workability testing for self-compacting concrete

Slump flow test

Freshly mixed concrete was subjected to standard and non-standard tests to evaluate the workability, bleeding capacity, and segregation potential. Standard slump cone (200mm by 100mm by 300mm) was filled with concrete and the mean diameter of the spread (known as slump flow) was measured on lifting the cone.

Box differential height

A box differential height test was carried out to evaluate the workability of concrete. The apparatus (Figure 3) consists of 300mm by 300mm by 400mm box with a movable partition at the centre. The freshly mixed concrete was filled in one half (150mm by 150mm by 400mm) of the box and then the partition was pulled to provide 75mm high opening. The fresh concrete flows through the opening into the empty section of the box. Once the flow was stabilized, the differential height was measured. The test was repeated and the average of two results is reported here as the differential height. The box apparatus can be modified to accommodate 10mm diameter reinforcing bars at 38mm spacing at the opening location. The presence of bars retards the concrete flow, thus increasing the differential height measured.

Segregation test

Flowing nature of concrete is prone to segregation when allowed to fall through a height. In this test, segregation of fresh concrete was measured by dropping the fresh concrete from 600, 800 and 1000mm heights using the modified compacting factor apparatus. The concrete collected in a standard 150mm diameter by 300mm high cylinder was allowed to harden in the mould. After 24 hours of casting, the concrete was removed from the cylinder and sliced into three 100mm high sections. The concrete density of these sections was determined to assess the segregation tendency of concrete.

Bleeding test

The bleeding of concrete was determined according to Australian Standard AS1012.6. The bleeding water from the mix was collected continuously to assess the bleeding capacity of concrete.

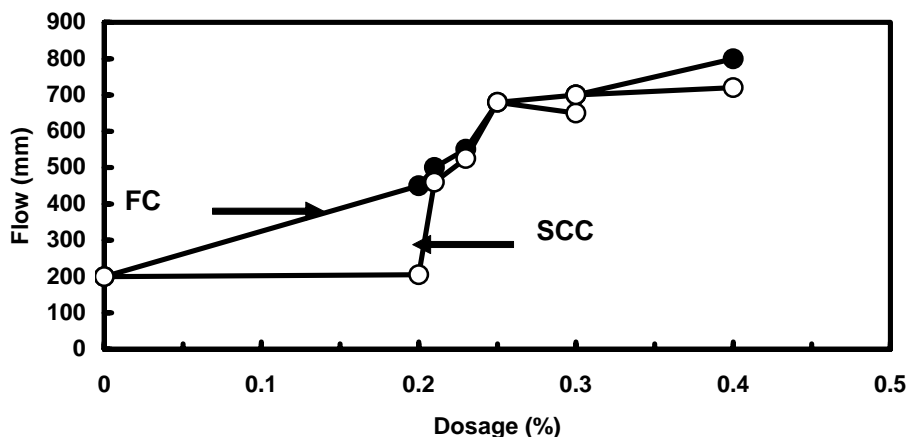


Figure 4: Effect of superplasticiser dosage on slump-flow for flowing concrete and self-compacting concrete

Testing of hardened concrete

Standard cylinders were cast from fresh concrete and the test cylinders were demoulded after 24 hours. They were placed in a water bath, maintained at a temperature of 20°C. Cylinder strength in compression at the ages of 3, 7 and 28 days and in-direct tensile strength at 28 days were carried according to AS 1012. The drying shrinkage of concrete was monitored up to 8 weeks of drying on 100mm by 100mm by 300mm long prisms. The shrinkage specimens were water cured for 7 days prior to drying in the uncontrolled laboratory environment (mean temperature of 20°C and 65% R.H.).

RESULTS AND DISCUSSION

Effect of superplasticiser dosage on slump flow

Figure 4 shows the change in slump flow in relation to the superplasticiser dosage for flowing and self-compacting concretes. As expected the slump flow was increased with the increase of the superplasticiser dosage. Both concretes had nearly the same flow values when the superplasticiser dosage was more than 0.25%. For the slump flow range from 500 to 700 mm, the superplasticiser (Glenium 51) dosages were 0.39% and 0.54% for the self-compacting concrete. However, the dosages for the flowing concrete were 0.21% and 0.30%. This difference may be due to the binder material types as well as to the amount of free water in these concrete mixes. The free water content in the self-compacting concrete was 175 kg/m³, compared to 195 kg/m³ in the flowing concrete.

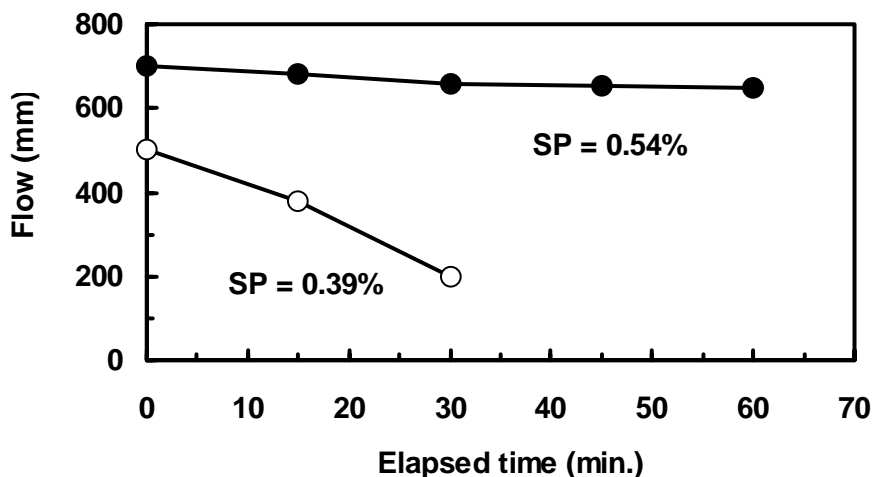


Figure 5: Effect of elapsed time on slump-flow for self-compacted concrete

Workability of self-compacting concrete

On the basis of the above study two superplasticiser dosages (0.39% and 0.54%) were used for self-compacting concrete. Figure 5 shows the slump flow loss with elapsed time for self-compacting concrete as affected by the superplasticiser dosage. As expected the slump flow gradually dropped from 700mm to 650mm in 60 minutes for the mix with higher superplasticiser dosage. When the initial flow was 500mm due to reduced dosage of 0.39%, the flow dropped from 500mm to 200mm within 30 minutes. The results suggest that the superplasticiser used is capable of maintaining workability.

Figure 6 shows the differential height variation with elapsed time as affected by the presence of reinforcing bars obstruction across the box opening. The results show that the differential height increased as the elapsed time was increased due to gradual stiffening process. When

the reinforcing bars were introduced across the opening, the differential the differential height was increased. With progress of setting of concrete, the effect of reinforcing bars on the workability of self compacting concrete is marginally affected. Both slump flow and differential height results indicate that stiffening of concrete had reduced the flow of self-compacting concrete. However, it is not possible to establish any relationship between slump flow and differential height.

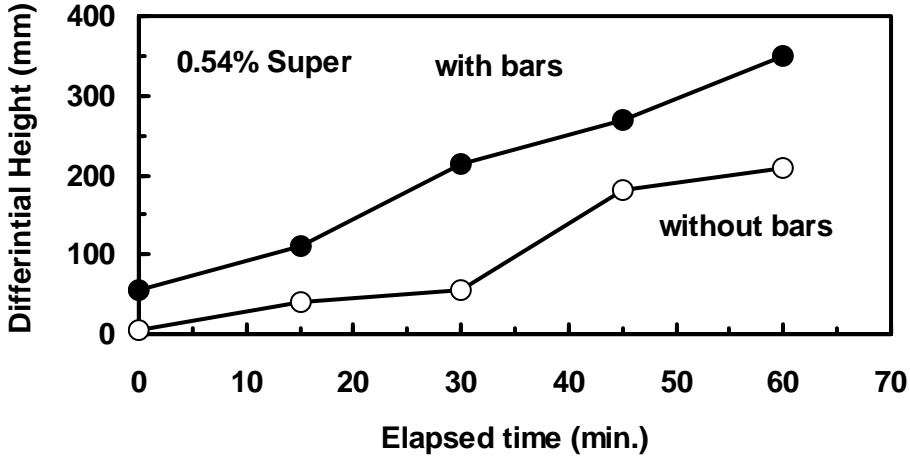


Figure 6: Effect of elapsed time on differential height for self-compacted concrete

Workability of flowing concrete

Figure 7 shows the slump flow loss with elapsed time for flowing concrete with the superplasticiser dosages of 0.21% and 0.30%. The initial slump flow was increased from 500mm to 700mm due to the increased superplasticiser dosage from 0.21% to 0.30%. The slump flow was reduced with the increase of the elapsed time. The slump flow loss was 60mm and 180mm after 15 minutes for the lower and higher superplasticiser dosages, respectively. However, from 15 to 60 minutes, the respective flow losses were 140mm and 120mm, indicating that the stiffening process is only marginally influenced by the superplasticiser dosage.

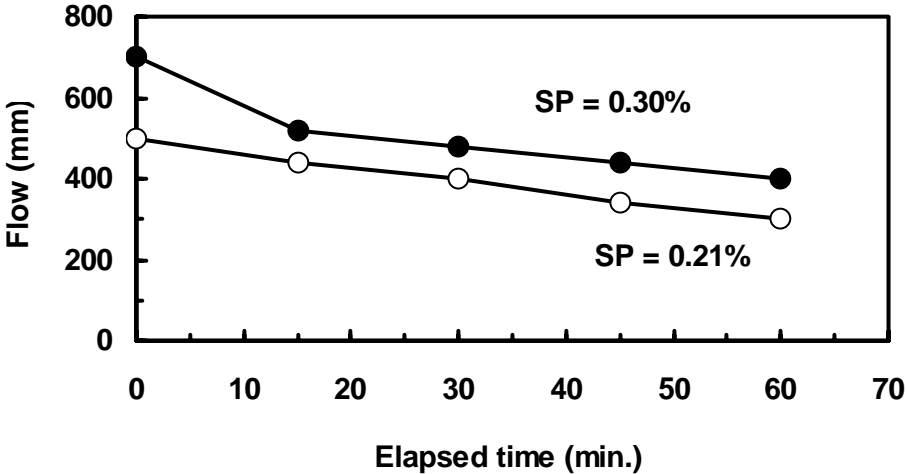


Figure 7: Effect of elapsed time on slump-flow for flowing concrete

The slump flow for the flowing concrete mixes with the superplasticiser dosage of 0.21% and 0.30% were 500mm and 700mm, respectively. Corresponding values for the differential heights were 50 and 130mm without the presence of reinforcing bars. With the presence of reinforcing bars, flowing concrete with 0.30% superplasticiser was failed to flow through the opening. The flowing concrete with 0.21% superplasticiser showed the differential height of 300mm with the presence of bars. However, this concrete failed to flow after 15 minutes with and without the presence of the bars.

Figure 8 shows the differential height variation with elapsed time for flowing concrete having 0.30% superplasticiser without the bars. Even after one hour, the flow property of concrete was maintained in the absence of any obstruction.

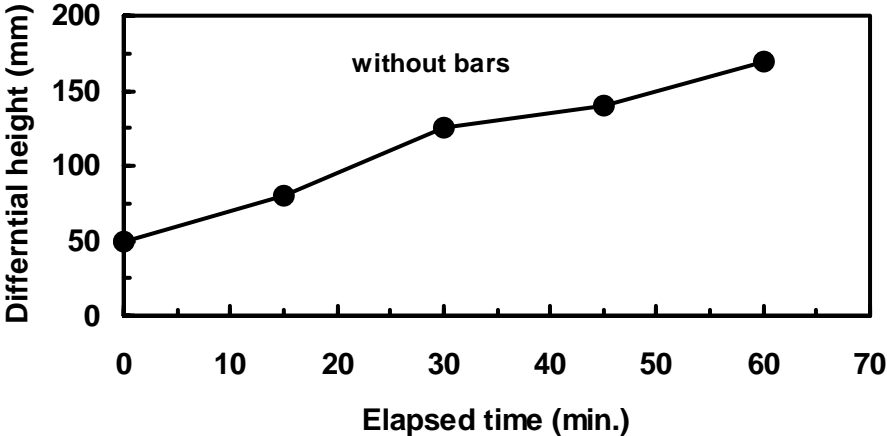


Figure 8: Effect of elapsed time on differential height for flowing concrete

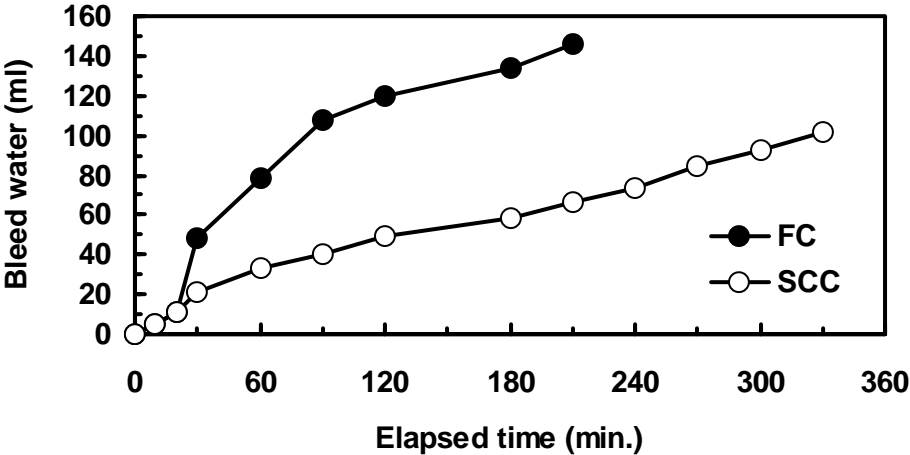


Figure 9: Bleeding capacity of flowing concrete ad self-compacting concrete

Bleeding of concrete

Figure 9 shows the bleeding process for flowing and self-compacting concretes, having 0.30% and 0.54% of superplasticiser, respectively. Flowing concrete although it has the lowest superplasticiser dosage showed high rate of bleeding compared to the self-compacting concrete. The low bleeding rate for the self-compacting concrete may be due to the combined effect of the presence of fly ash and low water content. Quality of fly ash is also found to

influence the bleeding capacity of self-compacting concrete (2). The results also show that the bleeding rate for the self-compacting concrete remained unchanged even after 5 hours of elapsed time. However, the rate of bleeding for the flowing concrete was reduced with the elapsed time although very high bleeding rate was observed for the first 90 minutes.

Table 2: Effect of Falling on Density (kg/m³) for Flowing and Self-Compacting Concretes

| Section | Flowing Concrete (0.30%SP) | | | Self-compacting Concrete (0.54%SP) | | |
|--------------|----------------------------|-------|--------|------------------------------------|-------|--------|
| | 600mm | 800mm | 1000mm | 600mm | 800mm | 1000mm |
| Top | 2365 | 2355 | 2385 | 2370 | 2350 | 2330 |
| Middle | 2370 | 2395 | 2380 | 2335 | 2350 | 2365 |
| Bottom | 2345 | 2335 | 2365 | 2325 | 2365 | 2320 |
| Top - Bottom | -20 | 20 | 20 | 55 | -15 | 10 |

Segregation of concrete

In order to evaluate the segregation tendency, the concrete mixes was allowed to fall through heights of 600, 800 and 1000mm into standard cylinder moulds. The hardened concrete cylinders were sliced into three equal sections on the removal from the moulds to study the density variation due to possible segregation. Table 2 summarizes the results obtained with flowing concrete and self-compacting concrete using three identical cylinders. In general, the top sections of the cylinders had marginally higher density than the corresponding bottom sections of the cylinders. It can be concluded that the test conducted failed to show any segregation risk for both types of concrete although bleeding rate was different as discussed earlier.

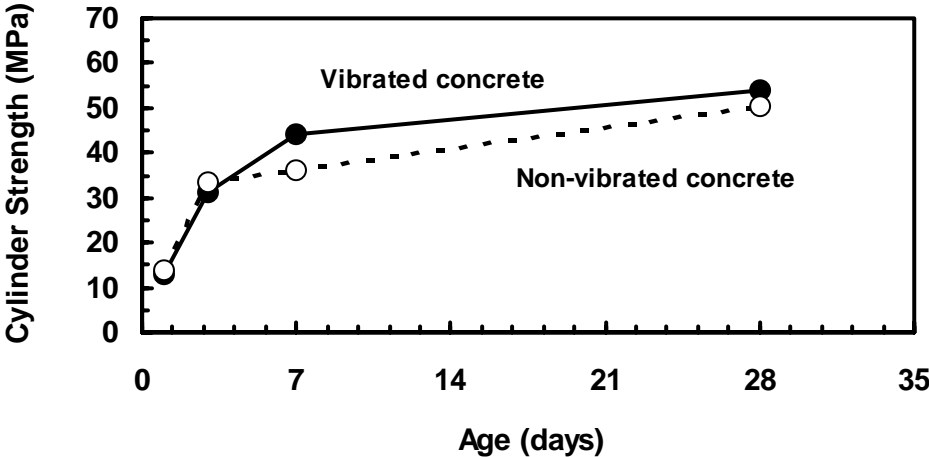


Figure 10: Effect of compaction on cylinder strength for flowing concrete (0.30%SP)

Effect of Compaction on Compressive Strength

Figures 10 and 11 show the development of cylinder strength with age up to 28 days for flowing concrete and self-compacting concrete, respectively. The results show that the early age is marginally affected as the result of applied vibration during moulding the test cylinders. Vibrated concrete at the ages of 7 and 28 days were noticeably higher than the corresponding non-vibrated concrete. The cylinder strength at 28 days for non-vibrated self-compacting concrete with 0.54% superplasticiser dosage was 40MPa compared to 56MPa for the vibrated concrete. The self-compacted concrete with the superplasticiser dosage of 0.39%, the 28-day

strength for non-vibrated concrete was 31.6MPa compared to 54.2MPa for the vibrated concrete. These results suggest that the compressive strength of matured self-compacting concrete is considerably improved with additional vibration at the time of placing.

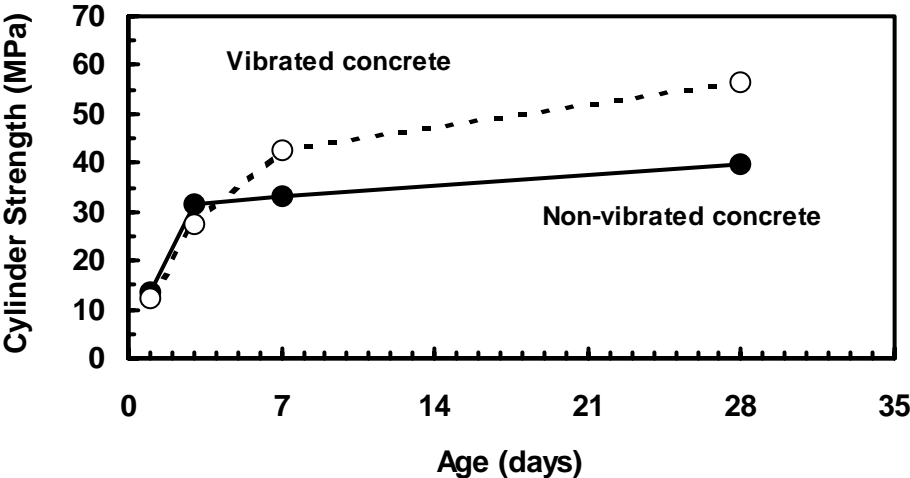


Figure 11: Effect of compaction on cylinder strength for self-compacting concrete (0.54%SP)

Effect of Compaction on Tensile Strength of Flowing and Self-Compacting Concretes

Table 3 summarizes the tensile strength for vibrated and non-vibrated flowing and self-compacting concretes at the ages of 7 and 28 days. Both concrete types showed improvements in tensile strength with the age of concrete. Vibration at the time of moulding the test specimens resulted in noticeable increases in the tensile strength for both concrete types. For the vibrated concretes, the ratios of tensile to compressive strengths were 0.101 and 0.070 for the self-compacting concrete and flowing concrete, respectively with the corresponding maximum superplasticiser dosage. The improved tensile strength for self-compacting concrete is also reported by Gibbs (1).

Table 3: In-direct Tensile strength of Flowing and Self-Compacting Concrete

| Age (days) | Flowing Concrete (0.30%SP) | | Self-compacting Concrete (0.54%SP) | |
|------------|----------------------------|----------|------------------------------------|----------|
| | Non-vibrated | Vibrated | Non-vibrated | Vibrated |
| 7 | 3.43 | 4.02 | 3.53 | 3.71 |
| 28 | 3.84 | 4.11 | 4.28 | 4.60 |

Table 4: Drying Shrinkage (microstrains) of Flowing and Self-Compacting Concrete

| Age (days) | Flowing Concrete | | Self-compacting Concrete | |
|------------|------------------|----------|--------------------------|----------|
| | 0.21% SP | 0.30% SP | 0.39% SP | 0.54% SP |
| 14 | 203 | 277 | 227 | 182 |
| 28 | 335 | 355 | 324 | 281 |
| 56 | 375 | 430 | 382 | 313 |

Drying Shrinkage of Flowing and Self-Compacting Concretes

Drying shrinkage increased gradually with a decreasing rate for all concrete mixes with the increase in the drying time. Table 4 summarizes the drying shrinkage results for both flowing concrete and self-compacting concrete after drying periods of 14, 28 and 56 days. The 56-day

drying shrinkage for the flowing concrete was increased from 375 microstrain to 430 microstrain when the superplasticiser dosage was increased from 0.21% to 0.30%. However, 56-day drying shrinkage for self-compacting concrete was decreased from 382 microstrain to 313 microstrain when the superplasticiser dosage was increased from 0.39% to 0.54%. The results failed to indicate any clear influence of superplasticiser dosage on

CONCLUSIONS

Based on the experimental studies on the properties of flowing concrete and self-compacting concrete the following conclusions could be made:

1. Bleeding capacity for flowing and self-compacting concretes is influenced by the superplasticiser dosage.
2. Although significant difference in bleeding capacity was noted between flowing and self-compacting concretes, no noticeable segregation was observed between these concretes, using the falling concrete test method.
3. Flowability of self-compacted concrete is reduced with elapsed time, superplasticiser dosage and presence of steel reinforcement.
4. Vibration found to increase the later age strength for both flowing and self-compacting concrete.
5. Mix proportions, superplasticiser dosage and binder material type used is responsible for the variation in the concrete properties of flowing and self-compacting concretes. Therefore, proper mix design is essential to optimize the performance of both flowing and self-compacting concrete.

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