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A study on the properties of freshly mixed high performance concrete

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Abstract

The physical properties of freshly mixed high performance concrete were investigated. Physical state and quality of fresh concrete were monitored batch by batch. The properties of fresh high performance concrete were determined in respect of slump, slump flow, V-funnel flow, air content, temperature, and unit weight. It was observed that the properties are interrelated, particularly the flow and the air content. The indication of flowability was more pronounced in terms of V-funnel flow than slump flow. This result suggests that the traditional slump test is not efficient to evaluate the workability and flowability of high performance concrete.

Keywords: Fresh concrete; Workability; Fly ash; Silica fume; High performance concrete

1. Introduction

There is no shortage of information on the properties of hardened high performance concrete (HPC). Numerous publications are available showing that the range of outstanding properties of hardened HPC can be obtained not only in the laboratory but also in real construction. However, information on the properties of freshly mixed HPC is not enough and tends to be scattered in many publications on hardened concrete. Wallevik and Gjørv [1,2], Tattersall and Banfill [3], Tattersall [4], and Murata [5] investigated the rheology of fresh concrete. Hobbs [6–8] also undertook a number of studies that related the workability and water demand of fresh concrete. Such sources focus more on the fundamental aspects of rheology of ordinary mixes rather than on the practical workability parameters of high performance concrete mixes. A recently published book [9] has concentrated on the workability and pragmatic tests for fresh concrete in general, and the author has also surveyed a number of practical tests applicable to HPC.

Quality of fresh HPC refers mainly to its workability and flowability. Unit weight, air content, and concrete temperature also have important roles in assessing the concrete quality. Workability is usually measured by slump. High performance concrete, which is to be self-compactable and flowable, should have slump greater than 190 mm [10]. Slump flow and V-funnel flow can measure the flowability. Slump flow should range from 50 to 70 cm for high performance concrete [11]. Recently, Japanese researchers have found an ingenuous method of incorporating the V-funnel flow test to indicate the flowability of freshly mixed HPC [12]. Compared to ordinary concrete, HPC has extraordinary rheological properties, especially its super-workability and flowability, that make it superior to other concrete mixes. This paper reports some quality characteristics of freshly mixed HPC.

2. Experimental

2.1. Materials

Locally available crushed stone granite aggregate, mining sand, and Type I normal Portland cement were used in this study. Class F Malaysian fly ash and Elkem silica fume have been used as mineral admixtures. Sulfonated naphthalene condensate-based superplasticizer (SP) and Darex air entraining admixture (AEA) were also used as liquid chemical admixtures. Normal tap water (pH = 6.9) was used as mixing water. The physical properties of the materials are shown in Table 1.

2.2. Mix proportions

Four types of high performance concrete with two water-binder ratios were designed including the control mix. These are normal Portland cement (NPC), silica fume (SF),

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Table 1
Physical properties of the materials

Items	Specific gravity	Absorption (%)	Maximum size	Fineness modulus	Solid content (%)
Coarse aggregate	2.62	0.90	19 mm	6.84	–
Fine aggregate	2.60	1.20	4.75 mm	3.01	–
Cement	3.15	–	–	–	–
Silica fume	2.20	–	–	–	–
Fly ash	2.26	–	–	–	–
Superplasticizer	1.21	–	–	–	40
Air entraining Admixture	1.02	–	–	–	8

fly ash (FA), and silica fume-fly ash (SFFA) concrete. Sherbrooke mix design method [13] was followed and many trial mixes were conducted to get the optimum proportions. The proportions of the constituent materials obtained from mix design were based on saturated surface dry condition. Thus, necessary corrections were made to get the weight of materials in air dry basis. The details of various mix proportions are given in Table 2.

2.3. Scope of tests

Materials were weighed on air dry basis. The quantity of concrete prepared in each batch was at least 10% in excess of the requirement. Water for mixing was corrected for aggregate absorption and the amount of water contributed by superplasticizer was considered. The constituent materials were mixed in a rotating pan-type mixer (capacity 0.05 m^3) at ambient temperature. Immediately after completion of mixing, fresh concrete was sampled for the determination of slump, slump flow, V-funnel flow, concrete temperature, air content, and unit weight. ASTM standard was followed to determine slump and slump flow [14]. Concrete temperature was also measured according to ASTM standard [15]. Air content and unit weight were measured according to British standards [16,17]. V-funnel flow was determined by V-funnel apparatus shown in Fig. 1. This apparatus is similar in concept to the apparatus designed and used by Japanese researchers [12].

3. Results and discussion

The properties of freshly mixed high performance concrete were determined in respect of slump, slump flow, V-funnel flow, air content, unit weight, and concrete temperature. These are given in Table 3. It was observed that the properties of fresh composite are interrelated, especially the two characteristic flows and the air content. The relationships between the two characteristic flows and the air content are shown in Figs. 2 and 3.

The average slump of different mixes was maintained between 23 and 25 cm by adjusting the mix proportions and dosages of superplasticizer and air entraining admixture. The average slump flow of the mixes was in the range of 50 to 58 cm, which showed reasonably good flowability. Slump and slump flow at 35% water-binder ratio were higher than those at 50% water-binder ratio. The main reason is that the mix with 35% water-binder ratio possesses a higher volume concentration of cementitious particles, but a lower volume concentration of aggregates. The cement-paste aggregate ratio of the mix with 35% water-binder ratio is higher than that with 50% water-binder ratio. Thus, the viscosity of the mix with 35% water-binder ratio lowers and leads to higher slump and slump flow results. Moreover, high performance concrete usually shows a gluey behavior due to its cohesiveness, which plays a part in reducing the flow rate. Incorporation of superplasticizer would lessen the water demand and help the mixes to reach higher fluidity and plasticity. It also improves the packing of the concrete

Table 2
Details of mix proportions

			Binder (B)					
Concrete type	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	Cement (kg/m^3)	Silica fume (kg/m^3)	Fly ash (kg/m^3)	Water (kg/m^3)	SP (%B)	AEA (%B)
NPC[a]	1013	675	530	–	–	185.5	1.75	0.04
SF[a]	1002	667	477	53	–	185.5	2.25	0.07
FA[a]	1003	668	477	–	53	185.5	1.75	0.09
SFFA[a]	1002	668	477	26.5	26.5	185.5	2.15	0.08
NPC[b]	1055	703	400	–	–	200	1.00	0.06
SF[b]	1046	697	360	40	–	200	2.00	0.07
FA[b]	1047	698	360	–	40	200	1.00	0.09
SFFA[b]	1046	698	360	20	20	200	1.50	0.08

[a] W/B = 35%.
[b] W/B = 50%.

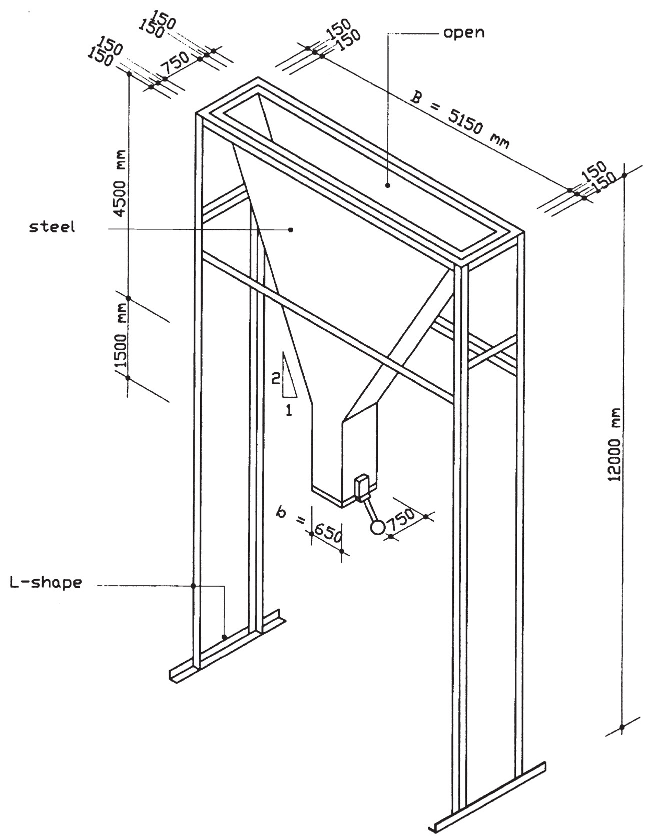

Fig. 1. V-funnel apparatus used.

mix by improved grading in the range of the fines, especially the binder. Mixes with 35% water-binder ratio contained higher amount of superplasticizer. This might be another reason why the mixes with 35% water-binder ratio exhibited higher slump and slump flow.

The indication of flowability was more pronounced in terms of V-funnel flow. The mix with 50% water-binder ratio exhibited higher V-funnel flow compared to the mix with 35% water-binder ratio. This is possibly due to the presence of a greater volume of aggregate and a higher water content. Another reason might be the increased influence of gravity. Since the mix of 50% water-binder ratio contains a higher mass of aggregates and it has more fluidity due to the presence of excessive water, the influence of gravity becomes more dominant and therefore it quickens the falling of concrete mass.

Workability assessment in high performance concrete requires especial consideration. High performance concrete is more thixotropic and consequently requires a test, which involves imparting energy into the mix and then measuring how much it moves. The traditional slump test is inappropriate for high performance concrete since the concrete does not slump appropriately when the mold is lifted. Consequently, for a particular, measured slump, the practical workability of high performance concrete is far greater than that of conventional concrete. This is even partly true with the flow test. However, the flow test is the best compromise for routine quality control. Therefore, in this study V-funnel flow test was performed together with slump and slump flow test. This attempt correlates the opinion of P.L. Male [18]. It should be further mentioned that in this study V-funnel was used instead of O-funnel to measure the flowability of concrete. In O-funnel, freshly mixed concrete moves equally over the entire inner surface, which tends to cause the arching of aggregate in the opening. This tendency has been reduced in V-funnel apparatus.

The recommended air content in fresh concrete depends on the purpose for which the concrete is to be used, the location and climatic condition, the maximum size of aggregate, and the richness of the mix. Usually, the desirable air content ranges from 3 to 6% [19]. For high performance concretes, which are to be used in nonfreezing environment such as in Malaysia, theoretically there is no need for entrained air. However, in order to improve the handling, placeability, and finishability of concrete, use of a small amount of entrained air in fresh concrete is strongly suggested [13]. In the present study, the average air content for all mixes was kept between 1.5 and 2.3%. It is true that air content improves the workability but excessive air content is not beneficial to the flowability. From the results of this study, it was observed that higher air content tends to decrease the flowability. From Figs. 2 and 3, it is suggested that an air content between 1.5 and 2% is adequate to maintain excellent workability and flowability, especially for hot weather concreting.

Table 3
Properties of freshly mixed high performance concrete

Concrete type	Slump (cm)	Slump flow (cm)	V-funnel flow (L/s)	Air content (%)	Unity weight (kg/m^3)	Concrete temperature (°C)
NPC[a]	25.0	57.0	0.18	2.0	2412	31.5
SF[a]	25.0	58.0	0.19	2.3	2370	31.0
FA[a]	23.5	53.0	0.12	1.9	2365	31.0
SFFA[a]	24.0	55.0	0.16	2.1	2367	31.0
NPC[b]	24.0	51.5	0.53	1.5	2392	31.0
SF[b]	24.0	52.0	0.54	1.6	2355	30.5
FA[b]	23.0	50.0	0.35	1.8	2362	30.5
SFFA[b]	23.5	51.0	0.46	1.7	2358	30.0

[a] W/B = 35%.
[b] W/B = 50%.

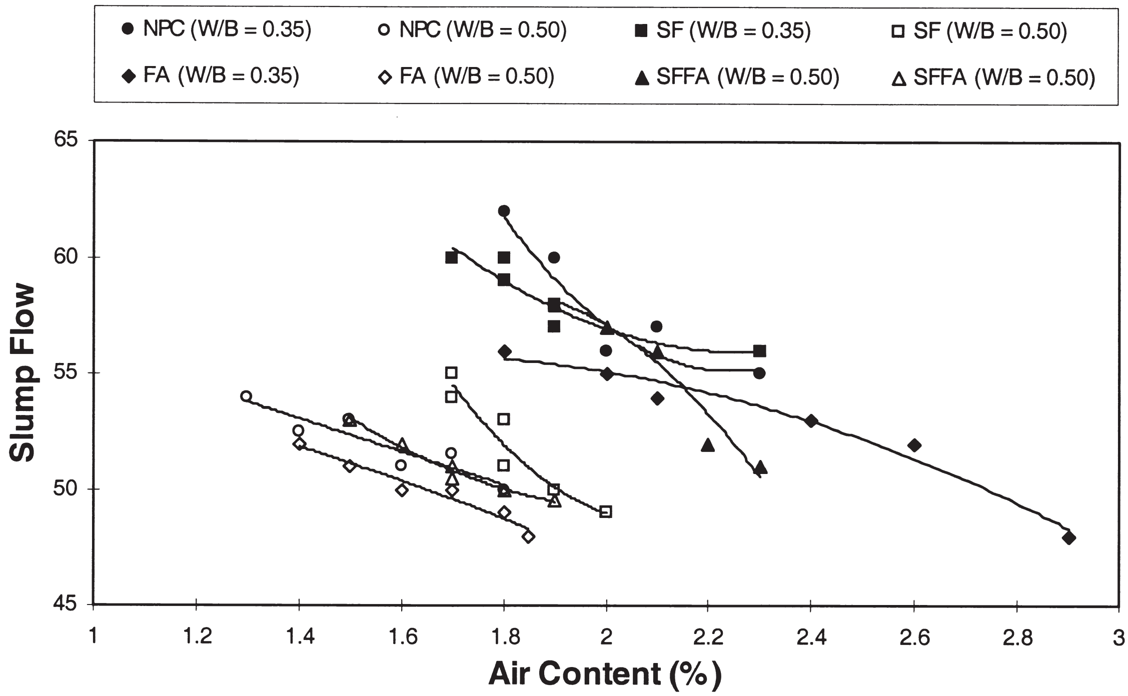

Fig. 2. Relationship between slump flow and air content.

The quality of freshly mixed high performance concrete is also a function of temperature. The higher the temperature is, the higher the evaporation is, the higher the loss of water and air content is, and thereby the lower the workability is. The concrete temperature should be maintained within the range of 15 to 25°C [20]. It is well established that the control of the parameters of the air bubble system becomes rather difficult when concrete temperature is higher than 25°C. In this study the mixing was made in ambient temperature and the temperature of all concrete mixes was in the range of 30 to 31.5°C. Therefore, it was difficult to get the required air content. However, balancing the dos-

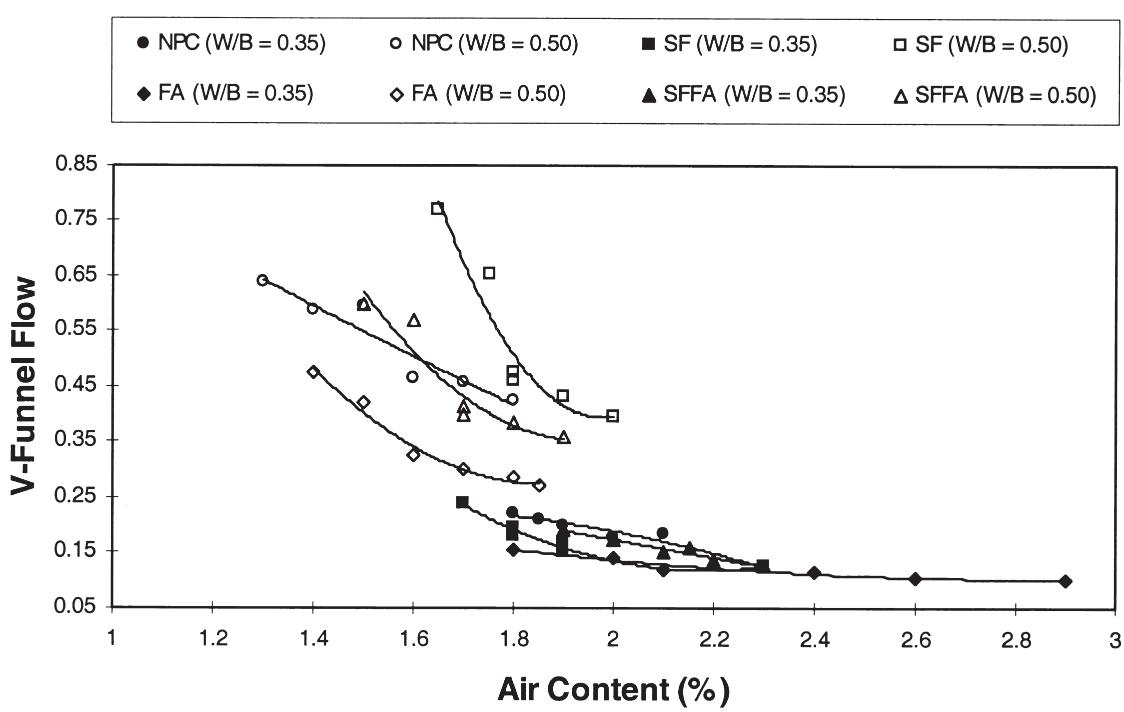

Fig. 3. Relationship between V-funnel flow and air content.

ages of superplasticizer and air entraining admixture, minimum air content of 1.5% was maintained. At this point, it is suggested that the production and delivery of high performance concrete in hot climate should provide better control of air content to maintain the workability and flowability.

The unit weight of different mixes was in the range of 2355 to 2412 kg/m^3. It varied mainly due to the differences in mix proportions, the presence of mineral, and chemical admixtures. The mixes with 35% water-binder ratio produced higher unit weight than those mixes with 50% water-binder ratio. This is perhaps due to the higher content of cementitious materials in the mix of 35% water-binder ratio.

It was also distinguishable that among pozzolanic concretes, silica fume concrete exhibited the highest slump, slump flow, and V-funnel flow. The use of silica fume results in more cohesive concrete without bleeding or segregation. It is also more effective to produce flowable concrete. The ultrafine silica fume spheres act like ball bearings in the concrete and form part of the pore water solution and thereby increase the flowability. Although silica fume concrete seems sticky, in a body it is more flowable than any other concrete.

In the present study, silica fume concrete needed higher dosage of superplasticizer, whereas fly ash concrete utilized a lower dosage that was almost similar to the dosage used for normal Portland cement concrete. It follows that the concrete containing silica fume offers larger specific surfaces, which demand a higher amount of superplasticizer to reach a chosen consistency when mixed with water. Silica fume particles, which caused the increase in the dosage of superplasticizer, are in the size range in which the flocculation forces act. The flocculation of the particles decreases the mix fluidity or conversely, it causes the increase in the demand of superplasticizer. This explanation is supported by one earlier work in the related field [21]. In addition, silica fume concrete required a smaller amount of air entraining admixture compared to fly ash and silica fume-fly ash concrete. In fact, silica fume concrete should need a higher dosage of air entraining admixture, but it also depends on the presence of superplasticizer. In the presence of superplasticizer, the demand of air entraining admixture decreases [21]. Since silica fume concrete needed a higher dosage of superplasticizer, it comparatively required a lower dosage of air entraining admixture.

In order to optimize the composition of high performance concrete in a given location, it is very important to first find the cement that has the lowest rheological reactivity, that is, the cement that will fix the least amount of water immediately after mixing, and second, find the superplasticizer that will not compete with ettringite crystals [22]. Unfortunately, there are no theoretical means to predict either of these behaviors. Concrete producers usually have to proceed by trial and error, monitoring the slump loss of their concrete, which can be a quite long and fastidious procedure. In this study, a number of trial mixes were prepared in order to find the best combination of binder and superplasticizer to maintain excellent rheological properties in freshly mixed concrete.

4. Conclusions

The rheological reactivity of cement was negligible and the superplasticizer was compatible with the cement in producing the concrete mixes. Freshly mixed high performance concrete produced excellent workability and flowability. Its slump and slump flow were much higher than the conventional concrete. Silica fume coupled with superplasticizer provided better workability and flowability compared to other mineral admixtures. In addition, the conventional slump test was not appropriate to evaluate the workability of high performance concrete. The V-funnel flow test made amends for this discrepancy.

Excessive air content was not conducive to the flowability. An air content between 1.5 and 2% air was the best compromise to maintain the flowability in fresh mixes. It was also comprehended that the mixing temperature of high performance concrete should be maintained within the range of 15 to 25°C to ensure the better control of air content and flowability.

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