Cost Effective Solution For Self-Compacting Concrete Technology

Nguyen T. Nien, Dang H. Minh

Abstract: Although self-compacting concrete (SCC) has excellent applicability for elements with complicated shapes and congested reinforcement, its supply cost could be two to three times of that of conventional concrete depending on the composition of the mixture and the quality control of concrete producers, which in turn might limit the applications to general construction. In this paper, the authors proposed the cost effective solution for SCC technology involving the industrial sand usage with application of combination-type for proportioning SCC. The advantages of industrial sand usage are two-fold: firstly this sand can be manufactured with the customized fine content, which can play a role to increase the powder content, and secondly the replacement of natural sand could relieve the scarcity of this material. SCC using industrial sand of strength class 30MPa was successfully designed in this study. Not only were the rheological properties in agreement with guideline and recommendation for SCC, but also the mechanical properties including compressive strength, flexural strength, splitting tensile strength and elastic modulus comply with the one prescribed in Eurocode for this type of concrete strength class. Besides, the cost analysis pointed out that this type of SCC has a 20% lower price on the basis of volume 1m$^3$ in comparison with the conventional SCC.

Index Terms: natural sand, industrial sand, self-compacting concrete-SCC, powder-type SCC, combination type SCC,

1. INTRODUCTION

Self compacting concrete (SCC) was first developed in Japan in 1986 as a quality assurance concept to address the issues like long production times, unhealthy work environment in cast in situ concrete technology [1]. The SCC can flow through and fill the gaps of reinforcement and corners of moulds without any need for vibration and compaction during the placing process [2]. Though the concept was thought to be a tool to enhance long-term durability of structures having members with congested reinforcements, the excellent user-friendly characteristics of SCC are of great attraction today in traditional construction industry also [3]. Although the use of SCC has many technical, social, and overall economic advantages, its supply cost could be two to three times of that of conventional concrete depending on the composition of the mixture and the quality control of concrete producers. Such a high premium has somehow limited SCC applications to general construction. In France [4], the cost of SCC is 50–100% higher than normal concrete, and to reduce this cost in general building construction, self-leveling concrete has been proposed, at a cost only 12% higher than that of normal concrete. Or in Singapore [5], because all mix ingredients are imported from overseas, the cost of supplying SCC is about 150% higher than normal concrete. And currently, in Vietnam cost of 1m$^3$ SCC is about 1.5-1.7 times cost of 1m$^3$ normal concrete of the same strength class. When designing a SCC mix, a suitable mix is selected among Powder-type by increasing the powder (fines) content (550–650 kg/m$^3$), VMA-type by using low fines (350–450 kg/m$^3$) and high VMA dosage and combination-type by using moderate powder (fines) content (450–550 kg/m$^3$) and optimum VMA in consideration of structural conditions and applications [6]. Powder-type of SCC is characterized by a low water–cementitious ratio (w/cm) and a high powder content and can be used for heavily reinforced structures [7]. The common constituent materials used for proportioning SCC are cement, addition material (the most common is limestone filler), aggregates (natural stone and sand), superplasticizer and water. Among these materials, the limestone filler and natural sand are actually key factors to raise the price of SCC in Vietnam. The former is due to the fact that it needs to be imported from overseas, while the latter is mainly because of the scarcity of the material [8]. In the light of that, the authors proposed the cost effective solution for SCC technology involving the use of industrial sand, as illustrated in Figure 1, instead of limestone filler and natural sand, with application of combination-type for proportioning SCC. The advantages of industrial sand usage are two-fold: firstly this sand can be manufactured with the customized fine content (size less than 0.14 mm) [9], which can play a role as limestone filler, and secondly the replacement of natural sand could relieve the scarcity of this material, consequently the price of SCC using industrial sand would be lowered moderately.

Fig. 1. Industrial sand for construction

2 MATERIALS AND METHOD

The material used for the experimental study are presented as follows:

2.1 Cement

Cement used in this study is ordinary Portland cement PC40 with commercial band Ha Tien, which is conforming to the European cement standard EN 197-1. Physical and mechanical characteristic of cement are given in Table 1.

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Ms. Nguyen T. Nien is currently lecturer at Industrial University of Ho Chi Minh City, No. 12 Nguyen Van Bao, Ward 4, Go Vap District, Ho Chi Minh City, Vietnam

Dr. Dang H. Minh is currently lecturer at Industrial University of Ho Chi Minh City, No. 12 Nguyen Van Bao, Ward 4, Go Vap District, Ho Chi Minh City, Vietnam
2.2 Limestone filler

In this study, commercial limestone filler was used to increase the powder content of the mix, as the “powder type” was selected for the SCC. The filler had a specific density of 2.2g/cm³ and passed the sieve 0.14 mm totally.

2.3 Fine and Coarse Aggregates

Natural sand from Dong Nai River was used as fine aggregate for the concrete mix. In addition, both of crushed stone with maximum size of 20mm and industrial sand were brought from the stone quarry at the area of Dong Nai province-Vietnam. Characteristic of fine and coarse aggregates is provided in Table 2. Besides, in order to obtain grading of aggregates, sieve analysis was also carried out, the results are shown in Table 3. It is important to note that almost 25% of industrial sand passes the sieve 0.14 mm, i.e. it is a fine sand, and this is a main reason why fineness modulus of this sand is smaller than that of natural sand used in this study.

### Table 2: Characteristic of coarse and fine aggregates

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Units</th>
<th>Crushed stone</th>
<th>Natural sand</th>
<th>Industrial sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific density</td>
<td>g/cm³</td>
<td>2.71</td>
<td>2.64</td>
<td>2.7</td>
</tr>
<tr>
<td>Bulk density</td>
<td>g/cm³</td>
<td>1.48</td>
<td>1.55</td>
<td>1.65</td>
</tr>
<tr>
<td>Water absorption</td>
<td>%</td>
<td>0.9</td>
<td>4.5</td>
<td>1.9</td>
</tr>
<tr>
<td>Clay, silt and dust content</td>
<td>%</td>
<td>1.5</td>
<td>0.96</td>
<td>1.5</td>
</tr>
<tr>
<td>Fineness modulus</td>
<td></td>
<td>-</td>
<td>2.34</td>
<td>2.11</td>
</tr>
</tbody>
</table>

2.4 Chemical Admixtures and Water

A high-range water reducer admixture, which is a third generation polycarboxylate superplasticizer, was used. Besides, in order to improve segregation resistance and cohesiveness of fresh concrete, viscosity modifying agent was also used to produce SCC mix. Water used in this study was tap water at the local area. Characteristic of chemical admixtures and water is shown in Table 4.

### Table 4: Characteristic of superplasticizer (SP), viscosity modifying agent (VMA) and water

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Units</th>
<th>SP</th>
<th>VMA</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific density</td>
<td>g/cm³</td>
<td>1.075</td>
<td>1.05</td>
<td>1</td>
</tr>
<tr>
<td>pH value</td>
<td></td>
<td>4±6</td>
<td>7±8</td>
<td>7</td>
</tr>
<tr>
<td>Solid content</td>
<td>%</td>
<td>38</td>
<td>38</td>
<td>-</td>
</tr>
</tbody>
</table>

2.5 Mix proportion

Two types of SCC mixes corresponding to strength class of 30MPa at the age of 28 days were prepared. This strength class was chosen on the basis of the marketing demand at the local area [9]. The first one was designed as a common “powder-type” SCC involving cement, limestone filler, crushed stone, natural sand, superplasticizer and water. While the second one was considered as a “combination type" SCC involving cement, crushed stone, industrial sand, superplasticizer, viscosity modifying agent and water [6]. Some “trial-and-error” were involved, the final mix proportion of these SCC is presented in Table 5.

### Table 5: Mix proportion of SCC

<table>
<thead>
<tr>
<th></th>
<th>Cement</th>
<th>Limestone filler</th>
<th>Crushed stone</th>
<th>Natural sand</th>
<th>Industrial sand</th>
<th>Superplasticizer</th>
<th>Viscosity modifying agent</th>
<th>Water</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC1</td>
<td>305</td>
<td>250</td>
<td>756</td>
<td>785</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SCC2</td>
<td>305</td>
<td>-</td>
<td>628</td>
<td></td>
<td>1147</td>
<td>4.5</td>
<td></td>
<td>180</td>
</tr>
</tbody>
</table>

2.6 Specimen preparation and experimental program

After mixing, SCC mixes were subjected to several tests at fresh state, some of them are illustrated in Figure 2. Also, their fresh properties are provided in Table 6. Notably, it can be observed that the slump-flow value, T₅₀₀, U-box and V-funnel values of SCC mixes in this study, which represent filling ability, passing ability and segregation resistance of SCC, are in agreement with the recommendation for SCC mix [7]. This implies that SCC mixes were properly proportioned and the fine content in the industrial sand used in SCC2 helped to improve rheological properties at fresh state.

### Table 6: Rheological properties of SCC mixes

<table>
<thead>
<tr>
<th></th>
<th>Slump-flow, mm</th>
<th>T₅₀₀, s</th>
<th>U-box, mm</th>
<th>V-funnel, s</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCC1</td>
<td>705</td>
<td>2</td>
<td>20</td>
<td>7</td>
</tr>
<tr>
<td>SCC2</td>
<td>650</td>
<td>3.5</td>
<td>25</td>
<td>10</td>
</tr>
</tbody>
</table>
Fresh SCC mixes were then poured into a series of moulds in order to produce a series of standard specimens for mechanical tests. For each type of SCC, 6 cube specimens (150x150x150 mm$^3$), 6 prism specimens (100x100x400 mm$^3$) and 6 cylindrical specimens (diameter 150 mm and height 300 mm) were prepared for determination of compressive strength, flexural strength and splitting tensile strength at the age of 7 and 28 days. Besides, additional three cylindrical specimens (diameter 150 mm and height 300 mm) were cast to define elastic modulus at the age of 28 days.

3 RESULTS AND DISCUSSION

As mentioned above, fresh properties of SCC mixes in this study comply with the guideline and recommendation for SCC. Thus, hardened properties and cost evaluation of SCC are considered below.

3.1 Hardened properties

Test results of average compressive strength of SCC1 and SCC2 are shown in Figure 3. Looking into this figure, both of SCCs achieve strength class of 30 MPa, as designed. It can be observed that the average compressive strength of SCC1 and SCC2 at 7 days was about 80% that at 28 days. Besides, compressive strength of SCC1 is 10% higher than that of SCC2. The reason might be due to rheological properties of SCC1 at fresh state (Table 6) is better than that of SCC2. This results in the SCC1 being more compacted than SCC2, which in turn yields higher compressive strength at hardened state [11].

Regarding flexural strength and splitting tensile strength of SCC1 and SCC2 at 7 and 28 days, Figure 4 and Figure 5 respectively show a similar result as occurred in terms of compressive strength of SCC1 and SCC2. The average flexural strength and splitting tensile strength of SCC1 is 8-9% higher than that of SCC2 at the age of 7 and 28 days.
Lastly, the average elastic modulus at the age of 28 days of SCC1 is 5% higher than that of SCC2, as shown in Figure 6. The explanation for this outcome could be due to the less content of coarse aggregate in SCC2 than that in SCC1 [11]. Besides, the elastic modulus of SCC1 and SCC2 complies with the one prescribed in Eurocode for concrete of this type of strength class [12]. This indicates that although SCC2 involve conventional constituent materials such as cement, crushed stone, industrial sand, admixtures and water, it can still yield SCC mix.

4 CONCLUSION

In this paper, two types of SCC mixes have been proportioned successfully. The first is the common powder-type SCC involving high powder content of cement and limestone filler plus crushed stone and natural sand, apart from superplasticizer and water. While, the second one consists of cement, crushed stone, industrial sand, superplasticizer, viscosity modifying agent and water. Both of SCCs not only were in agreement with guideline and recommendation for SCC mixes in terms of rheological properties at fresh state, but also mechanical properties including compressive strength, flexural strength, splitting tensile strength and elastic modulus comply with the one prescribed in Eurocode for concrete of strength class 30MPa at the age of 28 days. Besides, the cost analysis with the local currency unit indicated that the second one was 20% cheaper than the first one due to mainly cost of constituent material. Thus, with the use of the second one, the cost effective solution for SCC technology can be achieved properly.

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REFERENCES


