Properties of Self-Compacting Concrete with Different Sources of Coarse Aggregates

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Abstract. Aggregate size and its source are crucial for concrete properties. This paper presents the evaluation of the properties of self-compacting concrete (SCC) which mixed with coarse aggregate from different sources. Coarse aggregate from three sources which are commonly available in Vientiane Capital, Mekong River (MK), Ngum River (NG) and Crushed Mountain Stone (MT) were used for this study. Six different mixed proportions with two maximum aggregate size 19mm and 12.5mm for each aggregate source were prepared. Ordinary Portland Cement Type I and Fly ash class C were used as binders. The replacement ratio of fly ash to cement was fixed at 20% and w/p ratio was 0.36. Sika Viscocrete-3180MR was used as water reducing admixture with 0.95% by weight of binders. The results show that, for the fresh concrete properties, the coarse aggregate with maximum size of 12.5mm from Mekong River is the most suitable aggregate comparing to other sources. For the hardened concrete with 28-day curing, the highest compressive strength is the mixed proportion MK12 for aggregate size 12.5mm. As seen, the coarse aggregate with 12.5mm of Mekong River is the most appropriate aggregate among three sources which has a flow-ability and higher compressive strength.

Keywords: self-compacting, aggregates, binders, flow-ability, compressive strength.

1. Introduction
Self-Compacting Concrete (SCC) is a flowing concrete mixture that is able to consolidate and completely filling in formwork under its own weight without the vibration during the placing of concrete, even in the presence of congested reinforcement. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete. SCC was first introduced in the late 1980’s by Japanese researchers. SCC is highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding [1]. Self-compacting concrete offers a rapid rate of concrete placement, with faster construction times and ease of flow around congested reinforcement. The fluidity and segregation resistance of SCC ensures a high level of homogeneity, minimal concrete voids and uniform concrete strength, providing the potential for a superior level of finish and durability to the structure. SCC is often produced with low water-cement ratio providing the potential for high early strength, earlier demolding and faster use of elements and structures. The elimination of vibrating equipment improves the environment on and near construction and precast sites where concrete is being placed, reducing the exposure of workers to noise...
and vibration. The improved construction practice and performance, combined with the health and safety benefits make. SCC is a very attractive solution for both precast concrete and civil engineering construction. EFNARC has published their “Specification & Guidelines for Self-Compacting concrete” which, at that time, provided state of the art information for producers and users [2]. Researchers have set some guidelines for mixture proportioning of SCC, which include i. reducing the volume ratio of aggregate to cementitious material [3], [4], ii. increasing the paste volume and water-cement ratio (w/c), iii. carefully controlling the maximum coarse aggregate particle size and total volume; For SCC, it is generally necessary to use super-plasticizer in order to obtain high mobility. Natural aggregates is the major incidents in concrete and its properties affected to concrete properties. Some researchers have proposed a mixture proportioning system for SCC [5]. The maximum coarse aggregate particle size and total volume are essential to the rheological characteristics of SCC mixes. This study is being carried out to evaluate of the properties of self-compacting concrete (SCC) which mixed with coarse aggregate from different sources in Vientiane, Lao PDR.

2. Experimental details

2.1 Materials and mix proportions

Ordinary Portland cement (OPC) having a specific gravity of 3.13 is used for all concrete mixtures. Fly ash, class F, having a specific gravity of 2.0 is used as mineral admixture. High performance superplasticizer (SP), Sika Viscocrete-3180MR is used as water reducing admixture. Table 1 shows the physical properties of aggregates for this experiment. Three different sources of coarse aggregates are used in this study, Mekong River, Ngum River, and Crushed Mountain and the fine aggregate is river sand. All mixed proportion use the same fine aggregate. These aggregates conform to ASTM C33, standard specification concrete aggregates.

Table 1. Physical properties of standard aggregates

| Aggregate type | Unit weight (g/cm³) | Absorption (%) | Specific gravity | Los Angeles | Flakiness Index | F.M |
|----------------|--------------------|----------------|------------------|-------------|-----------------|-----|
| Mekong River stone (MK) | 1.63 | 1.65 | 0.81 | 2.56 | 26.8 | 36.61 | - |
| Ngum River stone (NG) | 1.53 | 1.51 | 1.25 | 2.55 | 36.5 | 14.96 | - |
| Crushed Mountain Stone (MT) | 1.36 | 1.53 | 0.6 | 2.66 | 22.35 | 41.43 | - |
| River sand | 1.55 | - | 1.42 | 2.38 | - | - | 2.6 |

Table 2. Mixed proportions for different combination

| Designation of mixed proportion (Mixed ID) | Total binder (kg/m³) | Cement C (kg/m³) | Fly ash F.A (kg/m³) | W (kg/m³) | W/P ratio | SP % | SP (l/m³) | Coarse Aggregate “G” (kg/m³) | Sand “S” (kg/m³) | G/S ratio |
|-----------------------------------------|----------------------|------------------|---------------------|------------|------------|--------|----------|---------------------------|-----------------|-----------|
| MK19 | 458 | 382 | 76 | 147 | 0.36 | 0.95 | 4.12 | 661 | 879 | 40/50 |
| MK12 | 458 | 382 | 76 | 147 | 0.36 | 0.95 | 4.12 | 661 | 879 | 40/50 |
| NG19 | 458 | 382 | 76 | 145 | 0.36 | 0.95 | 4.12 | 606 | 904 | 40/50 |
| NG12 | 458 | 382 | 76 | 145 | 0.36 | 0.95 | 4.12 | 606 | 904 | 40/50 |
| MT19 | 473 | 394 | 79 | 154 | 0.36 | 0.95 | 4.25 | 614 | 915 | 40/50 |
| MT12 | 473 | 394 | 79 | 154 | 0.36 | 0.95 | 4.25 | 633 | 907 | 40/50 |

The mixed proportions in this study are shown in Table 2. Six series of mixed proportion of concrete were prepared with three different sources of coarse aggregate. The maximum of coarse aggregate size for each source is 19mm and 12.5mm. MK19, MK12, NG19, NG12, MT19, and MT12 are the samples
that used the maximum size of coarse aggregate 19mm and 12.5mm for the coarse aggregate from Mekong River (MK), Ngum River (NG) and Crushed Mountain Stone (MT) respectively. Following guidelines of EFNARC for rheological properties of concrete in fresh state and using ACI 273R-07 method of mix design as reference, initial mix design was carried. The replacement ratio of fly ash to cement is 15% by weight of binders for all mixed proportions. Dosage of super plasticizer (SP) is 0.95% by weight of binders. As shown in the table, the ratio of coarse aggregate to fine aggregate is fixed at 40/50 and water powder ratio is 0.36.

2.2 Sample preparation and Testing Method
After testing the properties of mixing materials which shown in table 1, all designation mixed proportions as shown in table 2 were mixed one by one respectively. After mixing, the investigation of fresh concrete properties of self-compacting concrete were carried. The slump flow test is used to assess the horizontal free flow of SCC in the absence of obstructions. On lifting the slump cone, filled with concrete, the concrete flows. The average diameter of the concrete circle is a measure for the filling ability of the concrete. The time T500 is a secondary indication of flow. It measures the time taken in seconds from the instant the cone is lifted to the instant when horizontal flow reaches diameter of 500mm. The flow ability of the fresh concrete can be tested with the V-funnel test, whereby the flow time is measured. The funnel is filled with about 12 liters of concrete and the time taken for it to flow through the apparatus is measured, the flow time will increase significantly. According to guidance of EFNARC [2], a funnel test flow time less than 6s is recommended for a concrete to qualify for an SCC. The passing ability is determined using the L-box test10. The vertical section of the L-Box is filled with concrete, and then the gate lifted to let the concrete flow into the horizontal section. The height of the concrete at the end of the horizontal section indication of passing ability. The specified requisite is the ratio between the heights of the concrete at each end or blocking ratio to be 0.8-1.0. Self-compacting concrete is characterized by filling ability, passing ability and resistance to segregation. Many different methods have been developed to characterize the properties of SCC. No single method has been found until date, which characterizes all the relevant workability aspects, and hence, each mix has been tested by more than one test method for the different workability parameters. Table 3 gives the recommended values for different tests given by different researchers [2], [6], for mix to be characterized as SCC mix. For hardened concrete, six cylindrical specimens with dimension of 15x30 cm for compressive strength were cast for 28-day curing age and six specimens with the same dimension were cast for tensile strength test.

Table 3. Recommended limits for different properties [2]

| Property           | Range     |
|--------------------|-----------|
| Slump flow Diameter| 650-800mm |
| $T_{500}$          | 2-5 sec   |
| V-funnel           | 6-12 sec  |
| L-Box $H_2/H_1$    | 0.8-1.0   |

3. Results and Discussion
3.1 Properties of fresh concrete
The fresh properties of each mix were evaluated. The tests were carried out to determine the effect of maximum size and sources of coarse aggregate on the filling ability, passing ability, and segregation resistance of SCC. The rheological characteristics of mixes MK19, MK12, NG19, NG12, MT19, and MT12 are discussed as below. Figure 1 shows the results of slump flow tests. The value of slump flow represent the distance of horizontal free flow. As shown in the figure, almost mixed proportions for 19 and 12.5mm particle size aggregate, slump flow characteristics are between 650-750 mm, which satisfy the EFNARC requirement, 650-800mm; except, MT12, which is lower than 650mm. Thus, all the mixes are assumed to have good consistency and workability from the filling ability point of view. MK12 is
4% free flow better than NG12. However, the mix with crushed mountain stone show the wide range of variation. This variation illustrates the effect of the shape of coarse aggregate variables on filling ability of SCC mixes.

The value of T500 represent the time required for the concrete flow to reach a circle with a 500mm diameter as shown the results in Figure 2. The results of slump flow in figure 1 almost consistent. However, the results of T500 in figure 2 is vary. If the passing time is longer means the flow rate is slower. As seen in the figure 2, only two mixes, MT19 and NG12 are satisfy EFNARC requirement which ranges 2-5 sec. Some mixes for both, 12.5mm and 19mm maximum coarse aggregate size mixed, the flow rate is longer than requirement. This vary range of flow rate may affected by combination of size and shape of the aggregate. However, if time passing of T500 is greater than 5 seconds, those mixtures generally considered a high viscosity SCC which is required for resistance of segregation. This variation illustrates the effect of coarse aggregate variables on the filling ability of SCC mixtures. This agrees with the study carried out by Krishna1 et al [7] and Guru Jawahar et al [8].

The L-Box is used to measure the passing and filling ability of SCC mixes. The value of H2/H1 represent the blocking ratio (BR). The L-Box test results are shown in Figure 3. The results show that the mixes with 12.5mm maximum size of coarse aggregate give values of (BR) lower than the mixes with 19mm maximum size of coarse aggregate. The smaller size presents the lower blocking ratio. It is corresponded to the study by Khaleef et al [9]. This is due to the tendency of the mixes with larger maximum size of aggregate to jam the flowing, while the mixes with the smaller maximum size of coarse aggregate will flow freely without stopping. Almost of mixed proportions are satisfy EFNARC requirement which ranges the (BR) from 0.8-1.0; except, MT12.

The V-Funnel is used to measure filling ability by measuring the flow rate of SCC mixtures. The test results of V-funnel are shown in Figure 4. The results reveal the influence of the maximum size of
coarse aggregate on the flowing time. It can be seen from the figure, the larger maximum size of coarse aggregate leads to an increase in the flow time. From the results, the flow time of the mixes with 12.5mm maximum size of coarse aggregate is, 20% by average, faster than the mixes with 19mm maximum size of coarse aggregate. Almost of the mixtures are satisfy EFNARC requirement which ranges from 6-12 sec; except, NG12 which is the natural river aggregate with maximum coarse aggregate size of 12.5mm. The flow rate of NG12 is fastest comparing to the other mixes. Due to the shape of aggregate from Ngum River (NG) is round and smooth.

3.2 Properties of harden concrete

From the test results presented in Figure 5 and Figure 6, it can be noticed that the compressive strength and tensile strength of the mixes with 12.5mm maximum size of coarse aggregate and the mixes with 19mm maximum size of coarse aggregate give the same tendency. The average compressive strength of the mixture with 12.5mm maximum size of coarse aggregate is almost the same with the mixture with 19mm maximum size of coarse aggregate as shown in Figure 5. Similarly, the tensile strength of the mixture with 12.5mm maximum size of coarse aggregate is almost the same with the mixture with 19mm maximum size of coarse aggregate as shown in Figure 6.
Due to the Self-compacting concrete (SCC) is able to flow under its own weight and does not require any external vibration for compaction. Due to this highly workable concrete that can flow under its own weight through restricted sections without segregation and bleeding. It is sufficiently fill voids without tending to segregation resulted in a higher bonding strength in the interface transition zone (ITZ) around the aggregate particles. This is in agreement with Gencel et al [10]. The tensile strength test results of SCC in this study, by average, obtain 10% of compressive strength. The results show that tensile strength of SCC is commonly same as normal concrete by obtaining 10% of compressive strength.

4. Conclusion
In this study, properties of self-compacting concrete (SCC) with different sources of mixing coarse aggregate have been investigated. The conclusions derived from this study are summarized as follows:

1. The coarse aggregate with maximum size of 12.5mm and 19mm from Mekong River show the better rheological characteristics for the filling ability, passing ability. The 12.5mm of maximum aggregate size from Mekong River is the most suitable aggregate comparing to other sources.
2. The highest compressive strength is the mixed proportion MK12 for aggregate size 12.5mm. The tensile strength obtained 10% of compressive strength.
3. The coarse aggregate with 12.5mm of Mekong River is the most appropriate aggregate among three sources which has a flow-ability and higher compressive strength.

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