Preliminary investigation on the use of dolomitic quarry by-product powders in grout for self-compacting concrete applications

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ABSTRACT: Self-compacting concrete (SCC) flows under its own weight without requiring external vibration for compaction. This is very useful in applications where normal vibrated concrete cannot be used such as narrow forms and reinforcement congested members. To attain the self-compacting property, it is required that the concrete have adequate viscosity, high deformability and high resistance to segregation. This can be achieved by adding mineral admixtures (fillers) and/or viscosity modifying agents (VMAs). The former is the main practice in Europe and processed limestone powder is the most commonly used filler in the production of SCC. However, the quarrying process of the production of mineral aggregate results in large amount of fine materials (quarry dust) as a by-product. These significant amounts of environmental wastes pose a real concern to manufacturers due to their impact on the environment, leading to economic consequences. Dolomite powder, locally available from dolomitic quarry dust, can be utilised as an alternative material to produce SCC. This paper, therefore, investigates the fresh properties of cement grout using dolomite powder as a cement replacement compared to limestone powder. Preliminary characterisation of the dolomitic powder as well as the workability, flowability, cohesion and strength of the grout were examined to understand the influence of using the dolomite powder on these properties. Mixes containing 0-20% of dolomite powder and limestone powder were prepared. Mini slump, Marsh cone and Lombardi plate were used to observe the fresh properties of grout containing these powders, while compressive strength will be measured for all hardened samples at 7 and 28 days.

KEY WORDS: Self-compacting concrete; Dolomite; Grout; Quarry.

1 INTRODUCTION

Quarry dust, or quarry by-product powder, is a waste material, created as a by-product of aggregate production. Due to the large number of aggregates which are manufactured, the chemical compositions of quarry dust vary greatly [1]. However, this material offers the opportunity for aggregate manufacturers to streamline their processes by utilising a waste product, therefore reducing time spent disposing of this material and possibly increasing revenue through using it to replace proportions of cement. While increasing sustainability of the cement, overall cost of production would decrease making this an attractive idea for both cement and aggregate manufacturers [2].

One of the potential applications to use quarry dust is in self-compacting concrete (SCC) as it utilises large quantities of finely ground materials to attain the required viscosity, deformability and resistance to segregation [3]. Grout mixes are often used to test the compatibility of a mix prior to embarking on a full trial with concrete mixes [4]. Concrete trials are often heavily resource, energy and time consuming, thus smaller grout mixes are often a fruitful first approach to initially test the compatibility of the mix components in a more time and cost-efficient way. Through these trials, non-efficient cement and superplasticizer combinations are often discovered and this prevents large amounts of resources being wasted during the testing process [4].

The fresh and mechanical properties of grouts can be altered by numerous factors including the water-binder ratio, the use of chemical admixtures and the use of fillers/supplementary cementitious materials within the grout.

The use of fillers and supplementary cementitious materials would largely influence rheological and mechanical properties on grout and concrete, depending on both the chemical composition of the material and the proportion of it used within the mix [5]. Typical supplementary cementitious materials used within the construction industry include fly ash, ground granulated blast furnace slag (GGBS), silica fume and rice husk ash. These are industrial by-products and so produce a more sustainable building material. Limestone and finely ground silica are examples of mineral filler materials which are often used within cementitious suspensions. The use of mineral fillers, such as limestone, to replace proportions of ordinary Portland cement (OPC) typically produces a more workable, less cohesive mixture with a decreased compressive strength [6–8].

In their work Esquinas et al. [9,10] concluded that it is possible to obtain good quality SCC concerning durability by replacing commercial siliceous filler (SF) with dolomitic recovery filler, sourced from hot-mix asphalt plants (RF), with good performance in terms of aggressive agent attack, according to the levels set by the Spanish Code for Structural Concrete. Similarly, Dehwah [11] evaluated the mechanical properties of self-compacting concrete (SCC) prepared using quarry dust powder (QDP), silica fume (SF) plus QDP or only fly ash (FA) and reported that incorporating QDP (8–10%) had mechanical strengths equal to or better than those of SCC prepared with either SF plus QDP or FA alone.

Ho et al. [1] compared the rheological properties of a quarry dust from granite fines and processed limestone powder and 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. Some quarries contain large amount of dolomitic rocks and the utilisation of their processing dust in concrete is yet to be investigated.

Therefore, the aim of this study is to assess the effect of a quarry dust (QD) from dolomitic source and a processed limestone powder (LS) on the fresh and mechanical properties of cement-based grouts as a necessary step towards full utilisation in SCC mixes. Different proportions of LSP and QD were used as replacements for Portland cement. Various percentages of replacement were carried out at two different superplasticizer dosages. This will allow the extent of the impact of superplasticizer on the fresh properties of the mixes, containing each of the fillers, to be compared. While LSP is already a commonly used filler for cement replacement, carrying out mixes containing limestone allows for comparisons to be drawn between a filler which is known to be effective for this purpose and a filler which has different properties.

2 MATERIALS AND METHODS

2.1 Materials

CEM I 52.5 was used as the main binder in this study. Processed limestone powder (>95% $CaCO_3$ and Quarry dust powder (mainly dolomitic) were the main fillers in this study. Commercial SP, based on modified polycarboxylate polymers, was used.

It should be noted that the quarry dust was collected from the accumulated stack in a local quarry and dried in an oven at 105 ℃ ±5℃. Once dried, the powder was ground in a pestle and mortar.

2.2 Mix Design

To ensure that the effects of the quarry dust and limestone could be thoroughly analysed and compared, a total of 12 mixes were carried out (details of the mixes are presented in Table 1). One of these mixes was a reference mix of only cement, to allow for comparison of properties. Each filler replaced cement at proportions of 5%, 10%, 15% and 20%.

Table 1. Mix design.

Filler type	Mix	Cement %	Filler %	W/B	SP dosage%*
None	1	100	0	0.4	0.3
	2	100	0	0.4	0.4
LS	3	95	5	0.4	0.3
	4	90	10	0.4	0.3
	5	85	15	0.4	0.3
	6	80	20	0.4	0.3
	7	80	20	0.4	0.4
QD	8	95	5	0.4	0.3
	9	90	10	0.4	0.3
	10	85	15	0.4	0.3
	11	80	20	0.4	0.3
	12	80	20	0.4	0.4

* As a percentage of the dry mass of powders

A water-binder ratio of 0.4 was constant throughout all mixes. A superplasticizer (SP) dosage of 0.3% was used for all percentages of filler replacement. However, two additional mixes were carried out at a filler replacement of 20% with an SP dosage of 0.4% alongside an additional mix with 0% filler replacement and an SP dosage of 0.4%. These additional mixes gave an indication of the impacts of superplasticizer on the workability of the mix.

As this is an initial investigation into the effects of quarry dust and limestone on the grout mixes, the filler proportions were the only factor varied within this investigation. Additionally, three mixes at a higher superplasticizer dosage were produced to study the effect of SP dosage.

2.3 Mixing and Testing

All grout mixes which were prepared had a volume of 1.2 litres. In an effort to keep all factors, except for filler replacement, constant, the mixing procedure for all mixes was standardised. This ensured the validity of the investigation. The room temperature was also kept as constant as possible throughout the investigation.

All mix components, except for water, were first measured in kilograms as per the mix design. This was carried out using the same scale for all mixes. The water was then measured using a measuring cylinder. The cement and filler were combined and mixed by hand in a separate container until the binder appeared evenly mixed.

The water was poured into the mixing bowl and the superplasticizer was then added. The wet mix components were then mixed for one minute at 140 rpm. Once this initial mixing was complete, half of the binder was introduced to the mix and these components were mixed for 30 seconds at 140rpm. The next step was adding the final half of the binder and mixing this for another 30 seconds at 140 rpm. Once this was completed, another minute of mixing at 140 rpm was carried out. The mixture was then left for 30 seconds of rest before 3 minutes of mixing at 200 rpm was completed.

Once this was completed, several tests were carried out to determine the fresh properties of the mixes. The first test which was carried out was the mini slump test, which was initially carried out approximately 2-3 minutes after mixing had been completed. The next test carried out was the Lombardi plate cohesion test, 5-6 minutes after the mixing. Then, the Marsh cone test was carried out approximately 9-10 minutes after mixing. The grouts were hand mixed thoroughly throughout the testing process to ensure fluidity of the mixes was kept as constant as possible. The mud balance was then used to calculate the specific gravity of the mix.

Upon completion of the workability tests, the grout was poured into 50mm x 50mm cube moulds for the 7- and 28-day compressive strength tests.

The mini slump test is carried out to test the workability of a grout mix, through measuring the spread of grout from a mould. A cone shaped mould and smooth plate were used to carry out this test. The cone shaped mould has an upper inner diameter of 19mm, a lower inner diameter of 38.1mm and a height of 57.1mm. The mould and plate were initially dampened with water to reduce friction between the fluid and the mould. The mould was placed on the centre of a smooth plate and consequently filled with grout. The cone was lifted vertically and the grout inside was allowed to flow freely. When the grout stops moving, the spread diameter was measured at four right

angles using a measuring tape. The average diameter is then calculated from these values.
The Lombardi plate test was used to measure the cohesiveness of the fluid mix. A thin steel plate and electronic scale were necessary for this test. The steel plate is 100 x 100mm with a thickness of 1mm. The steel plate was hung up and the set is then placed on top of an electronic scale and once the weight settles, the scale value set to zero. The clean, dry steel plate was then removed and submerged into the grout mix. Once fully covered, the plate was removed from the suspension and the excess fluid was allowed to drip. When the dripping stopped, the plate was hung back up on top of the scale. The final value on the scale is the amount of grout which has stuck to either side of the plate.
The density of the mix needs to be found, using the mud balance, prior to calculating the cohesion value. To find the relative cohesion of the mix, the weight of the grout remaining on the plate should be divided by the area of both sides of the plate and the density of the suspension.
For grouts, relative cohesion is calculated as a thickness and its units are therefore millimetres. A highly cohesive grout may have a relative cohesion between 0.2mm and 0.4mm, while low cohesion grouts may have relative cohesion values around 0.06mm [12].
The Marsh cone was used to indicate the flow properties of the grout mix. A flow cone and stand to hold the cone throughout the test, alongside a measuring cylinder are necessary for this test. The flow cone used is a metal cone with a capacity of 1500ml and an outlet orifice of 8mm diameter.
The inside of the flow cone was initially dampened with water to reduce friction between the grout mix and the cone. A measuring cylinder, which can hold at least one litre of fluid, was placed directly under the outlet. The flow cone was then filled with 1.2 litres of grout with the outlet covered. A timer should be started at the same time the outlet was uncovered. The time taken for 700ml of grout to flow through the flow cone was measured.
Grouts which take longer than 75 seconds are not suitable for use within grouting [12]. However, this is more relevant to grouts being tested for purposes such as injection grouting.
The mud balance is used to determine the specific gravity of a fresh cementitious suspension. Within this project the Fann 140 mud balance was used. The cup, within the mud balance, was filled by pouring grout into it from a measuring cylinder. The cup is full when a small amount of grout escapes from the top of the lid. This excess grout was then removed so it did not skew the results. The cup and beam were then placed on the fulcrum and the weight was adjusted until the system was balanced. The system is completely balanced when the bubble in the spirit level is centred. The density was then read off a scale at the bottom of the beam. In the case of this mud balance, the specific gravity is given in units of g/cm^3.
The grout was poured into 50mm x 50mm cube moulds for the 7- and 28-day compressive strength tests. Once the fresh grout was poured into the moulds, it was covered in polythene sheeting. After 24 hours, the cubes were removed from their moulds and placed into a curing tank which was set at 20°C until they were ready to be tested.
A Servo Plus compression testing machine was used to test three grout cubes from each mix at both 7 days and 28 days. Three cubes were tested from each mix, to allow for average values to be calculated.
The cubes were removed from the curing tank and dried before testing. They were then placed into the machine and loaded at a rate of 50kN/minute. The testing machine gave a value for both maximum load (kN) and maximum strength (MPa) of each cube.

3 RESULTS AND DISCUSSIONS

The results of mixes are summarised in Table 2. The additional mixes carried out, with a higher dosage of superplasticizer, were only tested for fresh properties and thus the mechanical test results for these mixes are marked as NA (not applicable) in the table. Several grout mixes (e.g. Mix10 and 11) were highly viscous to allow for effective testing. They stopped flowing through the Marsh cone before 350ml, therefore a flow time for 700ml could not be recorded in these instances. The results of these mixes were marked as NM (not measurable). The results will be discussed in the next sections.

Table 2. Results Summary

Mix	Mini slump (mm)	Cohesion meter (mm)	Flow time (s)	Specific gravity (g/cm^3)	fc' 7 days (MPa)	fc' 28 days (MPa)
1	117.5	0.25	141	2.10	81.4	97.5
2	131.5	0.14	106	2.00	NA*	NA
3	131.8	0.21	121	2.00	68.2	90.5
4	144.2	0.18	114	1.97	65.4	86
5	147.5	0.17	79	1.96	63.5	79.5
6	140.3	0.15	75	1.93	58.4	68.6
7	159.5	0.13	69	1.92	NA	NA
8	118.3	0.27	174	2.00	57.1	87.0
9	89.50	0.28	534	1.99	55.3	83.4
10	70.00	0.55	NM**	2.00	52.1	72.6
11	60.00	0.65	NM	2.10	48.8	49.1
12	91.60	0.52	148	1.98	NA	NA

*NA= Not applicable, **NM= Not measurable

3.1 *Mini slump*

The reference mix, containing only CEM I, showed a slump test value of 117.5mm. In comparison, the slump test associated with 5% replacement by LSP was 131.8mm, while the slump test associated with 5% replacement by QD was 118.3mm. A continued increase in filler replacement up to a percentage of 20% for limestone gave a slump test of 140.3mm and for quarry dust of 60mm. The trend in workability occurring for both fillers depending on percentage of replacement can be seen in Figure 1.
The results confirmed the expected behaviour that an increased proportion of LSP, as a cement replacement, increased the workability of the mixes. The highest workability, within the four limestone mixes, was observed at a percentage replacement of 15%. However, it should be noted that the decreased workability between a percentage of replacement of 15% and 20% was only 7mm and thus, could have been the result of a slight experimental error.
An increase in slump of 25.5% can be seen between the reference mix with no replacement and the most workable limestone mix. This increased workability is caused by the fineness of the limestone powder, in comparison with the

particle size associated with the Portland Cement. The improved particle size distribution is associated with the increased workability. Previous studies carried out by Svermova et al. [13] and Ramezanianpour et al. [14] showed a similar trend in workability with increased addition of limestone powder.

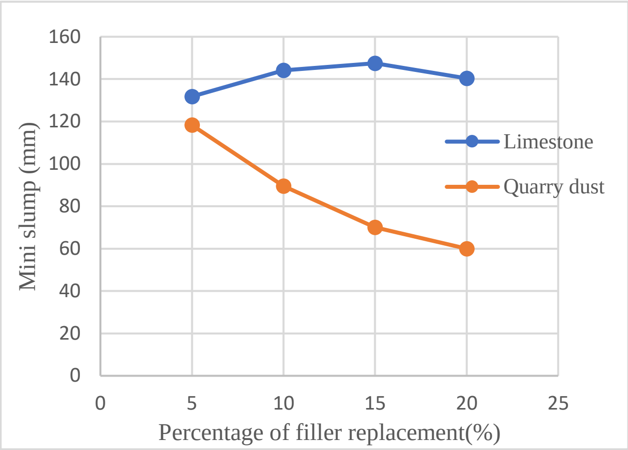

Figure 1 The effect of percentage replacement of limestone and quarry dust on mini slump (mm)

An increased proportion of quarry dust, as a cement replacement, significantly decreased the workability of the mixes. The lowest workability, within the four quarry dust mixes, was observed at a percentage replacement of 20%. A decrease in workability of 49% was observed between the least workable quarry dust mix and the reference cement mix. However, this trend was not observed within the studies carried out by Felekoglu [15] and Schankoski et al. [16]. In their studies, an increased workability was associated with the inclusion of QD. However, the QD used in this study had a larger particle size than that included within these studies. Therefore, the fineness of the filler may have been a significantly contributing factor in the decrease of workability. From Figure 1, it can be seen that the inclusion of quarry dust within a grout mix has a more significant impact than limestone on the workability, at the same percentage of replacement. The decrease in workability, caused by the inclusion of quarry dust, could be disadvantageous to a mix unless other parameters were optimised.

3.2 Cohesion

The reference mix, containing only Portland cement, had a relative cohesion of 0.25mm, which establishes it to be a highly cohesive mix according to Warner [12]. In comparison, the cohesion associated with the mix containing a 5% replacement of limestone was 0.21mm while the cohesion associated with the mix containing a 5% replacement of quarry dust had a cohesion of 0.27mm. The trends associated with percentage of filler replacement and relative cohesion for limestone and quarry dust can be seen in Figure 2.

An increased proportion of limestone was associated with a decreased cohesion in the mixes. The lowest cohesion determined was at a limestone replacement proportion of 20% with a relative cohesion of 0.15mm. This presents a decrease in cohesion of 40% when compared to the reference cement mix. This result correlates with the findings for workability, as an increased workability is related to a decrease in cohesion.

An increased proportion of quarry dust was found to be related to a significant increase in cohesion. The largest relative cohesion obtained was 0.65mm at a quarry dust replacement of 20%. This presents an increase of 160% in comparison with the 100% cement mix which agrees with the decreased workability associated with the mini slump results for the QD mixes.

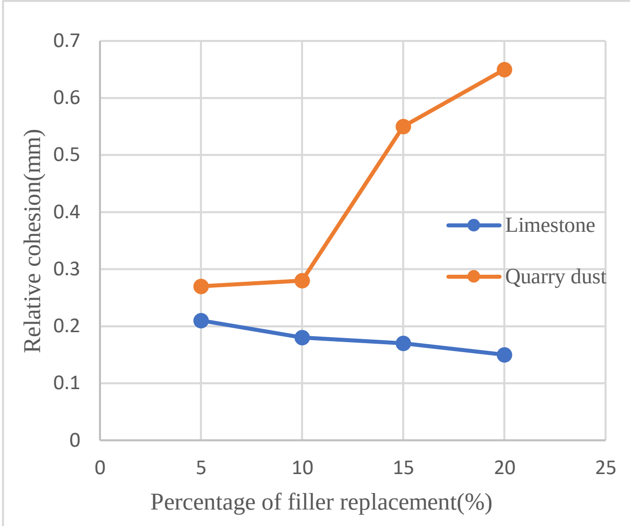

Figure 2 The effect of percentage replacement of limestone and quarry dust on relative cohesion (mm)

It can be seen from Figure 2 that the inclusion of quarry dust has a significantly greater impact on the cohesion than LSP. This agrees with studies carried out by Schankoski et al. [16] which found that to achieve a similar consistency of grout, a higher dosage of SP was needed for QD mixes in comparison to LSP mixes. Therefore, the QD grouts were more cohesive.

3.3 Flowability

The flow time associated with the reference mix was found to be 141s, while mixes containing 5% of limestone and quarry dust had flow times of 121s and 174s, respectively.

As predicted, the replacement of proportions of cement by limestone increased the flowability of the grout mixes tested and thus, reduced the flow time of the suspension. The limestone grout mix which provided the lowest flow time and therefore, the greatest flowability was a replacement of 20% with a flow time of 75s. In comparison with the reference mix, only containing CEM I, there was a 48% decrease in flow time. This increased flowability is often associated with the small particle size of limestone powders in comparison to PC. This trend can also be seen in studies carried out by Svermova et al. [13].

Increased proportions of quarry dust, replacing cement, were associated with significantly increased flow times and therefore, decreased flowability. The highest flow time which was recorded for the quarry dust mixes was 534s at 10% filler replacement, which is an increase of 279% when compared to the reference mix. These results disagree with those found in studies carried out by Felekoglu [15] and Schankoski et al. [16] as within both of these studies the mixes containing QD had

similar fresh properties to those of containing only cement. As previously mentioned, this may be as a result of the large particle size associated with the QD used in this project which requires the ongoing research on the particle size distribution and microscopy of QD.
Within the laboratory testing, the flowability of the mixes, with 15% and 20% replacement increased significantly leading to the stoppage of flow before 350ml of fluid had flowed through. This demonstrates that while a trend was not established for the flowability of the mixes at all replacement proportions, these mixes largely would not have been appropriate for use without altering other parameters, due to their significantly low flowability. A preliminary test on a mix containing 20% of QD after applying further grinding on the QD showed that it was possible to collect the 700ml of mix 11 in 540s. This indicates that the fineness of the QD plays a critical role in the flowability of the mix. Therefore, it is intended to grind the QD to the same level as LS for better comparison.

3.4 Effect of Superplasticiser (SP)

The increase dosage of superplasticizer increased the workability and flowability of all mixes while decreasing their cohesion. The increased SP dosage had the largest impact on the workability of the mix containing 20% quarry dust. The mini-slump values of the cement and limestone mixes were increased by 14mm and 19.2mm, respectively, whereas the mix containing quarry dust had a significant workability increase of 31.6mm. The impact of the increased SP dosage found the greatest decrease in cohesion, also coming from the mix containing 20% quarry dust, with a decrease of 0.13mm. However, it should be noted that the quarry dust mix was still the most cohesive mix, even with the addition of a higher SP dosage. Limestone yielded the greatest results in terms of flowability and workability with both levels of superplasticizer included within the mix.
The difference in flowability of the mixes containing 20% quarry dust cannot be compared, as the mix containing a superplasticizer dosage of 0.3% was not flowable enough to give a result which would allow for comparison. However, a significant increase in flowability was observed between the mix containing 10% quarry dust, with a lower SP dosage, and the mix containing 20% quarry dust, at a higher SP dosage. This significant increase demonstrates potential effectiveness in mixes containing this proportion of replacement of quarry dust, when a larger amount of SP is used within the mix.

3.5 Compressive strength

Compressive strength tests were carried out on each grout mix at 7 and 28 days to give an indication of the mechanical properties associated with the mix design.
The reference grout mix, with 100% cement, gave compressive strengths of 81.4MPa at 7 days and 97.5MPa at 28 days. In comparison, the compressive strengths for the mix replaced with 5% LSP were 68.2MPa at 7 days and 90.5MPa at 28 days. The compressive strengths for the mix replaced with 5% QD were 57.1MPa at 7 days and 87.0MPa at 28 days.
As the proportions of both limestone and quarry dust were increased, the compressive strengths at both 7 and 28 days were decreased. However, the compressive strengths of the mixes containing QD were lower than those of the LSP mixes at the same proportion of replacement. The average difference between the compressive strengths of the mixes containing LSP and QD at 7 days was 10.6 MPa while at 28 days the average difference was reduced to 4.3 MPa. The average difference between the compressive strengths of LSP and QD mixes indicates that the mixes containing LSP exhibit higher early strengths in comparison with the mixes containing QD. However, all mixes containing filler had a decreased compressive strength in comparison with the reference cement mix.
While compressive strength results agreed with the predicted trend for mixes containing LSP, studies previously reviewed by Dehwah [11] and Felekoglu [15] showed an increase in compressive strength when QD was included within the mix. However, this increase in compressive strength was not seen within this investigation.

4 CONCLUSION

This paper presents the findings of a preliminary investigation on the effects of limestone (LS) powder and quarry dust (QD) from dolomitic sources on the fresh and mechanical properties of cement-based grouts. The following conclusions can be drawn:

- Increased proportions of LS within cement-based grout resulted in an increased workability and flowability while causing a reasonable reduction in cohesion.
- Increased proportions of QD led to a significant decrease in mini-slump while causing an increase in flow time and cohesion.
- Both fillers reduced the 7-day and 28-day strengths of mixes with QD having greater effect than LS.
- The fineness of the QD is a key factor in determining its contribution to the fresh properties of the grouts and therefore an optimisation of this factor is required.
- Increasing the superplasticiser dosage has a positive impact on the fresh properties of all mixes tested.
- There is potential for the use of QD within construction materials, with the inclusion of larger volumes of superplasticizer in the mix design and/or optimising the particle size and fineness of the QD.

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