Effect of limestone powder as a partial replacement of crushed quarry sand on properties of self-compacting repair mortars

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Abstract. Self-compacting repair mortars (SCRM) are particularly desired for the rehabilitation and repair of reinforced concrete structures. The properties of SCRM can be improved by using chemical, mineral, polymer and fiber additives. In limestone quarries, considerable quantities of limestone fine powder are obtained during the process of crushing rock. These fine powders are being collected and their utilization is a big problem from the aspects of disposal, environmental pollution and health hazards. The introduction of limestone powder as cement and sand replacement present interesting possibilities to reduce the cement cost production, CO_2 emission and the conservation of natural resources. The effects of limestone powder content in crushed sand on the properties of SCRM are not studied. An experimental study was undertaken to find out the effect of limestone powder content on fresh and hardened properties of SCRM. SCRM mixtures were prepared using crushed sand partially replaced with limestone powder at varying percentages up to 30%. Results indicate that the limestone powder as sand replacement significantly improves the fresh and hardened properties of SCRM with a content ranging from 10 to 15%. The use of limestone powder in repair mortar and concrete application would offer technical, economical and environmental advantages for concrete producers.

Key words: Crushed sand, Limestone powder, Self-compacting repair mortar, Concrete repair.

1. Introduction

Self-compacting repair mortars (SCRM) are particularly desired for the rehabilitation and repair of reinforced concrete structures (Courard et al, 2002; Felekoğlu et al, 2006). The self-compactability of repair mortar may provide considerable advantages such as reducing the repair construction time and labor cost, enhancing the filling capacity in highly congested structural members (Khayat and Morin, 2002; Felekoğlu et al, 2007; O'Flaherty and Mangat, 1999). With the development of new generation high range water reducer admixtures, to obtain high filling rates is possible even for complex molding systems (O'Flaherty and Mangat, 1999). In structural repairs, the repair material should provide the targeted mechanical properties (Poston et al, 2001). The physical, mechanical and durability properties of SCRM can be improved by using chemical, mineral, polymer and fiber additives. For instance, producing of self-compacting mortars with the use of chemical additives, decreasing shrinkage and permeability and using mineral additives increased compressive strength (Edamatsu et al, 1999; Khayat and Guizani, 1997; Yurugi et al, 1995; Khayat, 1998; Zhu and Gibbs, 2005; Sonebi and Bartos, 1999).

As it is well known, there is a wide range of cementitious mortars based on cement and components similar to those of concrete. The composition of mortar could sometimes consist of more than one type of cement (i.e. special cement; like ultra-fine alumina cement) together with additions (i.e. silica fume, slag or fly ash), aggregates (normal, lightweight and special types, fillers), admixtures such as superplasticizers. The use of industrial by-products such as silica fume offers a low-priced solution to the environmental problem of disposing these industrial wastes. The viscosity of cement-based material can be enhanced by decreasing the water/cementitious material ratio or using viscosity-modifying agent. It can also be improved by increasing the cohesiveness of the paste through the addition of fillers such as limestone (Khayat, 1999). However, excessive addition of fine particles can result in a considerable increase in the specific area of the powder, which in turn can result in an increase of water demand to achieve the required consistency. On the other hand, for fixed water content, high powder volume increases interparticles friction due to solid-solid contact. This may affect the ability of the mixture to deform under its own weight and pass through obstacles (Nawa et al, 1998). For improving strength and durability properties, limestone powders produce a more compact structure by pore-filling effect. In the case of silica fume and fly ash, it also reacts with cement by binding $Ca(OH)_2$ with free silica by a pozzolanic reaction forming a non-soluble CSH structure (O'Flaherty and Mangat, 1999).

The influence of finely ground limestone and crushed aggregates dust on the properties of self-compacting concrete (SCC) mixes in the fresh and hardened state was comprehensively studied by Bosiljkov (2003). The utilization of sands rich in fines like limestone quarry dust may be a second alternative source of fillers. These sands may also enhance the cost effectiveness of SCC, by reducing the demand for external filler addition. The use of quarry dust in SCC is expected to offer significant economic benefits to quarries and concrete producers (Naik et al, 2005). In crushed fine aggregate production process and depending on the quality of aggregate and crushing process, a high fraction of fine aggregate may sometimes be very fine (Guimaraes et al, 2007). This portion can be as high as 10% to 15% by weight of total aggregate production. This very fine material may contribute as viscosity improver in SCC production (Johansen et al, 1999; Johansen et al, 2001). However, the quality of sands rich in fines should be carefully investigated before the use in concrete application. In case of normal concrete, the proportion of fines in sands is usually rather limited. Fine fraction of sand may affect the properties of SCC in an either positive or negative way (Topçu and Uğurlu, 2003). High content of dust in aggregate increases the fineness and the total surface area of aggregate particles, where surface area is measured in terms of specific surface, i.e. the ratio of total surface area of all particles to their volume. Aggregates with higher specific surface area require more water in the mixture to wet the particles surface adequately and to maintain a specific workability (Johansen et al, 1999; Johansen et al, 2001; Topçu and Uğurlu, 2003; Nehdi et al, 1996). Obviously, increasing water content in the mixture will affect the quality of concrete. The effect of inclusion of limestone fines in crushed sand on fresh and hardened mortar and concrete has been a major research topic for many years. It was found that up to 15% of limestone fines do not affect strength performance of limestone concrete manufacture (Bonavetti and Irassar, 1994; Chi et al, 2004). It has been established that 12–18% of fines could be allowed in sand without harmful effects on the physical and mechanical properties of mortar and concrete (Bonavetti and Irassar, 1994; Chi et al, 2004; Benabed et al, 2012; Bouziani, 2013; Bouziani et al, 2014; Benabed et al, 2014).

The durability of a concrete repair can depend on many factors. Those most often considered are cement reactivity with environment, low permeability, diffusion coefficient of species such as sulfate ions and compressive strength. The water absorption is also very important factor affecting durability such as freezing and thawing. The use of mineral additives may provide a way of improving the durability of SCRM depending on the type and amount of mineral additive used. In addition, in the absence of self-compactability the success of mortars depends on the compaction degree supplied at application site.

Ferraris et al. (2001) studied on the effect of addition of fine grounded materials with a comprehensive literature survey. They have concluded that the selection of a fine mineral admixture for improved concrete workability is not a trivial problem. At present, this selection cannot be predicted from the physical or chemical characteristics of the powders and can only be determined using the properly designed tests.

No detailed investigation has been done to study the effect of crushed limestone powder on properties of self-compacting mortars or SCC. In this research work, some part of sand is replaced with crushed limestone powder at quantities up to 30%, keeping all the other ingredients and proportions constant. The effect of varying the limestone powder content on the rheological properties of fresh SCRM was investigated using slump flow, flow time and viscosity measurements. The corresponding effect on mechanical properties of hardened SCRM was studied in terms of the compressive strength and flexural strength at ages of 3, 7 and 28 days. The water absorption capacity of SCRM was also assessed at age of 28 days.

2. Materials and methods

2.1. Materials

All mixtures were prepared using a Portland cement CEM I type with a strength class of 42.5. The chemical and physical properties of cement and limestone powder are given in Table 1.

Table 1. Chemical and physical properties of cement and limestone powder.

Chemical analysis (%)	Cement	Limestone powder
SiO_2	21.7	1.0
CaO	65.7	52.6
MgO	0.7	2.1
Al_2O_3	5.2	0.2
Fe_2O_3	2.7	0.2
SO_3	0.6	0.07
MnO	-	-
K_2O	0.4	0.04
TiO_2	-	0.01
Na_2O	0.7	0.06
CI	0.01	-
Loss of Ignition	0.3	43.63
Physical properties		
Specific density	3.15	2.7
Fineness (m^2/kg)	300	350
Compressive strength at 28 days (MPa)	44	-

The mineralogical composition of limestone powder was determined by X-ray diffraction and is presented in Figure 1 indicating that calcite mineral is the main component of limestone powder.

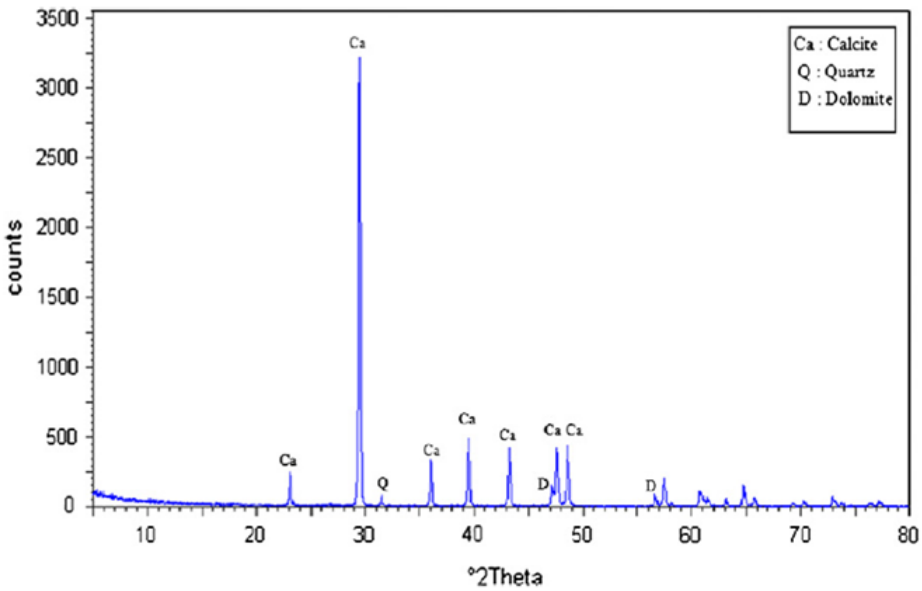

Fig 1. X-ray diffraction of limestone powder.

In order to determine the surface characteristics of the limestone powder, scanning electron microscopy (SEM) was performed and typical secondary electron image is presented in Figure 2. As seen on this figure, limestone powder presents angular shapes with rough surface texture. Crushed limestone sand (CS) was used in this investigation. The physical properties and sieve analysis results of CS are given in Table 2. Moreover, SEM image of this sand is given in Figure 3. SEM investigation reveals the angular shape of the crushed sand grains.

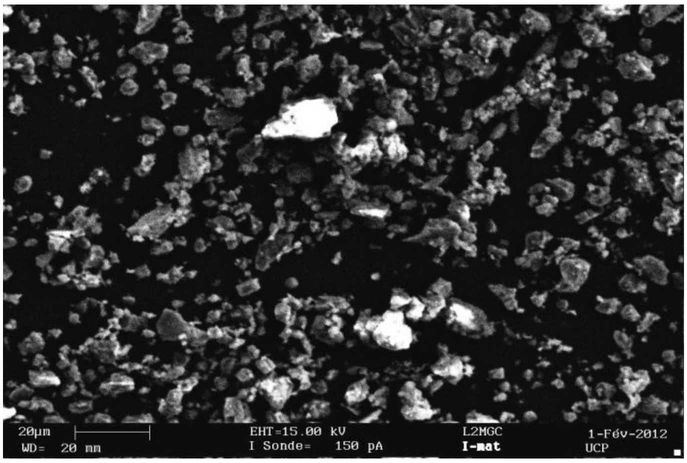

Fig 2. SEM of limestone powder.

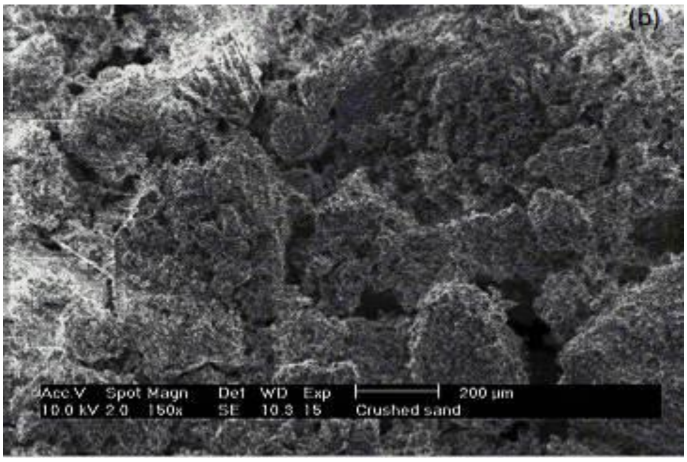

Fig 3. Angular shape of crushed sand grains in SEM view.

Table 2. Sieve analysis and physical properties of CS.

Sieve size (mm)	Cumulative passing (%)
2	100
1.25	87.15
1	80.43
0.8	72.79
0.5	56.22
0.2	36.10
0.16	26.5
0.125	20.58
0.063	5.93
0.05	4.5
Physical properties	
Specific density	2.68
Unit weight (kg/m^3)	1541
Fineness modulus	2.21
Sand equivalent (%)	71
Absorption (%)	5

A polycarboxylates type of third generation high range water reducing superplasticizer (SP) was used to achieve the desired fresh properties of SCRM. The solid content, pH and specific gravity of SP are respectively, 30%, 6 and 1.07.

2.2. Mixture proportions and mixing procedure

The mixture proportions were based on Okamura's method, with improvements made on the methods of selecting the fine aggregates content. The sand to mortar (S/M), the water to cement (W/C) and the superplasticizer to cement (SP/C) ratios were selected by a simple evaluation test for assessing the stress transferability of fresh SCRM as recommended by Edamatsu et al. (2003). The self-compactability of mixtures was obtained by increasing the SP dosage. SP requirement of all mixtures to reach the slump flow value of 280±20 mm were determined as suggested by Domone et al. (1999). SCRM were prepared with crushed limestone sand which was partially replaced by limestone powder at varying percentages of 0, 5, 10, 15, 20, 25 and 30%. For all mixtures, S/M and W/C ratios were kept constant. The mixture proportions are given in Table 3.

In the production of SCRM, the mixing process was kept constant to supply the same homogeneity and uniformity in all mixtures. The consisted of mixing the fine aggregates with cement for half a minute before adding 70% of necessary water during 1 min, then adding the remaining 30% of water containing SP during another 1 min. The mixing procedure continues for 5 min, after that the whole mix was kept settling for 2 min before remixing for just half a minute.

Table 3. Mix proportions of SCRM made with various limestone powder contents.

W/C	S/M	Cement (kg/m^3)	Crushed sand (kg/m^3)	Limestone powder (%)	Limestone powder (kg/m^3)	Water (kg/m^3)	SP (%)
0.4	0.5	697	1340	0	0	279	0.6
			1273	5	67		
			1205	10	135		
			1139	15	201		
			1072	20	268		
			1005	25	335		
			938	30	402		

2.3. Test methods

2.3.1. Fresh SCRM tests

Tests carried out on fresh SCRM involved mini slump flow and V-funnel flow time. The apparatus for the mini-slump flow test of self-compacting mortar consisted of a mould in the form of frustum of cone, 60 mm high with a diameter of 70 mm at the top and 100 mm at the base as shown in Figure 4. The cone was placed at the centre of a steel base plate, and was filled with SCRM with no compaction but finished with a trowel. Immediately after filling, the cone was lifted, the SCRM spreads over the table and the average diameter in mm of the spread measured. The SCRM spread was visually checked for any segregation or bleeding.

The V-funnel test was used to select a suitable water to powder ratio in the mix design (Okamura et al., 1993). The V-funnel as shown in Figure 4 was filled with 1.1 litres of SCRM, the gate was then opened and stopwatch simultaneously started. The watch was stopped when light first appeared, looking down into the V-funnel from above. The flow time (in sec) was then recorded.

2.3.2. Viscosity measurements

Viscosity measurements were performed on SCRM using a Brookfield DV-II model viscometer as shown in Figure 5. It is a rotational viscometer with a smooth-walled concentric cylinder so that at low stress values, wall slip (nearly yield stress) occurs resulting in inaccurately low yield stress measurements. Slip appeared to be more influential at low strain rates, thus resulting unusual low viscosity.

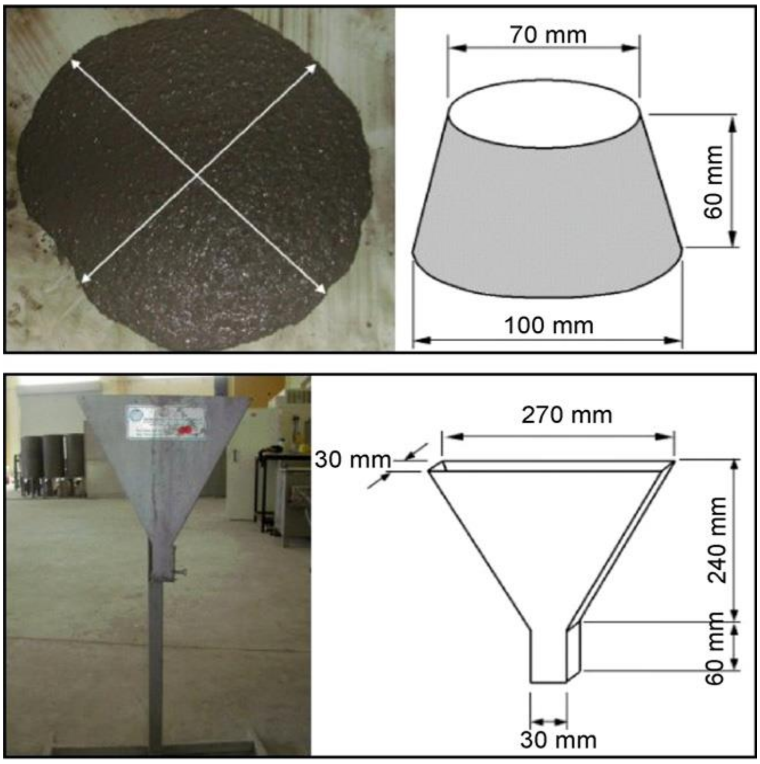

Fig 4. Typical dimensions of mini-spread flow cone and mini-V-funnel apparatus (Felekoğlu et al., 2006).

However, a decrease in the influence of slip was observed at higher rotational speeds. Therefore, the viscosity measurements were conducted at different rotational speeds and time dependent viscosity measurements were performed (Felekoğlu et al., 2006).

Fig 5. Viscometer used.

The measurements based on the viscosity were realized at the nine rotational speeds (0.5, 1, 2, 4, 5, 10, 20, 50 and 100) at 0 minutes after mixing. For this, the fresh mortar was prepared and placed into the pot of the viscometer. Pre-mixing was performed by increasing the rotational speed from zero to 60 rpm within 120 sec. The viscometer was terminated when the highest rotational speed was achieved. After that, a full cycle of increasing rotational speed by 9 steps from 0.5 to 100 rpm and back to rest with another 9 steps was performed. The average of viscosity readings determined at upwards and downwards of each rotational speed steps were recorded (Felekoğlu et al., 2006).

2.3.3. Compressive and flexural strength

The tests of compressive and flexural strengths of hardened SCRM were determined at 3, 7 and 28 days. After the completion of initial fresh SCRM tests, mixtures were poured into steel moulds without any vibration and compaction. Specimens were demoulded 24 hours after casting. After demoulding, specimens were cured in lime water at a temperature of 20 °C until age of testing. The flexural strength was conducted on 40x40x160 mm specimens by three-point bending test and the compressive strength was performed on the resulting halves from the flexural strength test.

2.3.4. Water absorption

To find out the absorption of SCRM, specimens of 40x40x160 mm were dried at a temperature of approximately 105°C for 72 hours, and this dry weight was designated as M_0. After final drying, cooling and weighing, the specimens were immersed in water at approximately 20°C for 24 hours. Then the specimens were taken out and their surfaces were dried by removing surface moisture with a towel, and weighed. This final saturated-surface dry weight was designated as weight M_1. The absorption of SCRM was calculated as following:

$$Absorption\ (\%) = (M_1 - M_0)/M_0 \qquad (1)$$

3. Results and discussions

3.1. Fresh properties of SCRM

Results of slump flow test are given in Figure 6. From this figure, it is evident that, as the percentage of limestone powder in SCRM increases, the slump flow increases for limestone powder content of up to 10% and then decreases for higher powder contents. This could be explained by the increase in the fineness and specific surface area of the crushed sand due to the increase in fines content and hence more water is required to wet the surface of particles and consequently flowability decreases.

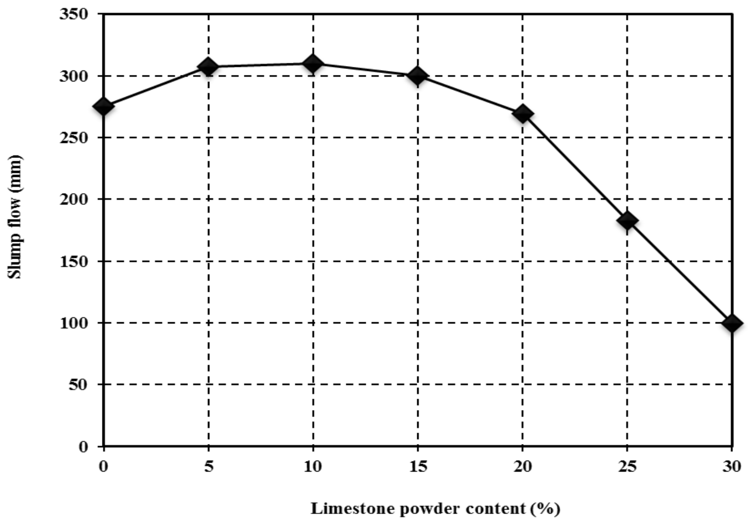

Fig 6. Slump flow test of SCRM made with various limestone powder contents.

V-funnel flow times of fresh SCRM test results are given in Figure 7. It can be seen from this figure that while the limestone powder content of fresh SCRM increases, the flow time of fresh SCRM increases. It is observed that when limestone powder content is 10 %, the SCRM achieved a better flowability. However, for limestone powder content more than 10%, a loss of flowability was obtained. This matches with the slump flow results in Figure 6. Limestone powder is usually used for improving the workability and reducing the bleeding of mortar (Erdoğan, 1997). It should also be noted that limestone powder provides cohesiveness and plasticity of a mortar.

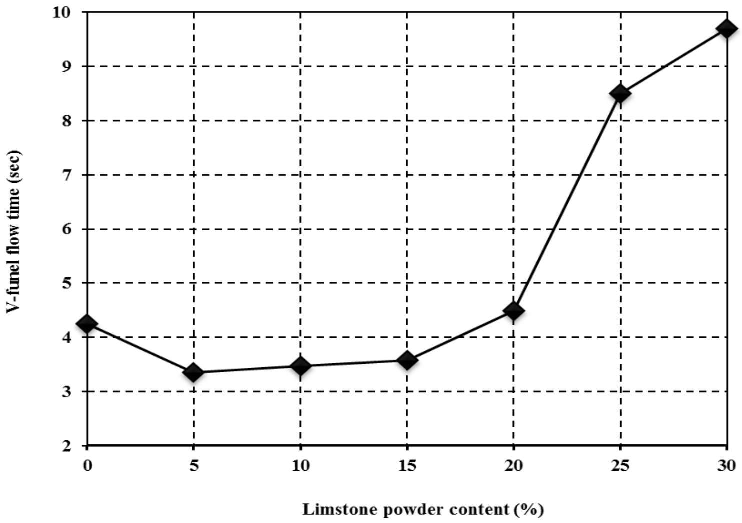

Fig 7. V-funnel flow time test of SCRM made with various limestone powder contents.

The highest V-funnel flow time was obtained for limestone powder content of 30%. The reason for this behaviour can be attributed to the fineness of limestone powders, since they were greater than cement particles (Felekoğlu et al., 2004). This suggests that the physical effect of the limestone powder on the properties of the fresh mortar depends on the water/cementitious material ratio and the addition percentages of limestone powders. Generally, the obtained results that the replacement of crushed sand by limestone powder strongly influences the flow resistance; it may increase or decrease the fresh properties of SCRM.

3.2. Viscosity

Variation in the viscosity of SCRM according to the rotational speed and limestone powder content is given in Figure 8. As seen in this figure, the SCRM with limestone powder content had consistently higher viscosity values than those without dust. The highest viscosity values were derived from 30% of limestone powder content. It was also observed that the high rotational speed reduced the viscosity of all mixtures whatever the powder content.

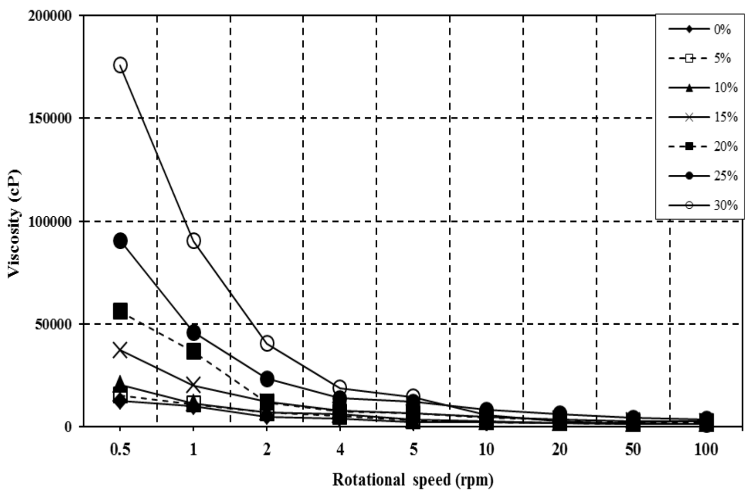

Fig 8. Viscosity of SCRM with various limestone powder contents at different rotational speeds.

This result was in good agreement with the findings of other studies reported in the literature in that replacing Portland cement with limestone filler at different replacement levels gave a marked increase in the viscosity of SCRM when compared of the control mixture (Felekoğlu et al., 2006). Tang et al (2000) mentioned about the effect of fly ash on viscosity increase and proposed that the fly ash can increase the energy demand in order to reach sufficient workability. The behaviour of all SCRM can be classified as pseudo-plastic. In other words, the viscous behaviour is evident for low rotational speeds, while at higher speeds, the flowable behaviour becomes dominant.

An example of the curve obtained of viscosity change of SCRM at different rotational speeds is illustrated in Figure 9.

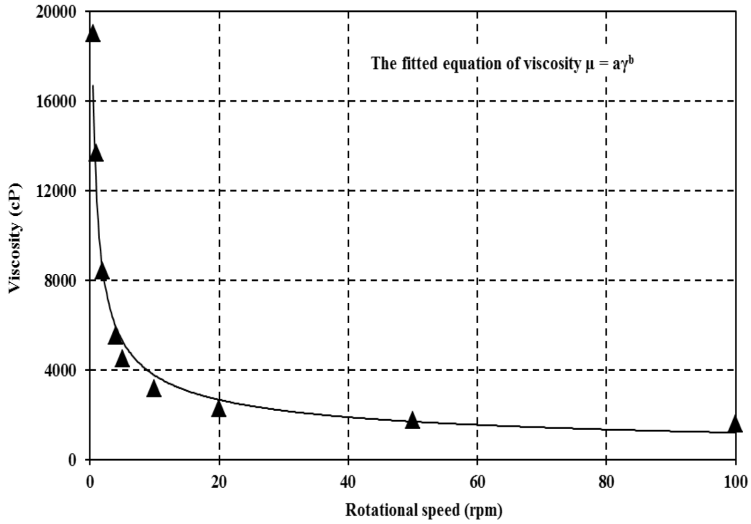

Fig 9. The fitted equation curve of viscosity of SCRM at different rotational speeds.

The results of viscosity measurement show that the behaviour of all mixtures is similar and can be best fitted with the power low model:

$$\mu = a\gamma^{b} \qquad (2)$$

μ = the viscosity in centipoise (cP);

γ = the rotational speed in revolutions per minute (rpm);

a and b = constants of the best fit equations.

The equation constants and regression coefficients of the best fit equations are presented in Table 4.

Table 4. The equation constants and regression coefficients of the best fit curves.

Limestone powder content (%) / Equation constants	0	5	10	15	20	25	30
a	1245	1680	778.5	117.5	227.7	185.7	404.4
b	-0.9	-1.02	-1.00	-0.52	-0.57	-0.49	-0.59
R^2	0.95	0.99	0.99	0.94	0.94	0.93	0.95

From this table, the regression coefficients (R^2) were superior than 0.90 for all SCRM indicating a good exponential correlation. Felekoglu et al (2006) proposed a similar equation representing the variation of viscosity at different rotational speeds of SCRM containing fly ash and limestone fillers.

In order to understand the possible mechanism of different mineral and inert admixtures on time-dependent viscosity, it is also important to characterize the micro-shape, surface texture, angularity and particle size distribution of powders. For this purpose, SEM images of limestone powders were investigated and presented in figure 2.

The limestone powders have a more angular and coarse structure, which can significantly change the viscosity of SCRM. Another factor affecting the fluidity of mixes is the zeta potentials of powders. Limestone powders have positive zeta potentials. It can be concluded that particle size distribution, micro-shape, surface structure and zeta potential changes are better parameters for rheological characterization of cement–powder–superplasticizer dispersion systems (Felekoğlu et al., 2006).

3.3. Correlation between fresh properties and viscosity

A plot was made between the V-funnel flow time and slump flow and viscosity measurements at 10 rpm rotational speed in Figures 10 and 11. The relationships between the flow time and viscosity correlate in certain case and have a linear tendency for both V-funnel time and slump flow and viscosity. However, the coefficient of correlation seems not very higher. The values of correlation coefficients for V-funnel flow time (R^2 = 0.75) and for slump flow (R^2 = 0.70). Similar results were also reported by other researchers (Felekoğlu et al., 2006; Güneyisi et al., 2009).

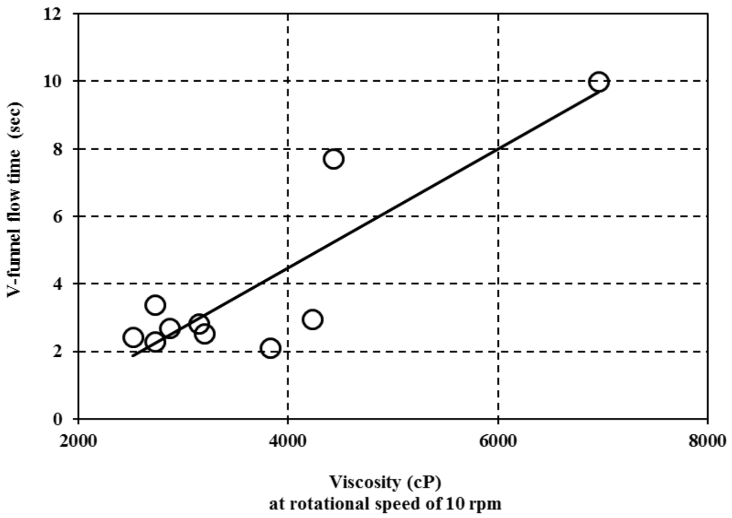

Fig 10. Relationship between V-funnel flow time and viscosity of SCRM.

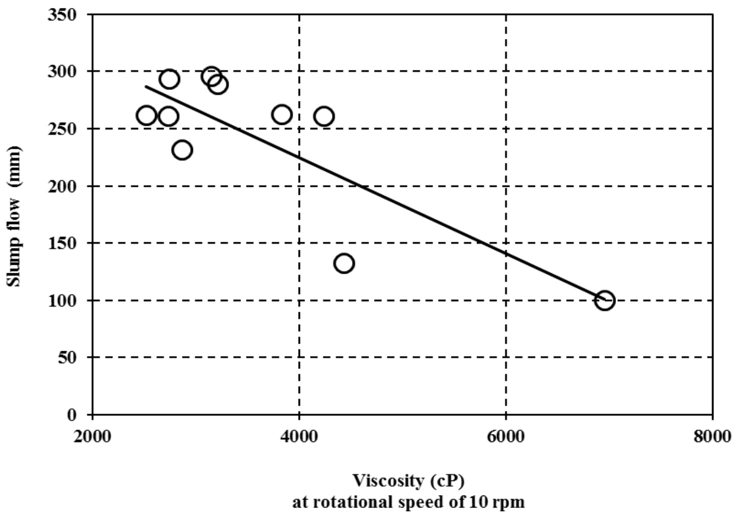

Fig 11. Relationship between slump flow and viscosity of SCRM.

Figures 10 and 11 show respectively that by increasing the viscosity, V-funnel time increases and slump flow decreases. As it is known, V-funnel and slump flow tests measure the flowability of self-compacting mortar and concretes. In fresh state, when the yield stress is exceeded, flow start and the shear stress will increase linearly with an increase in strain rate, as defined by viscosity as a measure of the ease of flow (Felekoğlu et al., 2006).

3.4. Compressive and flexural strength

The results of compressive strength at 3, 7 and 28 days are shown in Figure 12**.** It can be seen that the compressive strength at 3, 7 and 28 days increases to a maximum at limestone powder content of 10%. For limestone powder content higher than 10%, the compressive strength decreases. This is probably due to insufficient cement paste to coat all the crushed sand particles, which consequently leads to a decrease in compressive strength. For specimens without or with only 5% limestone powder, there are not enough fine particles to fill all voids between cement paste and crushed sand particles and hence, lower compressive strength values as compared to specimens with 10 % of limestone powder content.

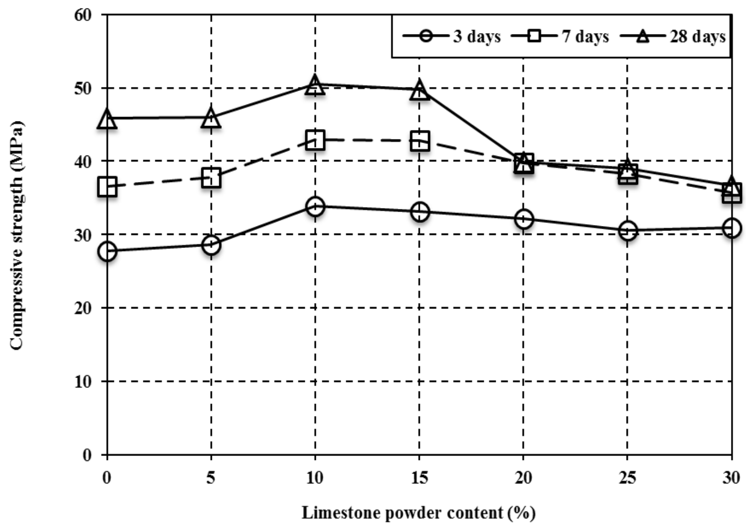

Fig 12. Compressive strength at 3, 7 and 28 days of SCRM made with various limestone powder contents.

Figure 13 shows also the relation of limestone powder content and flexural strength, which represents the average of three tests for 3, 7 and 28 days. It can be seen that the flexural strength increases to a maximum at limestone powder content of 10%. As the limestone powder content exceeds the value of 10%, the flexural strength decreases.

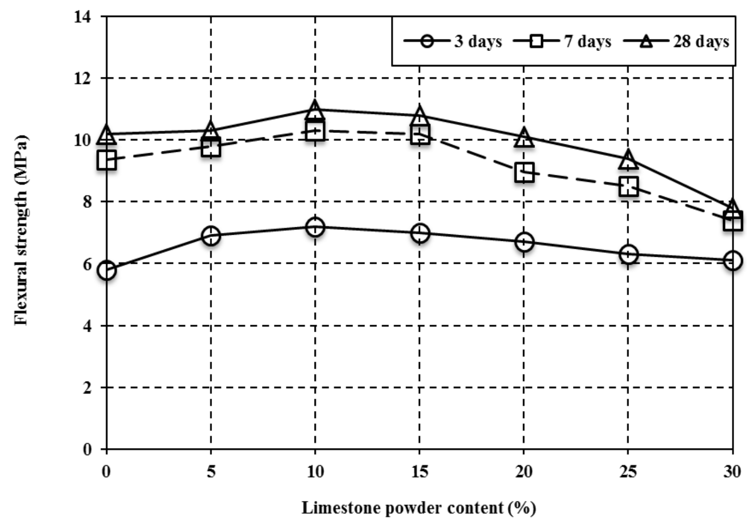

Fig 13. Flexural strength at 3, 7 and 28 days of SCRM made with various limestone powder contents.

Similar arguments as mentioned above for compressive strength can be applied also for flexural strength (Benabed et al., 2012).

Mortar is, of course, a mixture of the paste and aggregate, and it is the interface between these that is of interest. For the flexural strength could be supposed that it is more sensitivity of the transition zone between aggregate and matrix. Especially, as the bending load on the mortar increases, cracking will start in this zone, and subsequently propagate in to the hardened cement paste until crack paths are formed through the mortar. The increase in strength in systems of mortars containing pozzolanic materials play an important role in improving the aggregate-paste bond through the densification of the transition zone and formation of more calcium silicate hydrates (Shannag, 2000). In this study, the use of limestone powder in SCRM that they have worsening effect on the interfaced due to the lower pozzolanic activity. Thus they have reducing effect of the mortar strength.

In literature, limestone powder was described neither cementitious nor pozzolanic materials. Therefore, it is accepted that limestone powder contributes little to the strength of mortar (Erdoğan, 1997). As expected, the lowest flexural and compressive strength at 28 days was obtained for 30% of crushed sand by weight was replaced by limestone powder.

This result shows that limestone powder appropriate to improve deformability, but it is not completely effective on mechanical properties. However, includes substitutions of crushed sand with limestone powder (10 %) to positive effect on the mechanical strength.

The increase in strength can be explained with pore-filling effect of limestone powder and also provided suitable nucleus for hydration and by this way catalyzing the hydration (Gürol, 1999). Additionally, limestone powders reacted with C_3A phase of cement and supplied the formation of monocarboaluminate that partially takes part of ettringite; thus, increase at early strength values (Türker et al., 2004).

However, it seems that no additional hydration reactions take place to enhance the long-term strength of pastes incorporating limestone fillers.

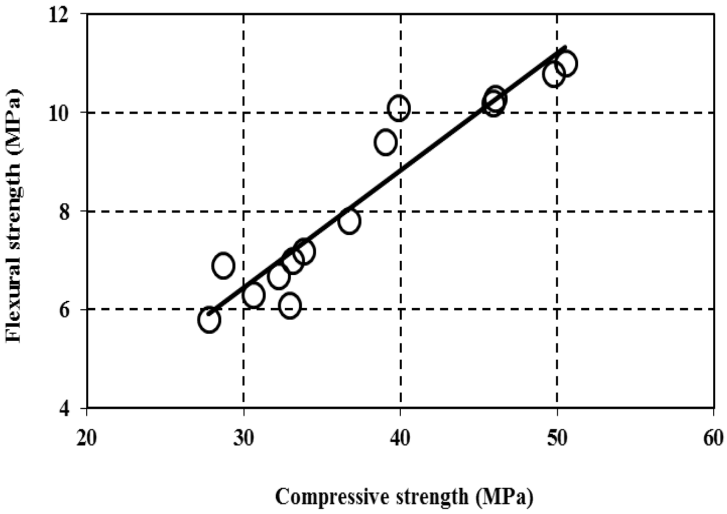

Fig 14. Correlation between flexural and compressive strength of SCRM made with various limestone powder contents at all ages.

Figure 14 plots the relationship between flexural and compressive strength of SCRM made with various limestone powder fines content at all ages, which gives a good linear correlation with a coefficient of correlation (R^2 = 0.95).

Figure 15 shows the results of SEM observation at 28 days of hardened SCRM containing 15% of limestone powder. The SEM image shows the good adhesion between the paste cement and the sand grains, which may lead to increase the mechanical strength. The existence of limestone powder in the cementitious matrix enhances the hydration reaction, as a result, the obtaining of dense structure.

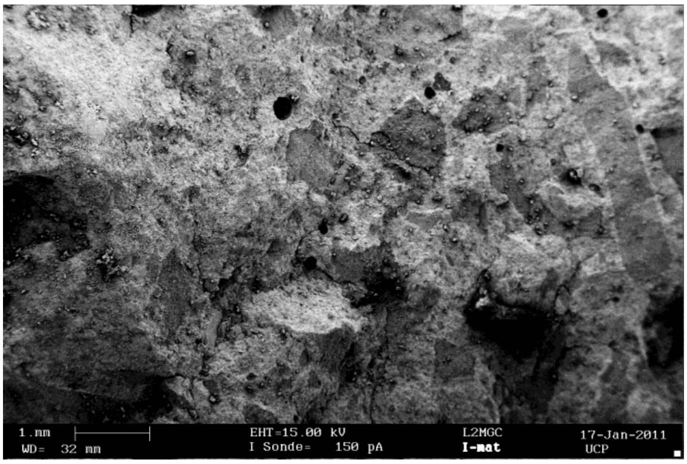

Fig 15. SEM view of hardened SCRM containing 15% of limestone powder at age of 28 days.

3.5. Water absorption

The results of water absorption of SCRM made with various limestone powder contents at age of 28 days are shown in Figure 16. According to Figure 16, the absorption percentage of SCRM decreased for limestone powder contents from 0 to 15%, and then it started to increase for 20, 25, and 30% of limestone powder contents. Limestone powder acts as filler in the SCRM and contributes to reduce the absorption of concrete. However, increasing the limestone powder content more than 15% causes an increase in absorption, which is a parallel leading with compressive strength.

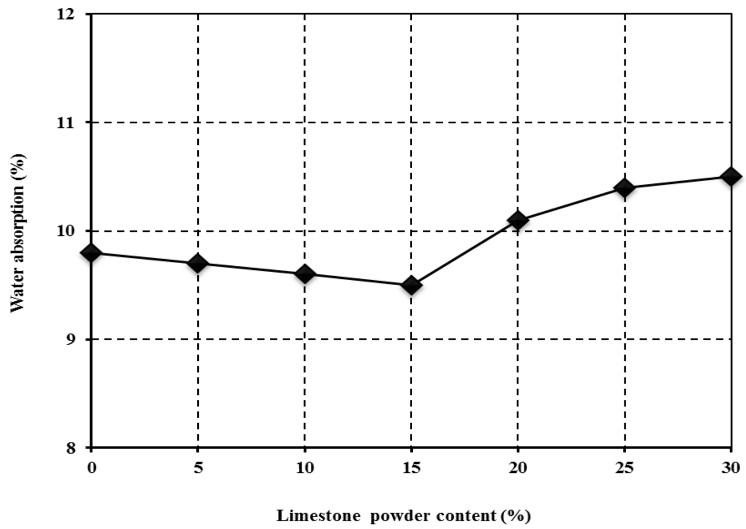

Fig 16. Water absorption percentages of SCRM made of various limestone powder contents at age of 28 days.

This situation may bring out the opinion that limestone powder could not form to block capillary pores sufficiently (by the supplementary CSH structure and filler effect) at 28 days. Filling the voids in a packed system may improve the arrangement of particles in the system, ensuring a better contribution of the interfaced to achieve adequate prevent on the SCRM absorption (Yahia et al., 2005).

Figure 17 plots the relationship between water absorption and compressive strength of SCRM made with various limestone powder fines content at age of 28 days, which gives a good linear correlation with a coefficient of correlation (R^2 = 0.94). This relation suggests that with the decrease in water absorption of SCRM, the SCRM is expected to have a high compressive strength.

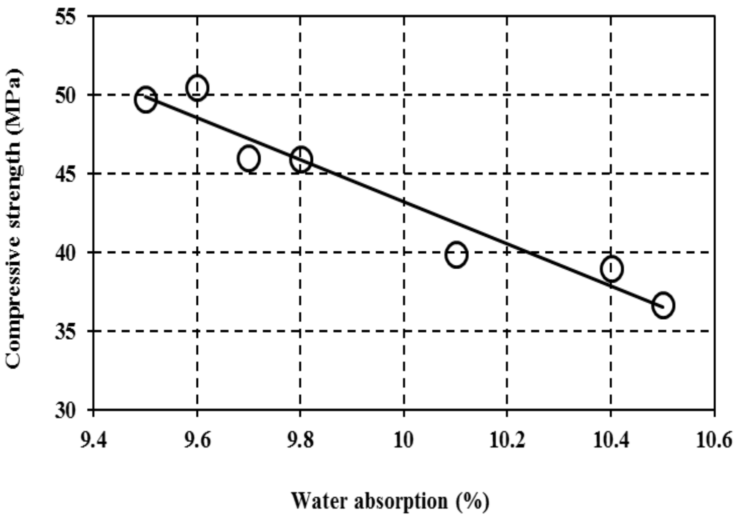

Fig 17. Correlation between water absorption and compressive strength of SCRM made with various limestone powder contents at age of 28 days.

4. Conclusions

The influence of limestone powder up to 30% as crushed sand replacement of SCRM fresh and hardened properties was investigated. Based on the results of this investigation, the following conclusions can be drawn:

1. The slump flow time of SCRM decreased whereas V-funnel flow time increased with the increase in limestone powder content beyond of 10%.
2. The viscosity of SCRM increased with the increase in limestone powder content. The viscous behaviour of SCRM is evident for low rotational speeds, while at higher speeds, the flowable behaviour becomes dominant.
3. Increasing the limestone powder content up to 10 % improved the compressive strength of SCRM. For higher limestone powder content, the compressive strength decreased gradually. A similar result was obtained for the flexural strength.
4. A good correlation exists between flexural strength and compressive strength at different curing times.
5. The minimum value for water absorption was obtained when the limestone powder content is 15%. Limestone powder contents higher than 15% increased the water absorption of SCRM.
6. A linear correlation exists between compressive strength and water absorption with a high coefficient of correlation.
7. Crushed sand with 10 to 15% of powder can be used successfully in production of SCRM with good rheological and strength properties.
8. The use of crushed quarry sand and limestone powder in self-compacting concrete and SCRM application would offer technical, economical and environmental advantages for concrete producers.

5. Recommendations for future work

In the framework of this study, only one water/cement (W/C) ratio was adopted. However, a possibility of change in the properties of SCRM by varying W/C ratio may be expected since the addition of superplasticizer (SP) is varied by W/C ratio. Therefore, more experiments with other W/C ratios or other types of powders and SP may be useful as a further study.

6. References

Benabed, B., Azzouz, L., Kadri, E. H., Kenai, S., & Belaidi, A. S. E. (2014). Effect of fine aggregate replacement with desert dune sand on fresh properties and strength of self-compacting mortars. Journal of Adhesion Science and Technology, 28(21), 2182-2195.

Benabed, B., Kadri, E. H., Azzouz, L., & Kenai, S. (2012). Properties of self-compacting mortar made with various types of sand. Cement and Concrete Composites, 34(10), 1167-1173.

Bonavetti, V. L., & Irassar, E. F. (1994). The effect of stone dust content in sand. Cement and Concrete Research, 24(3), 580-590.

Bosiljkov, V. B. (2003). SCC mixes with poorly graded aggregate and high volume of limestone filler. Cement and Concrete Research, 33(9), 1279-1286.

Bouziani, T. (2013). Assessment of fresh properties and compressive strength of self-compacting concrete made with different sand types by mixture design modelling approach. Construction and Building Materials, 49, 308-314.

Bouziani, T., Bédérina, M., Makhloufi, Z., & Hadjoudja, M. (2014). Mixture design approach to evaluate fresh properties of SCC made with various sands. Journal of Building Materials and Structures, 1(1), 1-9.

Chi, C., Wu, Y., & Riefler, C. (2004). The use of crushed dust production of self-consolidating concrete (SCC), Recycling Concrete and other materials for sustainable developement, Editors Tony C. Liu Christian Meyer. ACI International SP-219.

Courard, L., Darimont, A., Degeimbre, R., Willem, X., Geers, C., & Wiertz, J. (2002). Repairing concretes with self-compacting concrete: Testing methodology assessment. In: Proceedings of First North American Conference on the design and the use of self-consolidating concrete (SCC), Chicago, U.S.A, pp: 267-274.

Domone, P. L., & Jin, J. (1999). Properties of mortar for self-compacting concrete. In Proceedings of the 1st international RILEM symposium on self-compacting concrete, pp: 109-120.

Edamatsu, Y., Nishida, N., & Ouchi, M. (1999). A rational mix-design method for self-compacting concrete considering interaction between coarse aggregate and mortar particles. In Proceedings of the first international RILEM symposium on self-compacting concrete, Stockholm. Sweden, pp: 309-320.

Edamatsu, Y., Sugamata, T., & Ouchi, M. (2003). A mix-design method for SCC based on mortar flow and funnel tests. In: Proceedings of 3rd International RILEM Symposium on SCC, Reykjavik, Iceland, pp: 345-355.

Erdoğan, T. Y. (1997). Admixtures for concrete. First Edition, Middle East Technical University Press.

Felekoğlu B., Türkel S., & Baradan, B. (2004). The effect of powder type on the fresh and mechanical properties of self-compacting concrete, Turkish Ready Mixed Concrete Association, March–April, pp. 67–77, (in Turkish).

Felekoğlu, B., Tosun, K., Baradan, B., Altun, A., & Uyulgan, B. (2006). The effect of fly ash and limestone fillers on the viscosity and compressive strength of self-compacting repair mortars. Cement and concrete research, 36(9), 1719-1726.

Felekoğlu, B., Türkel, S., & Altuntaş, Y. (2007). Effects of steel fiber reinforcement on surface wear resistance of self-compacting repair mortars. Cement and Concrete Composites, 29(5), 391-396.

Ferraris, C. F., Obla, K. H., & Hill, R. (2001). The influence of mineral admixtures on the rheology of cement paste and concrete. Cement and concrete research, 31(2), 245-255.

Guimaraes, M. S., Valdes, J. R., Palomino, A. M., & Santamarina, J. C. (2007). Aggregate production: fines generation during rock crushing. International journal of mineral processing, 81(4), 237-247.

Güneyisi, E., Gesoğlu, M., & Özbay, E. (2009). Effects of marble powder and slag on the properties of self-compacting mortars. Materials and Structures, 42(6), 813-826.

Gürol, G. (1999). Components for Economic Concrete, cement/water/fine and coarse aggregate/chemical and mineral admixtures. J. Des. Constr, 164, 66-74.

Johansen, K. I., Mortsell, E., & Lindgard, J. (1999). Effect of adding natural fine sand rich in fines on the fresh concrete properties. Nordic Concrete Research-Publications, 22, 65-76.

Johansen, K., & Busterud, L. (2001). Low grade SCC with secondary natural sand rich in fines. In Second international RILEM symposium on SCC, Tokyo, pp: 303-308.

Khayat, K. H. (1998). Use of viscosity-modifying admixture to reduce top-bar effect of anchored bars cast with fluid concrete. Materials Journal, 95(2), 158-167.

Khayat, K. H. (1999). Workability, testing, and performance of self-consolidating concrete. ACI materials journal, 96, 346-353.

Khayat, K. H., & Guizani, Z. (1997). Use of viscosity-modifying admixture to enhance stability of fluid concrete. ACI Materials Journal, 94(4), 332-340.

Khayat, K. H., & Morin, R. (2002). Performance of self-consolidating concrete used to repair parapet wall in Montreal. In: Proceedings of First North American Conference on the design and the use of self-consolidating concrete (SCC), Chicago, U.S.A, pp: 475-481.

Naik, T. R., Kraus, R. N., Chun, Y. M., Canpolat, F., & Ramme, B. W. (2005). Use of limestone quarry by-products for developing economical self-compacting concrete," published at the CANMET. In ACI International symposium on sustainable developments of cement and concrete, Toronto, Canada, pp: 313-336.

Nawa, T., Izumi, T., & Edamatsu, Y. (1998). State-of-the-art report on materials and design of self-compacting concrete. In International workshop on self-compacting concrete, pp: 160-190.

Nehdi, M., Mindess, S., & Aïtcin, P. C. (1996). Optimization of high strength limestone filler cement mortars. Cement and Concrete Research, 26(6), 883-893.

O'Flaherty, F. J., & Mangat, P. S. (1999). Influence of constituents on the properties of self-compacting repair materials. In Proceedings of the first international RILEM symposium, pp: 263-274.

Okamura, H., Maekawa, K., & Ozawa, K. (1993). High performance concrete. Gihoudou Pub, Tokyo.

Poston, R. W., Kesner, K., McDonald, J. E., Vaysburd, A. M., & Emmons, P. H. (2001). Concrete repair material performance—Laboratory study. Materials Journal, 98(2), 137-147.

Shannag, M. J. (2000). High strength concrete containing natural pozzolan and silica fume. Cement and concrete composites, 22(6), 399-406.

Sonebi, M., & Bartos, P. J. M. (1999). Hardened SCC and its bond with reinforcement. In Self-Compacting Concrete: Proceedings of the First International RILEM Symposium held in Stockholm, Sweden, pp: 275-289.

Tang, C. W., Yen, T., & Chen, K. H. (2000). The rheological behavior of medium strength high performance concrete. In Second International Symposium on Cement and Conc. Tech., 2, 50-57.

Topçu, I. B., & Uğurlu, A. (2003). Effect of the use of mineral filler on the properties of concrete. Cement and Concrete Research, 33(7), 1071-1075.

Türker, P., Yeşilkaya, A., & Yeğinobalı, A. (2004). The hydration process and microstructural development of limestone Portland cements. Cem. Concr. World, 48(8), 50-66.

Yahia, A., Tanimura, M., & Shimoyama, Y. (2005). Rheological properties of highly flowable mortar containing limestone filler-effect of powder content and W/C ratio. Cement and concrete Research, 35(3), 532-539.

Yurugi, M., Sakai, G., & Sakata, N. (1995). Viscosity agent and mineral admixtures for highly fluidized concrete. Proceedings, Concrete under Severe Conditions, Environment and Loadings, 2, 995-1004.

Zhu, W., & Gibbs, J. C. (2005). Use of different limestone and chalk powders in self-compacting concrete. Cement and Concrete Research, 35(8), 1457-1462.