Limestone Filler in Wet-Mix Shotcrete

by Louis-Samuel Bolduc, Étienne Crépault, and Marc Jolin

The introduction of limestone filler in concrete mixtures has received increasing attention from researchers over the last decade. It is now generally well accepted that this product brings many benefits to both fresh and hardened concrete. Interesting and promising studies (Nehdi et al. 1998; Poppe and Schutter 2005; Esping 2008) have shown that controlled incorporation of limestone filler can:

- Improve workability and stability of fresh concrete;
- Increase the volume of paste;
- Reduce the heat of hydration, and therefore reduce the potential for thermal cracking;
- Reduce autogenous deformations and plastic shrinkage, again reducing the potential for cracking;
- Increase the mechanical properties; and
- Even slightly increase the early-age strengths.

The most interesting use of limestone filler is as a partial replacement of portland cement, particularly in high binder content mixtures where premature cracking may occur more easily. The incorporation of this product in high cement content mixtures can also significantly reduce the overall cost of the material. Moreover, with today's concerns and actions toward sustainability, the use of limestone powder in concrete reduces landfill disposal impacts as well as contributing to the reduction of the impact of the cement manufacturing process. A study from Audenaert and al. (2006) has also shown that the use of a filler with a fine gradation has no negative impact on the transport properties and the durability of concrete when used as partial replacement of portland cement.

This article presents a few results of a study undertaken by the shotcrete team at Laval University in Quebec, Canada. The main objective was to assess the potential improvements brought by the use of limestone filler in wet-mix shotcrete, particularly in its fresh state. The parameters studied are the rheology of the fresh concrete mixtures and the resulting pumping pressures.

Fig. 1: Limestone filler

Test Program

The idea behind this project was to further investigate concepts brought forth by Burns (2007) where mixtures containing different paste contents were prepared and pumped. His findings included a parameter named the critical paste content, defined as the volume of paste under pressure below which it is likely that blockage will occur in the conveying line (for a given aggregate gradation curve). Because fine limestone filler is often considered to increase the amount of lubricating paste in concrete mixtures, a series of new wet-mix shotcrete mixtures were prepared where 8% of the binder phase was replaced by an inert filler to ascertain the effect on fresh concrete and its pumpability.

The significance of this study resides in the fact that very little information is available in the literature concerning the effect on rheological properties of limestone filler in concrete and that, in fact, no information at all is available regarding wet-mix shotcrete.

Methodology

The methodology used in this study is to compare a control mixture with other mixtures where 8% of the binder is replaced by inert limestone filler. Different dosages of high-range water-reducing admixture and air entraining admixture (AEA) were also tested to cover a broad range of mixture designs used in Canada. The selected mixtures are presented in Table 1. The percentage in the mixture identification represents the targeted air content prior to pumping.

All mixtures were made from prebagged materials. The limestone filler used in this study is marketed under the name Betocarb™ 3-SA, produced by OMYA Inc. Betocarb™ 3-SA is mainly composed of calcium carbonate, and the particle size ranges between 0.0197 and 0.3937 mil (0.5 and 10 μm). As shown in Table 1, the water-cementitious material ratio (*w/cm*) of Control 3% is lower than that of the other mixtures.

Table 1: Mixture characteristics

Mixture	*w/cm*	Type GU cement		Silica fume		Limestone filler		Fine aggregate, < 0.2 in. (5 mm)		Coarse aggregate, 0.1 to 4 in. (2.5 to 10 mm)		Water		High-range water-reducing admixture	AEA
		lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	lb/yd^3	kg/m^3	L/m^3	L/m^3
Control 3%	0.40	714.2	423.7	56.5	33.5	—	—	1488.3	883	1368.7	812	308.8	183.2	3522	—
Filler 3%-A	0.44	654.3	388.2	57.0	33.8	58.1	34.5	1501.8	891	1378.8	818	311.3	184.7	4568	—
Filler 3%-B	0.44	655.8	389.1	57.0	33.8	58.2	34.5	1505.2	893	1382.2	820	310.8	184.4	4984	—
Filler 13%	0.43	604.8	358.8	52.6	31.2	53.7	31.8	1387.2	823	1274.3	756	285.5	169.4	4267	1182

Note: AEA=air-entraining admixture

Table 2: Fresh concrete properties and pumpability

Mixture	Slump		Air content, %	Paste content, %	Rheological properties		Pumping pressures	
	in.	mm			Yield stress, N-m	Plastic viscosity, N-m-s	Gauge #1 Bar	Gauge #2 Bar
Control 3%	3.1	77	4.6	38.0	6.8	7	31.70	33.82
Filler 3%-A	1.6	39	3.7	37.5	14	3.6	38.61	40.67
Filler 3%-B	3.1	78	3.5	37.4	7.7	4.1	30.33	31.44
Filler 13%	2.7	68	11	42.2	4.6	4.7	33.30	33.78

This makes sense because for the same amount of water, a portion of the binder is replaced by inert filler. Therefore, the ratio of water/effective cementing material is increased. In this study, the inert filler is used in place of cement as the small particles (<7.86 mil [200 µm]) are considered as part of the lubricating paste (Corinaldesi and Moriconi 2008; W.R. Grace and Co. 2005). As often found in fresh concrete studies, the *w/cm* is not a significant parameter in the rheology of concretes with high-fine content.

The concrete was produced in Laval University's laboratory and pumped into 50 ft (15 m) of 1-1/2 in. (38 mm) (inside) diameter rubber hoses. Along with the mounted mixer, the pump was a two-piston hydraulic pump with rock valve (Allentown Powercreter 10 Pump). Two pressure gauges, connected to a data acquisition system, were placed at the outlet of the pump to measure the pressure exerted on the concrete within the hose. They were placed at locations where the pressure would be maximal. The first one was mounted at the outlet of an elbow-type reducer (3 to 2 in. [76.2 to 50.8 mm]), and the second one was placed at the outlet of a straight line reducer (2 to 1-1/2 in. [50.8 to 38.1 mm]).

The apparatus used to measure the rheological properties was an IBB rheometer. It consisted of a motor that drives an H-shaped impeller with a planetary motion through a recipient filled with concrete. The speed of the impeller and the torque generated by the restricted motion were measured. By recording torque at different speeds, it was possible to represent the Bingham behavior of concrete. Therefore, the yield stress and the plastic viscosity were determined.

Fig. 2: Pressure gauges

Fig. 3: IBB Rheometer

Results and Discussion

The results from the laboratory testing are presented in Table 2. It should be noted that the mixtures prepared and pumped were done so in the order followed in Table 2. Therefore, a particular mixture design is based on the results obtained on the previous mixture.

First, the control mixture was inspired by Burns (2007); the Control 3% mixture was found to have the minimum paste content required for pumping. For the mixture Filler 3%-A, instead of incorporating only portland cement and silica fume, limestone filler was added. Note that the filler added to Filler 3%-A brought the fine content to the same volume as that of Control 3% mixture. The first two rows of Table 2 indicate that incorporation of limestone filler increased the yield stress and decreased the plastic viscosity. Even if the viscosity was reduced, however, the pumping pressure increased by approximately 20%, which was obviously caused by the high yield stress (or low slump) value.

Following the very stiff consistency obtained, an extra quantity of high-range water-reducing admixture was added to reach the same slump as Control 3%. Thus, the third row indicates that for an equal slump, the yield stress of Filler 3%-B was similar to that of Control 3%, the plastic viscosity was decreased, and the pumping pressures were slightly reduced.

Finally, the objective of the last mixture (Filler 13%) was to assess the influence of using the high initial air content concept (Jolin et al. 2000) on the rheological properties of fresh concrete containing limestone filler. The targeted air content before pumping was 13%, and the slump had to be similar to that of Control 3%. To obtain these properties, AEA was added to reach the targeted air content and then high-range water-reducing admixture was introduced to reach the slump needed. It is important to note that inevitably, if the water-binder ratio (*w*/*b*) is kept constant, the paste content is increased because of the higher air content (because air bubbles are considered to be part of the paste). Results show that for Filler 13%, the yield stress and viscosity were lower, and the pumping pressure was similar to that of Control 3%.

Conclusion

The main objective of this study was to assess the potential use of limestone filler in wet-mix shotcrete. Emphasis was placed on the pumpability of concrete containing a certain amount of inert filler. The important observation to keep from this short report is that, at equal slump, the replacement of cement by limestone filler seems to advantageously modify the rheological properties of fresh concrete (lower viscosity). It is possible to pump fresh concrete, containing a controlled amount of limestone filler, without increasing the pumping pressure in the conveying line.

Also, the incorporation of limestone filler allows a significant reduction of the cementing content in the mixture. This is particularly important and significant in the case of wet-mix shotcrete placed using small line pumps where the paste content required for pumping is higher than for larger hoses. The incorporation of inert filler could reduce the cost of the material, and also decrease the potential for cracking resulting from shrinkage and thermal effects. It appears that limestone filler represents a viable solution to resolve pumping problems.

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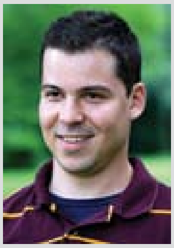

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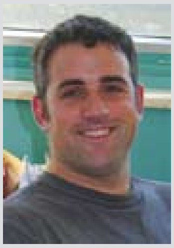

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