Rebound and Composition of in-Situ Polypropylene Fibre-Reinforced Shotcrete

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ABSTRACT

This paper presents the results of an experimental investigation into the rebound of polypropylene fibre reinforced shotcrete (PPFRSC). The effects of polypropylene fibre (PPF), fly ash (FA) and silica fume (SF) on the total rebound material and the composition of the in-situ shotcrete were investigated.

Six mixes were sprayed of which four mixes were initially optimised and investigated by laboratory tests. The remaining two mixes were commercially pre-packed shotcrete mixes. The total material rebound was measured and the factors affecting it were analysed. Samples were taken from the rebound and the freshly placed shotcrete for composition analysis.

About 80 % of the initial PPF dosage did not reach the mould and dropped in the area between the nozzle and the target surface. In general, the total rebound material was combined aggregate, of which the coarse aggregate represented about 60 to 75 %. Consequently, the presence of PPF had no effect on the total rebound material, whereas the coarse aggregate content, experience of nozzleman and binder type had noticeable influences. Mixes without coarse aggregate showed the least rebound. Fly ash was effective in reducing the total material rebound, particularly in the presence of silica fume. A reduction of 35 % and 55 % was observed for mixtures containing FA in the absence or presence of SF, respectively.

The composition of the in-situ shotcrete was significantly different from the proportions of the batched constituents. The in-situ shotcrete had much higher binder content and lower coarse aggregate content. The internal layer of the in-situ shotcrete was affected by the rebound more than the external layer.

KEYWORDS

Shotcrete, Rebound, Fly ash, Silica Fume, Polypropylene fibre

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1 INTRODUCTION

Fibres offer many advantages over traditional mesh reinforcement in shotcrete as they provide considerable benefits to all end-users including designers, contractors and owners. The most common fibres that are added to shotcrete are mainly steel fibres [Adams 1993; Cengiz and Turanli 2004]. However, using steel fibres has some disadvantages such as, hose wear and high cost. Polypropylene fibres (PPF), in contrast, do not have these adverse effects. Polypropylene fibre reinforced concrete (PPFRC) has an impact resistance and flexural toughness that compare favourably with those observed in concrete made with many other commercial fibres utilised at higher dosage rates [Malhotra *et al.* 1994]. The properties of PPFRC have been extensively researched [Badr *et al.* 2001; Bayasi and Zeng 1993; Zellers and Ramakrishnan 1994; Song *et al.* 2005; Badr *et al*. 2006; Sivakumar and Santhanam 2007]. However, there is very little information about using PPF in shotcrete. In particular, there is almost no information about the rebound of PPF and its effect on the total material rebound and, consequently, the composition of the in-situ shotcrete.

The process of applying shotcrete generally ensures that most of the aggregates and cementitious materials combine to form a mixture, which adheres well to the substrate. Unfortunately, considerable amounts miss the target or do not adhere to the substrate [Wood *et al.* 1993]. Rebound, which is the material that strikes the surface but does not adhere to it, is the most important and significant proportion of the total production losses. The rebound greatly influences the economic efficiency and also has an inconvenient environmental impact [Pfeuffer and Kusterle 2001]. The main questions that always arise with shotcrete applications are related to the amount of rebound [Jolin *et al.* 1999]. In addition to the economical and environmental factors, the amount of rebound and its composition has a direct effect on the composition of the in-situ shotcrete. Therefore, studying the amount of rebound and the factors affecting it are of great interest to the shotcrete industry.

2 MATERIALS, MIXES AND SPRAYING

2.1 Materials

Portland Cement (CEM1), conforming to BS EN 197-1 [2000], was used as main binder in this study. Fly ash and silica fume were used as cement replacement materials. The coarse aggregate used was quartzite natural gravel of 10-mm nominal maximum size. It had a specific gravity of 2.64, bulk density of 1585 kg/m3 and water absorption of 0.60 percent. Quartzite sand which complies with zone M of BS EN 12620 [2002] was used as a fine aggregate, with specific gravity and water absorption of 2.68 and 0.10 percent, respectively. Fibrillated PPF (Figure 1) were used in this study. The fibre has a length of 18mm and an average diameter of 55μm.

Figure 1. Polypropylene fibres used in this investigation.

2.2 Mixes

Six mixes were sprayed in this study. Four of these mixes were initially optimised from laboratory tests. The pre-sprayed composition of these four mixes is given in Table 1. The water content was decided during spraying by the nozelman according to the ease of 'shotability' of each mix.

The remaining two mixes were pre-packed mixes, which are commercially available for shotcrete applications. Both mixes (RDY1 and RDY2) were plain mixes (without fibres). A dosage of 2 kg/m^3 PPF was added to RDY1 in order to compare it to the other fibre-reinforced mixes. However, the producer of mix RDY2 recommended not to add fibres to the mix and, therefore, mix RDY2 was sprayed without fibres. Due to commercial reasons, the compositions of RDY1 and RDY2 are unknown except that both mixes did not contain coarse aggregate.

Table 1. Pre-sprayed mix proportions (kg *per* m^3).

Mixes	*CEM1*	*FA*	*SF*	*Gravel*	*Sand*	*Fibre*
CEM0	400	-	-	948	948	-
CEMF	400	-	-	948	948	2.0
FA30	280	120	-	948	948	2.0
FASF	248	120	32	948	948	2.0

2.3 Spraying

Shotcrete panels were produced by the dry process, which was more appropriate for this study due to economical and practical reasons. A dry-process pneumatic spraying machine was used with two rotary feed wheels for mixtures with and without coarse aggregates. For the former mixes, a 38-mm nozzle and material hose were used while a 25-mm nozzle and hose were used for the latter mixes.

Wooden square moulds of 1200-mm side and 100-mm depth were manufactured specially for this investigation. Before spraying, the moulds were positioned as vertically as possible (within 5 to 10°). Polyethylene sheets were placed underneath and around the moulds to collect the rebound.

For the laboratory developed mixes (CEM0, CEMF, FA30 and FASF), all ingredients except water were first mixed in the dry state in a conventional concrete mixer. Where applicable, PPF fibre was added after two minutes of dry mixing, which then continued for another two minutes. The dry mix was then fed through the hopper of the spraying machine, which conveyed the mix pneumatically through the material hose to the nozzle where water was added through the water ring. For all the shotcrete mixes, variations in the spraying process were minimised by keeping the shooting distance between the nozzle and the target-surface around one meter. Also, the spraying angle was as close to 90° as possible, as shown in Figure 2.

Figure 2. Spraying distance and angle were kept around one meter and 90°, respectively.

2.4 Measuring the Rebound and Composition Analysis

On completion of each shotcrete panel, the rebound was collected before starting the finishing process. After weighing the total material rebound, two representative samples were taken from each mix. The shotcrete surface profile was levelled to the edges of the mould using metal trowel. Immediately after finishing, samples of the in-situ shotcrete were taken from different locations.

The fresh samples taken from the rebound material and in-situ shotcrete were used for analysing the composition. A small part from each sample was immediately weighed and dried using a microwave oven to determine its water content, as recommended by BS 1881-128 [1997]. The remaining concrete was washed with an excessive amount of water and drained to separate the aggregate, which was then weighed to determine the total aggregate content in the sample. Using sieve analysis, the combined aggregate was then analysed to estimate the fractions of fine and coarse aggregates.

3 RESULTS AND DISCUSSION

3.1 Total Material Rebound

The total material rebound is shown in Figure 3. The values are given as a percentage of the finished in-situ shotcrete and also as a percentage of the total sprayed materials. The rebound values obtained for the different mixes are in good agreement with values reported by other investigators for dry-process shotcrete [Wood *et al.* 1993; Austin *et al.* 1996].

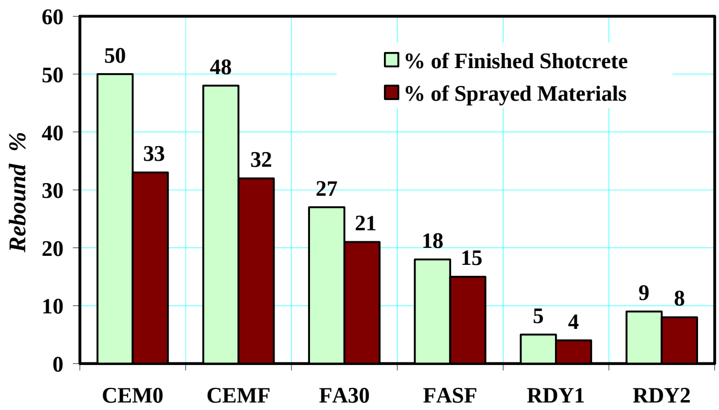

Figure 3. Total rebound as percentages of the finished shotcrete and of the sprayed materials.

It can be seen that the two ready-mixes RDY1 and RDY2 showed the least rebound due to the absence of coarse aggregate. In addition, since the nozzleman was familiar to spraying those mixes regularly his experience may have been a factor in reducing their rebound. The effect of the experience of nozzleman was previously reported [Adams 1993; Lars 1996]. The rebound of mixes containing fly ash (FA30 & FASF) was the best among the laboratory developed mixes.

The presence of PPF had no effect on material rebound, as the difference between the rebound of the control mix CEM0 and its counterpart fibre reinforced mix (CEMF) was negligible, as shown in Figure 3. Fly ash and silica fume effectively reduced the total material rebound. The use of fly ash reduced the rebound of the sprayed materials by about 35 % compared to the CEMF mix. Fly ash was even more effective in the presence of silica fume as the combination between them resulted in a reduction of about 55 % so that the rebound was only 15 % of the total sprayed material.

3.2 PPF Rebound

Most of the polypropylene fibres did not reach the target surface. On exiting from the nozzle, PPF separated from the concrete mixture due to the insufficient wet mixing. Consequently, and as a result of a different density, PPF gained a lower velocity compared to other constituents. Therefore, a considerable amount of PPF dropped down between the nozzle and the target surface, as shown in Figure 4. It was estimated that only 20 % of the fibres reached the mould. It can also be seen from the same figure that other constituents rebounded adjacent to the mould, unlike the fibres. The authors suggest that producing PPFRSC using the wet-process could probably eliminate this problem. It is expected that PPF would not be separated from a well-mixed matrix. However, the dry-process should still be able to produce this type of concrete if the initial fibre dosage was much higher the original fibre content. A factor of 5 could be used as a rough guide. Although this might appear a high factor, the low cost of PPF would not cause a noticeable increase on the total cost of the shotcrete.

It should be mentioned that the problem of embedding fibres in fresh-shotcrete is common regardless of the fibre type. For example, high number of steel fibres in the rebound and the insufficient adhesion of steel fibres to the shotcrete are always observed and have been subject to theoretical studies in attempts to understand and minimise this problem [Burge 1986; Cengiz and Turanli 2004].

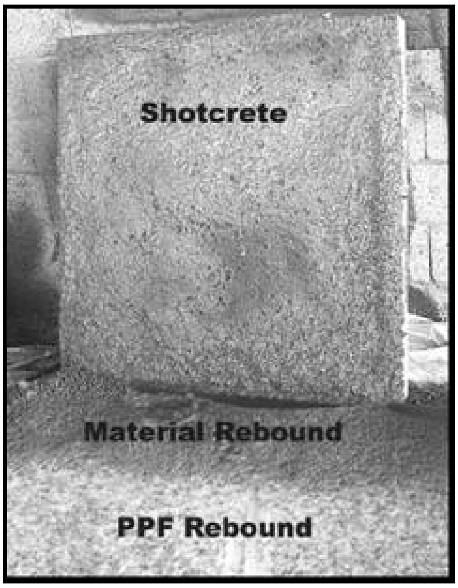

Figure 4. Material and fibre rebound.

3.3 Composition of the Rebound

Individual constituents rebound by different amounts due to their different sizes and densities. Samples from the rebound material were analysed in order to estimate the amount of each constituent. The estimated quantities were used to calculate important ratios such as coarse aggregate-to-rebound (g/R) and fine aggregate-to-rebound (s/R), as shown in Table 2.

The composition of the rebound was mainly combined aggregate with a high percentage of gravel. On average the combined aggregate in the rebound was about 80% of the total rebound material. About two-thirds of the combined aggregate in the rebound consists of coarse aggregate, which represented more than 50 % of the total rebound material compared to 27% fine aggregate in the rebound. Therefore, the gravel-to-sand ratio in the rebound was 2:1, whereas it was 1:1 in the pre-sprayed mixture. This can be attributed to the fact that heavier particles rebound more than the lighter sand grains and cementitious materials. This finding explains the low rebound values for the ready-mixes RDY1 and RDY2 as they did not contain coarse aggregate. However, it can be seen that neither PPF nor the binder type has clear effect on the total aggregate content in the rebound.

Table 2. Constituents of the rebound materials.

	Composition (kg *per m*^{3})				*Ratios*			
	Binder (*b*)	Gravel (*g*)	Sand (*s*)	Water (w)	*(g+s)/R*	*g/(g+s)*	*g/R*	*s/R*
CEM0	433	1361	757	63	0.81	0.64	0.52	0.29
CEMF	564	1277	646	95	0.74	0.66	0.49	0.25
FA30	520	1178	796	90	0.77	0.60	0.46	0.31
FASF	383	1602	544	69	0.83	0.75	0.62	0.21
Average	475	1355	686	79	0.79	0.66	0.52	0.27

3.4 Composition of the in-Situ Shotcrete

Samples of fresh in-situ shotcrete were analysed and the proportions are shown in Table 3. Comparing Table 3 to Table 1, it can be seen that the in-situ concrete proportions were different from those of the batched concrete. The shotcrete had much higher binder content and lower coarse aggregate content. The average binder content was about 700 kg/m^3, which is 75 % more than the intended 400 kg/m^3. This very high binder content could provide potential for alkali-silica reaction and early cracking through high heat of hydration [Cabrera and Woolley 1996]. It can also be noticed that the increase of the binder content was at the expense of coarse aggregate, which on average decreased to 592 kg/m^3, whereas the average fine aggregate content actually increased slightly from 948 to 994 kg/m^3.

Table 3. Composition of the in-situ shotcrete.

	Composition (kg *per m*^{3})				*Ratios*	
	Binder (*b*)	Gravel (*g*)	Sand (*s*)	Water (w)	w/*b*	*(g+s)/b*
CEM0	727	487	1079	179	0.25	2.15
CEMF	730	585	916	202	0.28	2.06
FA30	749	674	924	159	0.21	2.13
FASF	605	623	1057	174	0.29	2.78
Average	703	592	994	179	0.26	2.28

The w/*b* ratios of in-situ shotcrete varied from 0.21 to 0.29, with an average of 0.26, which can be considered as low values. This, in fact, is the main advantage of the dry-process because a high workability is not a requirement as the case for the wet-process.

There was no significant difference in the w/*b* and *(g+s)/b* ratios for mixes CEM0 and CEMF, indicating that PPF had no effect on the composition of in-situ shotcrete. As with conventional concrete, fly ash reduced the water demand for the shotcrete. However, adding silica fume to the fly ash mix resulted in a w/b ratio equal to that of the CEMF mix.

It was interesting to notice that the internal layer of the in-situ shotcrete was affected more by the rebound than the external layer. Most aggregate rebound from the first layer, as the particles hit the hard substrate with high velocity and rebound. The first layer forms a relatively soft substrate for the next layer and, therefore, the rebound from the external layer was less, as can be seen from Figure 5 (the yellow line indicates the demarcation between the first and subsequent layers). It can be seen that the internal layer (mould side) had very little aggregate compared to the external layer (spraying side).

Figure 5. Composition of external and internal layers of the FASF in-situ shotcrete.

4 CONCLUSIONS

For the shotcrete mixes and PPF used in this investigation, the following conclusions can be made:

- About 80 % of the initial PPF dosage did not reach the mould and dropped in the area between the nozzle and the main rebound material, which was next to the target surface. Consequently, the addition of PPF had no effect on the total rebound material, whereas the binder type had an obvious influence.

- Fly ash was effective in reducing the total rebound, particularly in the presence of silica fume. FA reduced the rebound by 35 % and 55 % in the absence or presence of SF, respectively.

- The sprayed materials rebound by different amounts due to different sizes and densities. The composition of the rebound was mainly aggregate with high percentage of coarse aggregate. On average, the combined aggregate was about 80 % of the total rebound material, of which the coarse aggregate represented about two-thirds. Neither PPF nor the binder type had a clear effect on the total aggregate content in the rebound.

- The composition of the in-situ shotcrete was significantly different from the proportions of the batched constituents. The in-situ shotcrete had much higher binder content and lower coarse aggregate content. The internal layer had less aggregate compared to the external layer.

- PPF had no effect on the composition of in-situ concrete, whereas the binder type has noticeable effect on the water-to-binder and aggregate-to-binder ratios.

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