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The use of quarry dust for SCC applications

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Abstract

Limestone powder has been the traditional material used in controlling the segregation potential and deformability of fresh self-compacting concrete (SCC). This paper deals with the utilisation of alternative materials, such as quarry dust, for SCC applications. Results from rheological measurements on pastes and concrete mixes incorporating limestone or quarry dust were compared. It was found that the quarry dust, as supplied, could be used successfully in the production of SCC. However, due to its shape and particle size distribution, mixes with quarry dust required a higher dosage of superplasticiser to achieve similar flow properties. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Filler; Granite fines; Rheology; Wastes

1. Introduction

Self-compaction is often described as the ability of the fresh concrete to flow under its own weight over a long distance without segregation and without the need to use vibrators to achieve proper compaction. The main functional requirements of fresh self-compacting concrete (SCC) have been well documented and discussed by many workers [1–5,8]. It is generally recognised that for SCC to perform efficiently, it should have an adequate plastic viscosity together with a low yield stress approaching the behaviour of a Newtonian fluid. To achieve these, some of the basic requirements are for mixes to have high powder content and the incorporation of surface-active agents, such as superplasticisers.

Inert fillers such as limestone are traditionally used to increase the powder content of SCC mixes. More recently, mineral admixtures have also been considered [6,7]

This paper presents results on the utilisation of granite fines as part of the powder content and discusses their compatibility with superplasticisers in SCC applications. These granite fines are often referred to as quarry or rock dust, a by-product in the production of concrete aggregates during the crushing process of rocks. This residue generally represents less than 1% of aggregate production. In normal concrete, the introduction of quarry dust to mixes is limited due to its high fineness. Its addition to fresh concrete would increase the water demand and consequently the cement content for given workability and strength requirements. Thus, the successful utilisation of quarry dust in SCC could turn this waste material into a valuable resource.

Another potential benefit in the utilisation of quarry dust is the cost saving. Obviously, the material costs vary depending on the source. In Singapore, the price of limestone powder as delivered can be as high as Portland cement (OPC). In this respect, the utilisation of quarry dust could play a part in lowering the supply cost of SCC, which is currently some 80–150% higher than that of normal concrete. In Sweden, the application of SCC is well established and according to Petersson [16], the cost of SCC is only 10–15% higher, while in France [17] the cost is 50–100% higher than normal concrete. Although SCC offers many technical and overall economical benefits, the higher supplied cost of SCC over normal concrete has limited its applications. Attempt to reduce the cost of construction with SCC based on a sandwich concept has been made [18].

2. Characteristics of powders

In general, powder is referred to as materials with particle sizes less than 0.125 mm [10] and these include cementi-

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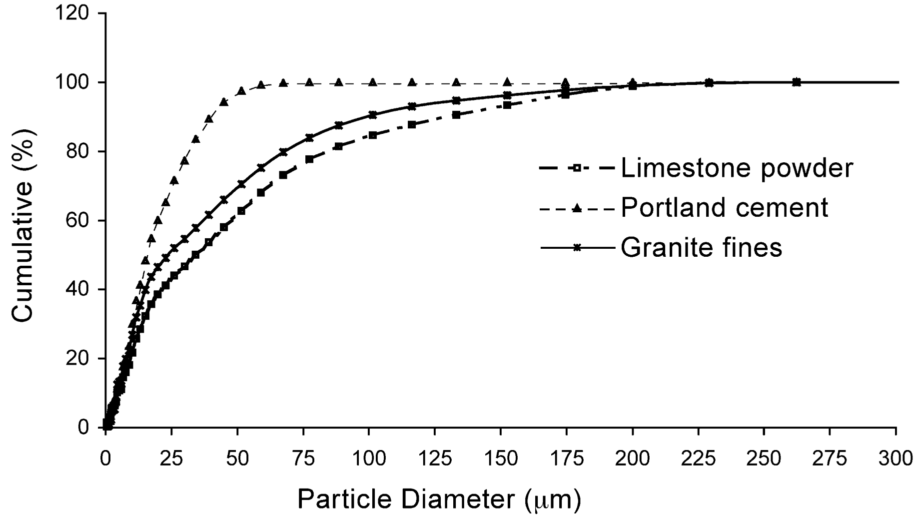

Fig. 1. Particle size distribution (cumulative percent) of powders used.

tious materials and inert fillers. According to Billberg [2], the rheology of concrete can only be optimised if the fine mortar part of concrete is designed so that its rheology is optimised. In this respect, fine mortar phase refers to particles less than 0.250 mm.

In this paper, powder refers to OPC, limestone (LS) and granite fines (GR) as supplied. The particle size distribution of the powders used in this study is presented in Fig. 1. Other physical properties are presented in Table 1. These properties were obtained using HORIBA Laser Particle Size Distribution Analyzer. As indicated, granite fines were finer than limestone powder and only a small portion (less than 0.5%) of granite fines or limestone has particles sizes greater than 0.250 mm. Fig. 2 presents typical images showing that the shape of granite fines is flakier and more elongated compared to limestone particles. These differences in shape and size distribution between inert fillers would have a large influence on the flow properties of SCC.

Rock types such as limestone and granite are commonly used in concrete without known chemical interactions with other mix constituents. However, superplasticisers are surface-active agents and possible influences due to mineralogical nature of these powders on surface effects may exist. Furthermore, the fineness of the granite fines may promote durability problem such as alkali–silica reactions. These issues warrant future investigations.

Table 1
Physical properties of powders

	OPC	GR	LS
Specific gravity	3.15	2.60	2.65
Specific surface area (cm^2/cm^3)	8364	6743	5946
Mean diameter (mm)	0.0195	0.0409	0.0506
Median[a] (mm)	0.0157	0.0238	0.0343
Mode[b] (mm)	0.0175	0.0106	0.0554

[a] Median: particle size dividing population exactly into two equal halves.
[b] Mode: the most common value of frequency distribution.

3. Paste rheology

It is well recognised [9,11,15] that the basic properties influencing the performance of fresh concrete in casting and compaction is its rheological behaviour, which is characterised through the yield stress and apparent plastic viscosity, defined most commonly by the Bingham model.

A coaxial-cylinder rheometer (Haake Votovisco 1) was used to determine the Bingham parameters for the pastes. This equipment can handle 0.9-mm maximum size particles. A series of preliminary investigations was carried out initially to identify the limitations of this equipment when applied to cement pastes. For the materials used in this study, it was found necessary to determine Bingham parameters by using a ramp-up strain rate from 0 s^{-1} to a maximum of 200 s^{-1} over a period of 5 min. Typical results are shown in Fig. 3.

Below strain rates of 50 s^{-1}, the flow curve may show irregular patterns with one or more peaks. This could be the fluidification of the paste resulting in a thixotropic region [12]. This behaviour was found to be typical of pastes with low water/powder (W/P) ratio having an inadequate or overdose of SP. For strain rates above 150 s^{-1}, some pastes showed signs of excessive shearing and exhibited the effect of shear thinning or thickening [13,14]. This paper reports the Bingham linear regression on strain rates between 50 and 150 s^{-1}. Note that these strain rates are arbitrary chosen and the resultant yield values and plastic viscosities are consequently mathematical parameters and not physical properties. It is expected that the strain rates chosen are dependent on the mix constituents and the equipment used. This may explain why the operating limits of yield stress and plastic viscosity for SCC [10] reported by various researchers were different and varied over a wide range.

In this research, it was considered necessary to determine firstly the influence of superplasticisers on rheological properties of plain cement pastes. Two commercially available

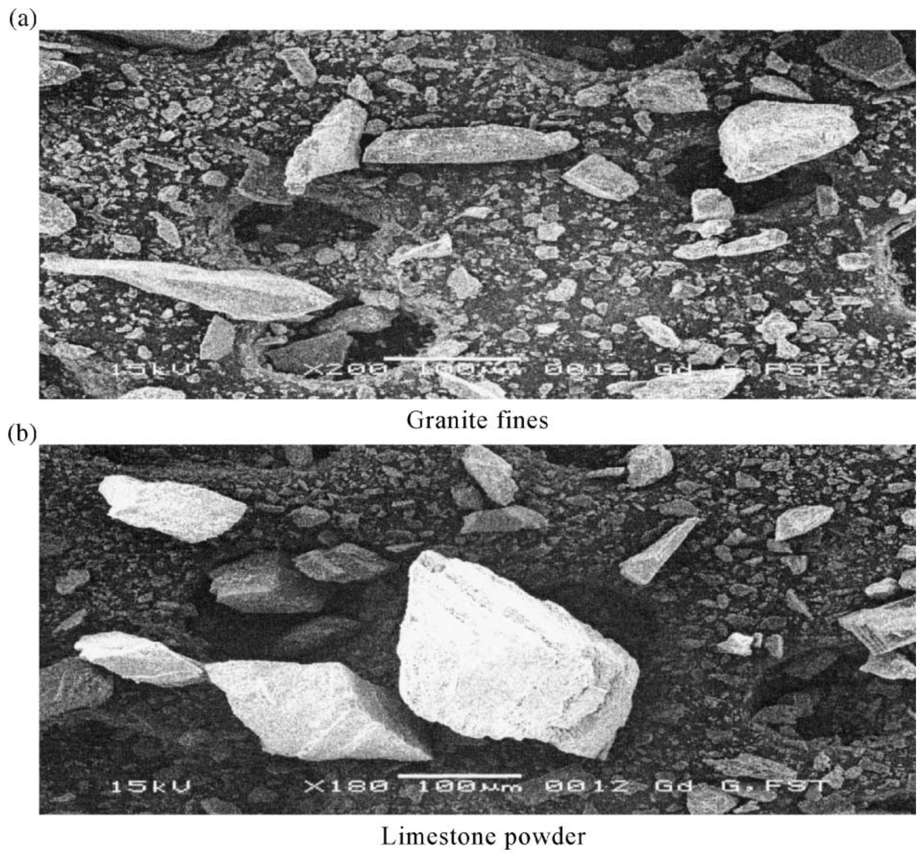

Fig. 2. Particle shapes of (a) granite fines and (b) limestone powder as supplied.

superplasticisers were used, identified as SPM and SPA. They belong to a new generation of superplasticisers based on polycarboxylated polyether and have been developed specifically for the production of SCC. Their solid contents by weight quoted by suppliers were 40% for SPM and 35% for SPA. Both admixtures comply with ASTM C494 Type F, Standard Specification for Chemical Admixtures for Concrete. Secondly, the influence of inert fillers and their compatibility with SPM and SPA on flow properties was investigated. In the second part, four sets of pastes were

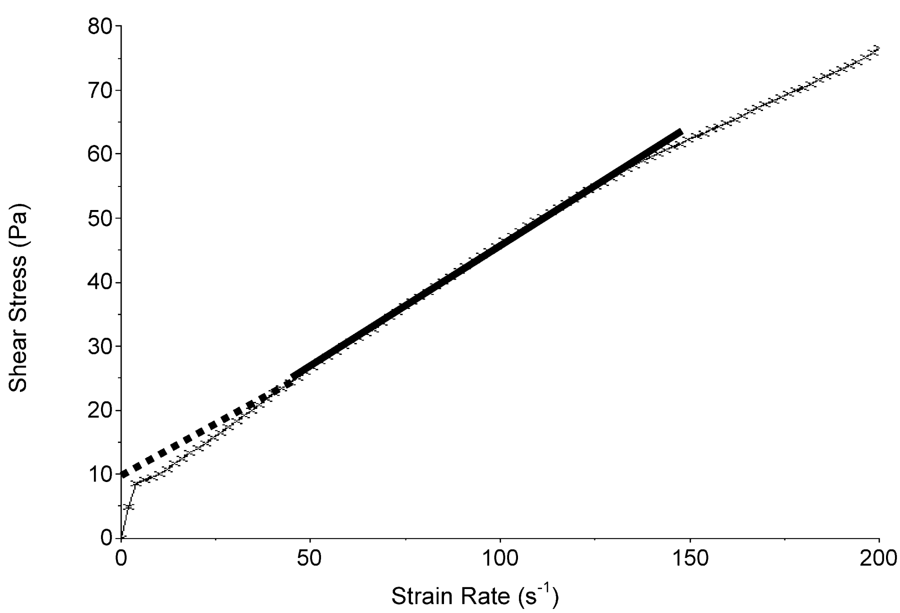

Fig. 3. A typical flow curve with Bingham linear regression performed.

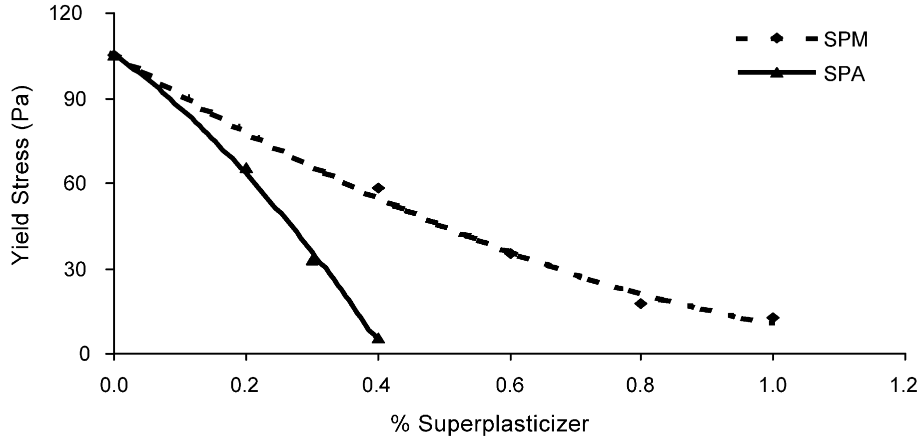

Fig. 4. Effect of different superplasticiser on yield stress of plain cement paste.

considered, and for each set of pastes incorporating granite fines or limestone powder, the inert filler represented 35%, 45% and 55% of the total powder content.

Superplasticiser was added such that yield stress of the cement paste approached zero. Pastes were obtained based on a W/P ratio of 0.36. This ratio was also used in the concrete mix design of SCC. For the paste investigation and ease of presentation, the superplasticiser dosages were expressed as percentages by weight of the total powder content.

The effect of different superplasticisers on Bingham parameters is demonstrated in Figs. 4 and 5. These results suggest that superplasticiser SPA is much more effective than SPM in reducing both the yield stress and apparent viscosity of these OPC pastes. In this example and for yield stresses approaching zero, the dosage required for SPM was about twice the amount needed for SPA. Similar trend was observed for other mixes incorporating limestone or granite fines (Table 2). It is generally recognised that the incorporation of superplasticisers reduces mostly the yield values and causes a limited decrease in apparent viscosity. Results from this study gave similar findings.

The demand for superplasticiser varied depending on the inert powder used. For example (Fig. 6), with inert filler content of 35%, the dosage of SPA required to reduce the yield stress to a common value of 20 Pa was 0.35% for paste incorporating granite fines compared with 0.15% for the limestone paste. Results presented in Table 2 also suggested that for low yield stresses, the amount of superplasticiser needed for granite mixes was generally doubled compared to corresponding limestone mixes. This would result in a higher cost of superplasticiser if granite fines were used instead of limestone powder in SCC production. This financial aspect must be taken into account if wastes, such as quarry dust, are utilised in concrete production for the purpose of cost saving. Due to the presence of coarse and fine aggregates in concrete mixes, the actual difference in superplasticiser dosages between mixes needs to be established as they may be slightly different to those obtained from pastes.

4. SCC concrete mixes

Four mixes were required in order to study the influence of inert fillers on the rheology of SCC. The mixes had W/P of 0.36 and the amount of granite fines and

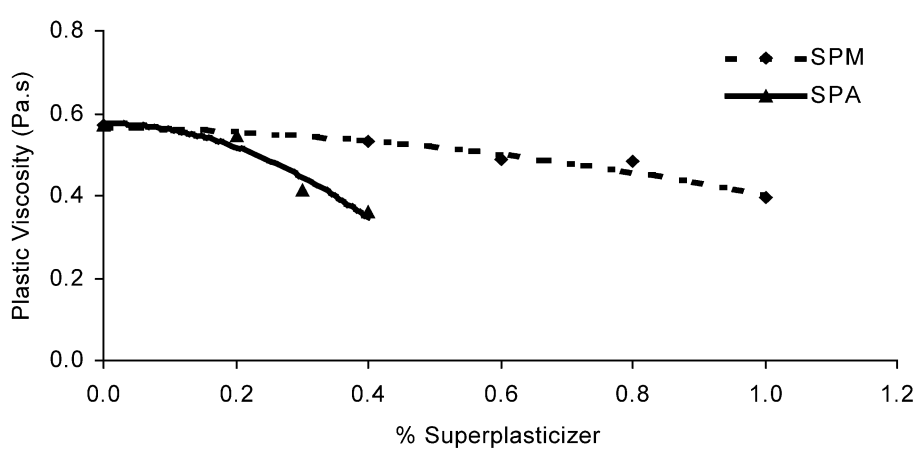

Fig. 5. Effect of different superplasticiser on plastic viscosity of plain cement paste.

Table 2
Bingham values of pastes with different inert powders and superplasticisers

Inert powder		% Superplasticiser		Yield stress (Pa)		Plastic viscosity (Pa.s)	
Type	%	SPM	SPA	SPM	SPA	SPM	SPA
Granite	35	0.40	0.20	41.7	61.0	0.37	0.38
		0.60	0.40	10.1	10.6	0.33	0.36
		0.80	0.50	6.7	1.9	0.30	0.34
	45	0.40	0.20	40.1	67.8	0.37	0.37
		0.60	0.40	2.8	17.2	0.28	0.33
		0.80	0.50	2.1	4.1	0.24	0.31
	55	0.40	0.20	35.3	29.7	0.39	0.36
		0.60	0.40	9.8	12.9	0.33	0.30
		0.80	0.50	2.8	2.8	0.24	0.26
Limestone	35	0.20	0.10	30.1	33.4	0.37	0.26
		0.30	0.15	8.8	10.8	0.27	0.21
		0.40	0.20	4.3	1.4	0.24	0.17
	45	0.20	0.10	14.2	23.3	0.24	0.22
		0.30	0.15	3.5	10.2	0.21	0.21
		0.40	0.20	–	4.3	–	0.19
	55	0.20	0.10	3.8	12.8	0.22	0.20
		0.30	0.15	0.4	6.3	0.18	0.18
		0.40	0.20	–	2.6	–	0.16

limestone powder used were either 35% or 50% by weight of the total powder content. Thus, GR35 represented the mix incorporating 35% granite fines. Superplasticiser SPA was introduced in all mixes. Mix details are shown in Table 3.

As indicated by results presented in Table 4, SCC mixes were successfully produced with similar flow properties using either granite fines or limestone powders. The slump flow values and blocking ratios obtained from L-box measurements were within recommended limits [1]. For granite mixes GR35 and GR50, the SPA dosages were higher than those required for limestone mixes of LS35 and LS50, respectively. This observation was consistent with the earlier finding obtained from pastes. For these concrete mixes and for materials used in this study, the difference in dosage was about 25%.

In order to confirm further the "self compactability" of concrete incorporating granite fines, a number of SCC

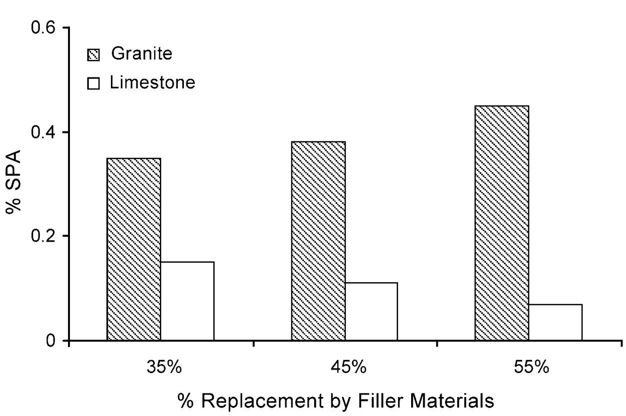

Fig. 6. SPA dosage requirement for different inert fillers for yield stress of 20 Pa.

Table 3
Mix details for SCC

Mix	Filler (% of powder)	Cement (kg/m^3)	Water (kg/m^3)	Coarse aggregate (kg/m^3)	Fine aggregate (kg/m^3)	SPA (l/m^3)
GR35	35	330	180	830	825	7.2
GR50	50	250	180	830	825	6.7
LS35	35	330	180	830	825	5.7
LS50	50	250	180	830	825	5.1

mixes of various proportions of OPC and granite fines were produced. Some of the specimens in each mix were consolidated using a vibrating table. The wet density and compressive strength of samples with and without vibration were compared and presented in Figs. 7 and 8. As indicated, the results were similar with compacted samples showing only a slight increase in density of 2% and strength of 5% higher. The small difference in results between SCC and intense vibration under laboratory conditions is likely to be less than that obtained between normal compacting practice on site and intense compaction on standard specimens.

The air content of two mixes was also determined. It was found that their initial air content was 3.4% and 4.5%. After compaction, the air content was reduced slightly to 3.3% and 4.4%, respectively. These results clearly demonstrated the self-compacting properties of these mixes and that granite fines could be used successfully to produce SCC. Note that technical information provided by the admixture supplier did not indicate the presence of air-entraining agent. However, some could have been included resulting in the high air content obtained.

5. Conclusions

Granite fines are often referred to as quarry dust, a by-product in the production of concrete aggregates during the

Table 4
Properties of granite and limestone SCC

Properties	Recommended values	GR35	GR50	LS35	LS50
Inert filler, type		Granite	Granite	Limestone	Limestone
Slump flow, spread (mm)	650–750	695	715	670	665
Slump flow, T 500 (s)		1.5	1.8	1.5	2.0
Slump flow, T final (s)		11.0	15.5	15.0	11.8
L-box, T 200 (s)		1.5	1.5	1.5	2.0
L-box, T 400 (s)		4.0	5.0	4.0	5.5
L-box, blocking ratio	0.75–0.85	0.82	0.83	0.80	0.75
28-d compressive strength (MPa)		42.0	25.0	36.5	24.5
Modulus of rupture (MPa)		4.0	3.0	4.0	3.0

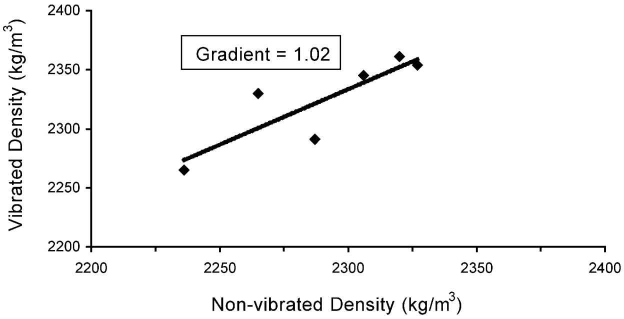

Fig. 7. Wet density (kg/m^3) of SCC mixes with and without compaction.

crushing process of rocks. For the materials supplied, the granite particles were finer than the limestone powder. The shape of the granite fines tends to be flakier and more elongated than the limestone particles. The difference in physical properties of these inert fillers affected the rheological properties of concrete.

This research demonstrated that the granite fines, as supplied, could be used successfully in the production of SCC. Compared to the use of limestone powder, both paste and concrete studies confirmed that the incorporation of granite fines required a higher dosage of superplasticiser for similar yield stresses and other rheological properties.

However, it is important to point out that as a waste material, the properties of granite fines are expected to vary over time. Furthermore, the fineness of granite fines could promote durability problems, such as alkali–silica reactions. These two issues would need to be addressed if the material is to be used with confidence.

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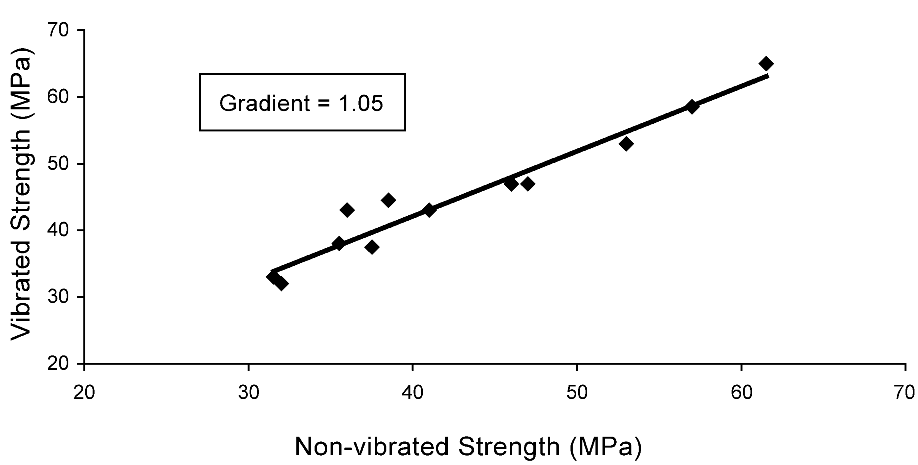

Fig. 8. Compressive strength of SCC mixes with and without compaction.

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