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Supplementary cementitious materials: Strength development of self-compacting concrete under different curing temperature

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Abstract

Three mixes were provided namely normal weight self-compacting concrete with Portland cement as a control (NWSCC-PC), lightweight self-compacting concrete with ground granulated blast furnace slag concrete (LWSCC-GGBS) and lightweight self-compacting concrete with limestone powder concrete (LWSCC-LSP). There were three cubes of each mix for each testing age, which were cured at 20, 30, 40 and 50°C to investigate the effect of curing temperature on strength development. They were tested at ages 0.125, 0.25, 0.5, 1, 2, 4, 7, 14 and 28 days. The results showed that the strength development of self compacting concrete strongly affected by curing temperature as it does with normal concrete. At early ages, the strengths development of concrete cured at higher curing temperature, were faster than that of concrete cured at lower temperature. The strength development of concretes cured at lower temperature, however, have higher strength at later ages.

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Keywords: Self compacting concrete, lightweight concrete, curing temperature, ggbs concrete and limestone powder concrete

1. Introduction

This research was conducted in Liverpool University UK, as a part of the author's PhD research study. The mix designs of the concretes were derived from Queen's University Belfast (QUB) through a research collaboration, developed between QUB and the University of Liverpool. The research aims to show the strength development of self-

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compacting concrete (SCC) cured under different temperatures. Self-compacting concrete that is also called as self-consolidating concrete, is a highly flowable concrete that can flow through and fill the gaps of reinforcement and corners of moulds with no segregation, purely by means of its own weight without any need for vibration and compaction during the pouring process [1-5]. Nomenclatures used in this paper are listed below:

1.1. Self compacting concrete

This type of concrete was firstly introduced in Japan by Okamura in 1986 [4-6]. The concrete was designed to solve the problem appearing in Japan at this time, where a number of skilled worker in Japan's construction were reduced, resulted in a decresing in the quality of produced concrete; such as durability due to poor compaction of the concrete. The use of self compacting concrete can give the following benefits [2, 3]:

- Minimize cost for placing and compaction as it can be placed faster and without mechanical vibration.
- With little of without remedial surface work can give good architectural finishing.
- Reduce construction period and labour savings.
- It is easy to fill a restricted section such as as coners or moulds and gaps between reinforcement.
- Improve the bond between concrete and reinforcement as compaction around the reinforcement improved.

To obtain the adequate performance of self compacting concrete, it was suggested to follow the three stages below [5, 7, 8]:

- Fresh age stage: the concrete should be self-compactable by its own weight without any need vibration.
- Early age stage: Initial defects should be avoided.
- Hardening stage: the concrete should be able to with stand external factors, such as bad weatther, chemical attact, etc.

Furthermore, they added that in order to obtain self-compacting concrete, both a high deformability of paste or mortar and the resistance of segregation between coarse aggregate and mortar when the concrete flows filling the form were needed. To achieve these requirements, therefore, it is needed to limit the aggregate content in a mix, a lower water-powder ratio and the use of super plasticizer. This aims to reduce the energy elasticity and tensile strength of the self-compacting concrete mixes. The horizontal flow of self-compacting concrete in the absence of stumbling block was assessed using the slump flow test as shown in Fig. 1 below [9].

Fig. 1: Slump flow test

1.2. The effect of supplementary cementitious materials (SCM) on the properties of self compacting concrete

The properties of filling and passing ability of self-compaction concrete using supplementary cementitious materials (SCM) such as fly ash, ggbs and silica fume increased [10]. Furthermore, Ravindrarajah et al. [11] found that replacing of fine and coarse with fly ash could improve the flow property and reduced segregation potential in producing high strength self-compaction concrete without affecting the early age strength. Even the addition of fly ash in SCC could increase the later age strength. The addition of ggbs as partial replacement of cement in concrete can improve the workability of self compacting concrete as reported by Boukendakdji at al [12]. They found that using 15% of ggbs to replace cement in concrete could improve the workability of concrete up to 20% over the concrete with Portland cement only.

The use of limestone powder as a filler in self-compacting concrete had been studied by Yet et al [13] and Schutter [14]. They found that the presence of limestone powder in self-compacting concrete influences the heat output of hydration in the concrete. They also found that the presence of limestone powder in self-compacting concrete affected the heat output of hydration in the concrete, where the cumulative heat release in self-compaction concrete containing limestone powder is higher than that of its equivalent concrete mix without limestone powder. The effect limestone powder on the hydration of cement is primarily to accelerate the hydration process.

2. Experimental work

Three mixes with the symbols of NWSCC-PC, LWSCC-GGBS and LWSCC-LSP were prepared to be investigated. The water binder ratio of NWSCC-PC is 0.45, which is higher than that of LWSCC-GGBS and LWSCC-LSP concretes, where both the concretes have the same water binder ratio i.e. 0.35. The cement used in this research was Portland cement type CEM I 42.5 supplied by Castle Cement Ltd. [15] and complied with the requirements of BS EN 197-1 [16]. The ggbs was supplied by Civil + Marine Ltd [17]. Furthermore, the lightweight aggregate used to produce lightweight concrete and lightweight self-compacting concrete was Lytag aggregate supplied by Lytag Ltd, which was its size ranged from 4 to 14 mm in accordance with BS EN 13055-1 [18]. Prior to mixing, two samples of the Lytag aggregate were weighed out, dried in an oven and then reweighed to calculate the amount of free moisture in the aggregate to determine the water absorption of the material. The admixtures used for the concretes were SPA-Sika Viscocrete Premier and SPA-Larsen Chemcrete.

The materials used in self-compacting concrete were added in the order: first, coarse aggregate, sand and 2/3 of the total water placed in the mixer and then mixed for 2 minutes. After that, the ggbs or limestone powder was then added and mixed for a minute. The cement was then added and mixed for another one minute. In the next stage, the remaining water and superplasticisers were added and mixed for 2 minutes to allow the superplasticisers to distribute evenly. It was found to be better to hold back some of the superplasticisers until after the slum flow test. The slump test was carried out on top of a moist (not wet) plastic sheet. The value of slump should be between 700 and 750 mm. If the slump value is less than 700 mm, then more superplasticisers should be added to the mix. If the slump value was higher than 750 mm, then mix was discarded and repeated.

The cube moulds with the size of 100 x 100 x 100 mm^3were filled until full without vibration as the concrete compacted itself by its own weight. The moulds were then wrapped with cling film and transferred into water tanks set to 30, 40 and 50^0C. For the concrete cubes cured 20°C (standard curing temperature) were left on the table for 24-hours, which they were covered with damp hessian and polythene sheeting. They were then demoulded and transferred into a water tank set at 20^0C. Furthermore, after 24-hours, the cube specimens cured at 30, 40 and 50^0C were demoulded and immediately after demoulding those concrete cubes were placed back into their curing tanks. Three cubes were made from samples of each mix for each testing age They were subsequently tested for compressive strength at 3, 6 and 12 hours, continuously at 1, 2, 4, 7, 14 and 28 days .

3. Results and discussion

Fig. 2 presents the effect of curing temperature on the strength development of NWSCC-PC, LWSCC-GGBS and LWSCC-LSP cured at 20, 30, 40 and 50°C [19]. The strength development of self-compacting concrete greatly depends on curing temperature as it does with normal weight concrete. As expected, the strength development of concrete cured at higher curing temperature at early age is higher than that of concrete cured at lower temperature; however, their strength is lower at later ages. Conversely, the strength of concretes that cured at lower temperature is lower than that of concrete cured at higher temperature, but they have higher strength at later ages. The figure shows that the 'crossover effect' occured at an earlier ages in NWSCC-PC and LWSCC-LSP concrete. This is believed to be due to the effect of of the use of high doses of superplasticizer that result in the concrete having a high degree of hydration, as the superplasticizer accelerate the hydration process. As the result, the formation of a dense hydrated phase around the un-hydrated binder particles, preventing water for further hydration, which is lead to lower strength at later ages.

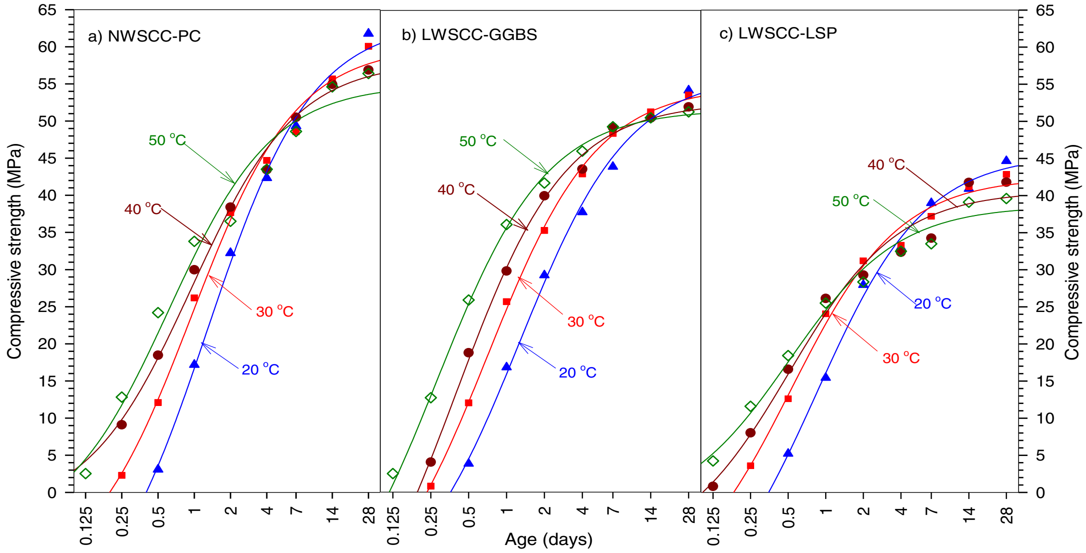

Fig. 2: Strength development of NWSCC-PC, LWSCC-GGBS and LWSCC-LSP concretes cured at 20, 30, 40 and 50^{0}C [19].

The effect of higher curing temperature at early ages on the LWSCC-GGBS concrete appears to be less than that on NWSCC-PC and LWSCC-LSP concretes. It is believed that the heat produced in the hydration process of LWSCC-GGBS is absorbed and used as activation energy for further hydration, while the NWSCC-PC and LWSCC-LSP do not need it; as the hydration reaction for both the concretes can occur with lower activation energy than that of needed for LWSCC-GGBS concrete. The strength at 28-days of LWSCC-GGBS concrete is higher than that of LWSCC-LSP concrete for all curing temperatures; although both the concrete expected to have a similar target mean strength; as both the concrete mixes have the same water binder ratio and the same replacement level of cement with GGBS and LSP i.e. 30%. The strength of LWSCC-LSP concrete ranged between 21 and 30% lower than that of LWSCC-GGBS concrete, where the maximum difference occured in concrete cured at 50°C.

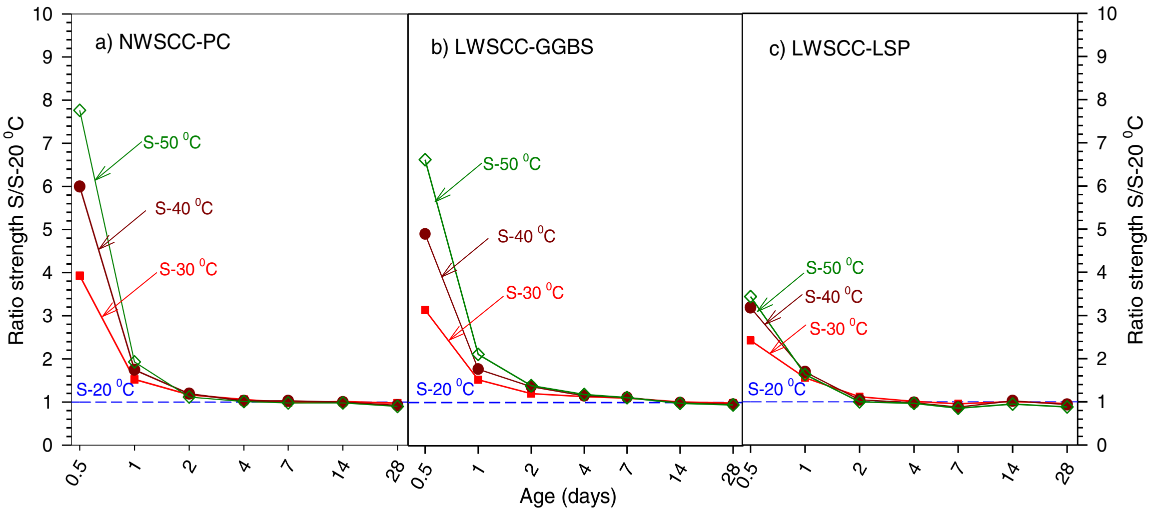

Fig. 3: Ratios strength development of WNSCC-PC, LWSCC-GGBS and LWSCC-LSP concretes cured at 30, 40 and 50^{0}C to that of the concretes cured 20^{0}C [19].

Fig. 3 above shows the strength ratio of NWSCC-PC, LWSCC-GGBS and LWSCC-LSP concretes cured at 30, 40 and 50^0C to the strength of concretes cured at standard curing temperature (20^0C) [19]. It is clearly shown that the highest curing temperature results in the highest strength ratio at very early ages. For the concrete NWSCC-PC, the ratio of strength of concrete cured at 30, 40 and 50°C to the strength of concrete cured at the standard curing temperature at age 6 hours after casting are 3.9, 6.0 and 7.77 respectively. Those are similar to the strength ratio of LWSCC-GGBS concrete at the same age. However, the strength ratio of LWSCC-GGBS concrete is higher than that of LWSCC-LSP concrete, although they have the same water-binder ratio and the same replacement level of cement. The ratios for LWSCC-GGBS concrete were 3.14, 4.90, and 6.62 for 30, 40 and 50°C respectively, and 2.42, 3.18, and 3.44 for the LWSCC-LSP concrete. This means that the effect of curing temperature on the strength development of LWSCC-LSP concrete at early age is lower, when it is compared to that of NWSCC-PC and LWSCC-GGBS concretes.

The *"crossover effect"* in the NWSCC-PC and LWSCC-LSP concretes occurred earlier age than that in the LWSCC-GGBS. This proves that the hydration process in concrete that used GGBS occurs slowly. The ratios of the strength of concrete cured at higher temperatures to that of concrete cured at 20^0C at age 28-days for all concretes are quite similar, with ranges from 0.88 to 0.99. The ratio of 0.88 is for LWSCC-LSP cured at 50°C, while 0.99 is for LWSCC-GGBS concrete that cured at 30°C. . All self-compacting concretes at age 1-day that were cured at 50^0C reached about 50% of their strength at age 28-days, i.e. 53.6%, 65.7% and 56.5% for NWSCC-PC, LWSCC-GGBS and LWSCC-LSP concretes, respectively. These are significantly higher than that for concrete cured at 20^0C, where the percentage strength of concrete at age 1-day to the strength at age 28-days are 27.8%, 31.1% and 34.6% for NWSCC-PC, LWSCC-GGBS and LWSCC-LSP concretes, respectively.

4. Conclusion

The effects of curing temperature on the strength development of lightweight self-compacting concretes at early age are similar to that of the normal weight concrete. The higher the curing temperature at early ages, the greater is the strength development gain compared to concrete cured under standard curing temperatures. However, their strengths at later ages are lower than that of concrete cured under standard curing temperature (20°C). The "*crossover effect"* also occurred on those concretes. However, the 'crossover effect' on the strength development of lightweight concrete due to higher curing temperatures (up to 40°C) at early age is much less than that of the normal weight concrete.

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