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The sandwich concept of construction with SCC

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Abstract

The cost of supplying self-compacting concrete (SCC) could be more than double to that of conventional concrete. In order to reduce this cost, it may be possible to cast structural elements in layers of SCC and conventional concrete. This paper introduces a 'sandwich' concept of layered construction and examines its possibility by addressing the issue of compatibility between mixtures of different rheological properties, focusing mainly on their interfacial zone during placement and the resultant strength of the composites. © 2001 Elsevier Science Ltd. All rights reserved.

Keywords: Compaction; Compatibility; Interface; Rheology; Strength

1. Introduction

The development of self-compacting concrete (SCC) was initiated in Japan and first reported in 1989 [1]. Since then, the application of this new material to construction has gathered momentum around the world, as reported in the first international symposium in Stockholm in 1999 [2], and later in the RILEM state-of-the-art publication on the subject [3]. Some of the latest contributions to the subject include those on the effect of air entrainment [4], mechanical properties [5], and precast applications [6]. Interests are also growing in similar areas such as self-levelling concrete [7] and underwater concrete [8]. However, according to Skarendahl [9], self-compacting ability of SCC can be, but is not necessary, equivalent to self-levelling ability, and underwater concrete shows many similarities in behaviour with SCC, but may be drastically different in many aspects.

Although the use of SCC has many technical, social, and overall economical 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 [7], the cost of SCC is 50–100% higher than normal concrete, and to reduce this cost in general building construction, self-levelling concrete has been proposed, at a cost only 12% higher than that of normal concrete.

Currently, in Singapore, because all mix ingredients are imported from overseas, the cost of supplying SCC is about 150% higher than normal concrete. Consequently, SCC is specified only to areas where it is most needed. These include places where access to conventional vibration is difficult, or where there are congested reinforcements. Interest is growing within the local industry to reduce this 150% premium.

2. The 'sandwich' concept

There are various ways to reduce the cost of construction using SCC. One relates to material costs and the other to construction techniques. This issue on cost reduction is the main emphasis of research currently undertaken at the NUS Centre for Construction Materials and Technology. This paper reports one such possibility by introducing a 'sandwich' concept of construction. This involves the casting of SCC and conventional concrete in layers within the same structural member. This concept is particularly applicable to large elements, where congested reinforcements occur only in limited areas of the structural member. These could include foundations and posttensioned members.

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For example, in raft foundations, such as those for high-rise buildings, the top and bottom of the slab are heavily reinforced. The design often calls for four layers of 32-mm-diameter bars at about 100–150-mm centres, sitting directly above one another. With the cover thickness of 50 mm or more, there exists a top and bottom concrete layer of about 250 mm thick, where the use of SCC would be advantageous. For a typical 2.5-m-thick raft, the middle layer of 2 m has very little reinforcement and the use of normal concrete (NMC) is considered sufficient and appropriate. If this sandwich system of SCC–NMC–SCC was possible, then the cost of concrete for the foundation would only be about 30% higher than that with the use of conventional concrete. This would seem to be much more economical than the 150% premium that one has to pay for the use of SCC over the entire structural member.

In addition to cost, the sandwich system could offer other benefits as well. For example, current practice of SCC often calls for high powder contents of 450–600 kg/m^3. This may result in more Portland or blended cement being used and, thus, higher temperature rise compared to conventional concrete. Normally, this would be considered as a disadvantage because of the increased risk of thermal cracking. However, with the proposed system of SCC–NMC–SCC and in terms of thermal gradient, this difference in cementitious content between the inner and outer layers could turn out to be an advantage. Based on the sandwich concept, NMC is the inner layer, which usually has the highest temperature rise. By having lower cement content, this inner layer may have a lower adiabatic temperature rise than that of the outer layer of SCC.

Viscosity agents are sometimes used instead of increasing the powder content. However, this tends to increase further the cost of SCC.

Note that the technique of casting mass concrete in layers, but of the same mixture constituents, is a common practice for concreting in the tropic [10]. For a typical 2.5-m-thick foundation, concrete is generally placed in layers having a thickness between 0.3 and 0.4 m so that the concrete can be compacted properly. More importantly, due to the tropical environment, casting temperatures usually fall between 28°C and 32°C. The common concern is obviously the heat of hydration, the resultant maximum temperature reached and the thermal gradient upon cooling. By casting concrete in layers, chilled water can be selectively added as mixing water for mixtures in the centre portion. This construction technique reduces the thermal gradient and is often used to satisfy specifications, which place a limit on the peak temperature and maximum differential temperature within a concrete element.

It is obvious from the above discussion that layered construction has many advantages, particularly for mass concrete production and for tropical weather concreting. However, the compatibility issue between different types of concrete needs to be resolved if this concept is to be applied with confidence.

The significance of thermal gradient is another important aspect of this sandwich concept. This topic is currently under investigation and is the subject of another discussion.

3. Experimental details

This research involved the use of SCC and normal concrete, both in their fresh state, placed above or next to each other under different interfacial conditions. Specimens prepared included composites of SCC and NMC, as well as reference specimens of plain SCC and NMC. Compressive strength, elastic modulus, and flexural strength (modulus of rupture) were determined from either cylinders or prisms.

For the cylinders, 200 × 100 mm diameter, five types of composites were produced and are shown in Fig. 1. Different interfacial conditions were obtained by varying the casting sequence, as follows:

(a) Type NS-O: normal concrete NMC was cast on top of SCC; only the NMC was vibrated but without any disturbance to the interface.
(b) Type NS-D: NMC placed on top of SCC and in addition to vibrating the normal concrete, the poker vibrator was allowed to penetrate 25 mm below the interface; this created a disturbed layer of approximately 50 mm.
(c) Type SN-O: only the NMC was vibrated, then SCC was cast on top without disturbing the interface.
(d) Type SN-D: NMC was vibrated first before casting a 25-mm depth of SCC and the interface vibrated by allowing the poker vibrator to penetrate 25 mm below the interface; after this, the rest of SCC was placed without any further disturbance.
(e) Type C-MX: composites were obtained by complete mixing of equal amounts of NMC and SCC, followed by vibrating the whole mixture.

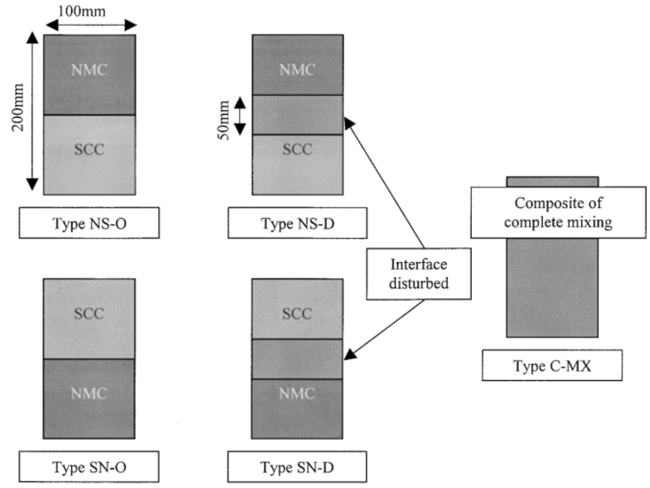

Fig. 1. Cylinders for compression and elastic modulus.

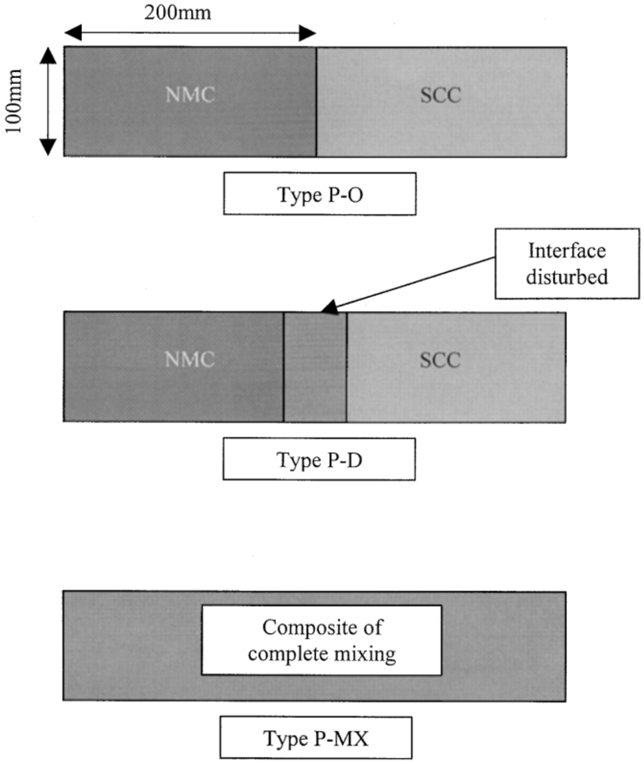

Fig. 2. Prisms for flexural strength test.

Prisms of 100 × 100 mm × 400 mm long, were prepared for determining the flexural strength from two-point loading tests. The prisms were cast on the side and three types of composites were produced as shown in Fig. 2:

(f) Type P-O: the NMC was cast and vibrated before SCC was placed next to it without any disturbance.
(g) Type P-D: in addition to vibrating NMC, the poker vibrator was allowed to disturb 25 mm from either side of the interface, creating a disturbed zone of about 50 mm.
(h) Type P-MX: the two mixes were placed in the mould simultaneously in equal amounts and the whole mixture was mixed and vibrated.

For the SCC mixtures, limestone powder and a polycarboxylated polyether type superplasticiser, identified as SPA, were used to control its rheological properties. As for the normal concrete mixtures, they utilised the conventional superplasticiser (SPD) with naphthalene polymers as active chemicals. Both superplasticisers are available commercially and, according to their suppliers, comply with the ASTM C494 Type F, Standard Specification for Chemical Admixtures for Concrete. Details of the mixtures are presented in Table 1. Results reported in this paper were extracted from a research report by Lim [11].

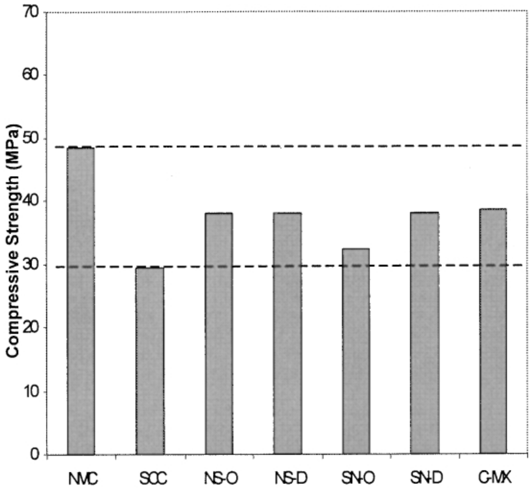

Fig. 3. Seven-day strength for normal and SCC mixes.

4. Results and discussions

The normal concrete mixture had a slump value of 180 mm. As for the fresh properties of SCC, the spread of slump flow tests was 670 mm over 15 s and the blocking ratio (L-box) was 0.80. These mixtures were designed to produce concrete of somewhat different 28-day strengths. This was achieved with the normal concrete having strengths of 62 MPa while for the SCC, the strengths was 36 MPa.

Since the normal concrete and SCC have different properties, they formed the upper and lower bounds of the composites. As the composites contain both SCC and normal concrete, their properties should fall somewhere between these limits. If any property of the composites should fall below the lower limit, incompatibility between mixtures is said to occur and the causes would then be investigated.

4.1. Compressive strength

The 7- and 28-day compressive strength results are presented in Figs. 3 and 4. As indicated, all composites had strengths above the lower limit.

In relation to the effect of disturbance to the interface, comparisons can be made between composites of Types NS-O and NS-D and also between SN-O and SN-D. It can

Table 1
Mix proportions for NMC and SCC mixtures

Mix	Filler (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Coarse aggregates (kg/m^3)	Fine aggregates (kg/m^3)	Chemical admixtures	
						Type	Amount (l)
NMC	0	455	160	960	785	SPD	4.3
SCC	170	330	180	820	820	SPA	5.7

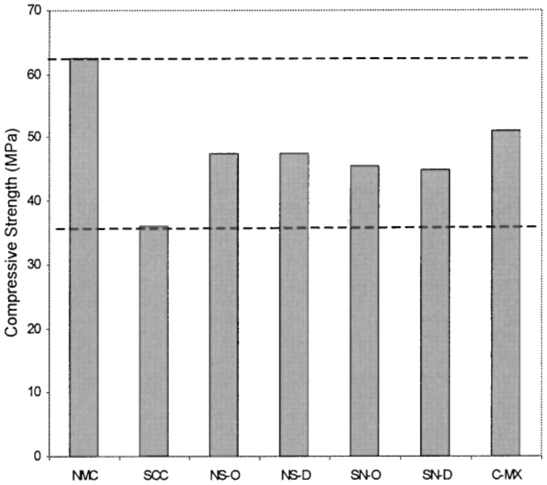

Fig. 4. Twenty-eight-day strength for normal and SCC mixes.

be observed in Figs. 3 and 4 that the strengths of composites with their interface disturbed were either similar to or slightly higher than the undisturbed samples. Therefore, one can conclude that, as far as compressive strengths are concerned, the disturbance at the interface only has a minor effect on increasing the strength of the composite.

Furthermore, by comparing composite Types NS and SN, it can be concluded that the placement of SCC on top or bottom has no significant effect on the compressive strength. Another observation is that composite Type C-MX generally exhibited a slightly higher strength than other composites. This could be the result of vibrating the whole mixture during production, thus, producing slightly denser concrete. Note that for other composites, only the normal concrete mixture was vibrated. These findings further demonstrated the compatibility between SCC and normal concrete.

4.2. Modulus of elasticity

Since the modulus of elasticity is directly related to strength, observations of results on elastic modulus were expected to be similar to those of compressive strengths reported above. Indeed, results presented in Fig. 5 confirmed the earlier findings on compatibility and that

- disturbance at the interface has only a minor effect on increasing the elastic modulus of the composite;
- placement of SCC on top or below of normal concrete had little effect on the modulus; and
- composite Type C-MX had a slightly higher elastic modulus than other types.

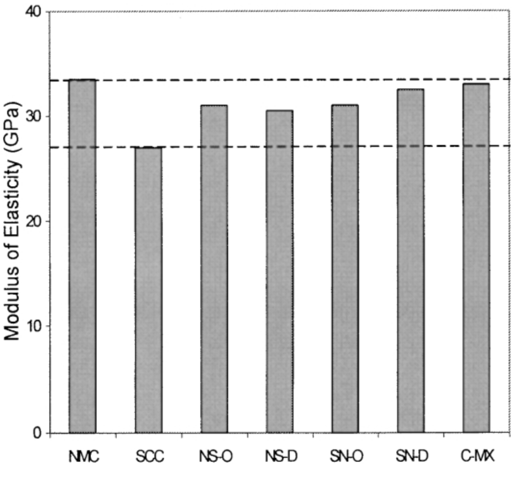

Fig. 5. Modulus of elasticity for normal and SCC mixes.

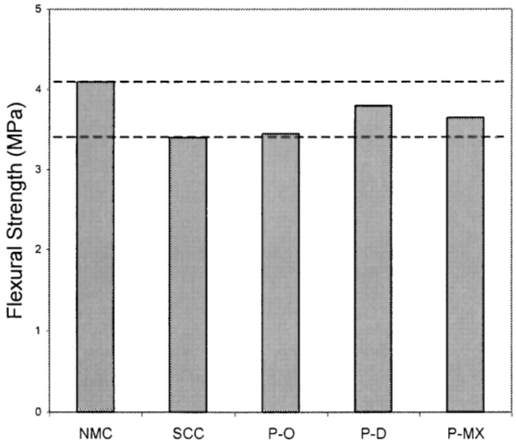

Fig. 6. Seven-day flexural strength for normal and SCC mixes.

4.3. Flexural strength

Similarly, the flexural strength of composites fell within the limits formed by the plain SCC and normal concrete as illustrated in Figs. 6 and 7. Although there were cases of the prism failing at the interface, the flexural strengths were similar to the lower bound placed by the SCC reference specimen. This was particularly so for composites where the interface was not disturbed. Thus, in terms of tensile strengths, there was an obvious but slight benefit in dis-

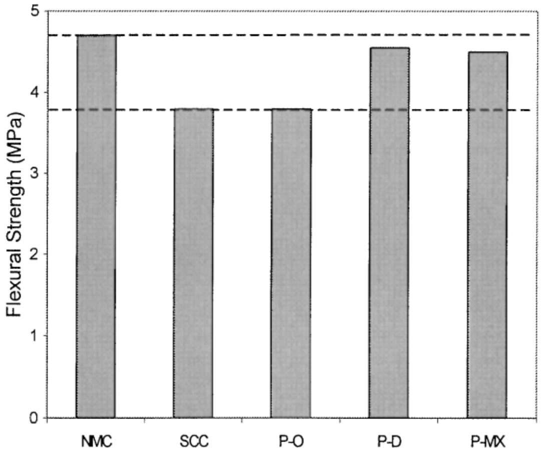

Fig. 7. Twenty-eight-day flexural strength for normal and SCC mixes.

turbing the interface for improved interaction between the two mixtures.

5. Conclusions

A ‘sandwich’ concept has been proposed in order to reduce the cost of construction utilising SCC. It involves the casting of concrete in layers of different rheological properties. This proposal necessitates the development of a test method to evaluate the compatibility between SCC and normal concrete.

Based on the test method developed and for the materials used in this study, it can be concluded that SCC and normal concrete are compatible and therefore can be cast next to, or above, one another in their fresh state. Composites can be produced with or without disturbance to the interface. However, the interface can be disturbed for improved interaction between mixtures. As expected, the weaker contributing mixture has a larger influence on the properties of the composite.

Using this test method, other combinations of chemical admixtures or mixture constituents are currently under investigation for their practical applications. The sandwich concept of SCC–NMC–SCC could be one way to reduce the cost of construction while realising the many technical benefits of SCC.

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