The Effect Of A Variable Percentage Of Limestone Filler On Some Mechanical Properties Of Self-Compacting Concrete

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Abstract

The first aim of this experimental program is to produce and evaluate Self-Consolidating Concrete (SCC); the second aim is to replace part of cement by predetermined percentages of limestone powder CaCO$_3$ (LSP) to find out the effect of a variable percentage of LSP on some mechanical properties of SCC. The study also takes into account the difference between using the LSP as a replacement or as an additive of cement to the mix. Six concrete mixes were prepared. The first one was without LSP (0%), second, third and fourth ones contained LSP as percentage replacement of cement in the order of 20, 30, 40% respectively, fifth and sixth mixes contained 20, 30% LSP but as an additive to the cement. Results showed that using LSP as replacement led to the production of SCC. Using LSP as replacement also led to economical advantages due to the decrease in plasticizer content, with no noticeable differences in mechanical properties of SCC, but causing a fluidity increase of SCC when using LSP as an additive.

Key words: Concrete mechanical Strength, Limestone Filler, Self-Compacting Concrete.
Introduction

Self-consolidating concrete (SCC) is defined as "a highly flowable, yet stable concrete that can spread readily into place and fill the formwork without any mechanical consolidation and without undergoing any significant separation"[1].

The concept of self-consolidating concrete was proposed in 1986[2], but the prototype was first developed in 1988 in Japan [3].

Precast, prestressed bridge elements, such as AASHTO Type III girders, have congested reinforcement and tight dimensional geometry, and therefore can benefit from the use of SCC.

SCC has been claimed to offer many advantages for the precast, prestressed industry including elimination of noise and problems related to concrete vibration, lower labor cost per member, and faster casting, thereby increasing productivity.

Due to the low water-cement ratio, SCC should have improved durability and strength. With regard to its composition, SCC consists of the same components as conventionally vibrated concrete, which are cement, aggregates, and water, with the addition of chemical and mineral admixtures in different proportions. Usually, the chemical admixtures used are high-range water reducers (superplasticizers) and viscosity-modifying agents, which change the rheological properties of concrete.

Mineral admixtures are used as an extra fine material, besides cement, and in some cases, they are used as partial replacement of cement. In SCC cement content may be partially replaced with, fly ash, slag cement, limestone filler, and silica fume, to improve the flowing and strengthening characteristics of the concrete.

Research Scope

The scope of this research is to find out the effect of a variable percentage of limestone filler on some mechanical properties of SCC.

Experimental Program

This research was conducted to find some properties of SCC such as splitting tensile strength, compressive strength, and flexural strength.

The experimental work consists of three sets of different specimens: cubes, cylinders, and beams, amounting to twelve cubes, three cylinders, and three beams for each mix, the water-cement ratio was 0.33.

The added ratios of limestone powder as a replacement of cement were 20, 30, and 40% by weight of cement with a reference mix having no limestone powder (zero%), making the number of tried mixes for this case four (see table 8) then two ratios of limestone powder (20 & 30%) were used as an additive material (not as a replacement), making the number of tried mixes in this other case, two.

The size of all the cast cubes were 4×4 inches (101.6×101.6 mm), cylinders were 4 inches (101.6 mm) in diameter and 8 inches (203.2 mm) in length and beams of (4×4) inches in cross section and 19.6 in (500 mm) in length, all beams were tested in a two point load manner, the total number of cast specimens was 102.

Slump flow, L-Box and V-Funnel tests were carried out in order to evaluate the filling ability and the self-compactability of the concrete.
Materials:
All materials used throughout this research were locally available. They included cement, water, fine aggregate, coarse aggregate, limestone filler, and a superplasticizer.

Cement: The type of cement used was Ordinary Portland Cement, produced in accordance with Iraqi Specification (IQS. No.5, 1985)[4]. The physical and chemical properties are given in Tables (1) and (2) respectively.

Fine aggregate: Medium sand in accordance with British Standards (B.S.) 882:1992[5] was used in this investigation. Its main properties are listed in Table (3), Figure (1) shows the particles size distribution.

Coarse aggregate: Coarse aggregate used was normal river gravel (irregular almost rounded maximum aggregate size (10mm) in accordance with B.S 882(1992). [5]Its physical properties are given in Table (4), while its sieve analysis and grading are given in Figure (2).

| Property                | Test result (Percentage) | Standard IQS, No.5 |
|-------------------------|--------------------------|--------------------|
| 1. Oxide composition:   |                          |                    |
| Alumina, Al₂O₃         | 4.7                      |                    |
| Silica, SiO₂           | 21.5                     |                    |
| Ferric Oxide, Fe₂O₃    | 2.41                     |                    |
| Lime, CaO              | 62.86                    |                    |
| Sulphuric Anhydride, SO₃ | 3.02                   | Max. 3             |
| Magnesia, MgO          | 2.25                     | Max. 4             |

| Property                | Test result (Percentage) | Standard |
|-------------------------|--------------------------|----------|
| 2. Compound composition:|                          |          |
| C₃A                     | 8.4                      |          |
| C₂S                     | 27.18                    |          |
| C₃S                     | 46.14                    |          |
| C₄AF                    | 7.3                      |          |

Table (1): Chemical composition of the O.P.C.

Table (2): Physical properties of the O.P.C.

| Property                     | Test result                  | Standard |
|------------------------------|------------------------------|----------|
| Fineness (Residue on sieve No. 170) | 9%                           | Max. 10% |
| Specific surface "Blaine"    | 3358.5 (cm²/gm)             | Min. 2250 |
| Initial setting time         | 150 (min.)                  | ≥45 (min.) |
| Final setting time           | 215 (min.)                  | ≤600 (min.) |
| Specific gravity             | 3.14                        |          |
| Compressive strength         |                             |          |
| 70.7 mm cubes at 3 days      | 21.4 (MPa)                  | ≥16.0 (MPa) |
| at 7 days                    | 36 (MPa)                    | ≥24.0 (MPa) |
Table (3): Relative properties of fine aggregate

| Type of fine aggregate | Color      | Specific Gravity | Absorption % | Compact unit weight (kg/m³) | Loose unit weight (kg/m³) |
|------------------------|------------|------------------|--------------|----------------------------|--------------------------|
| Medium sand            | Brown      | Oven dry basis   | 2.38         | 1.0                        | 1939                     | 1883                     |
|                        |            | S.S.D basis      | 2.36         |                            |                          |                          |

Table (4): Relative properties of coarse aggregate

| Type of coarse aggregate | Maximum aggregate size (mm) | Specific Gravity S.S.D | Absorption % | Compact unit weight (Kg/m³) | Loose unit weight (Kg/m³) |
|--------------------------|----------------------------|------------------------|--------------|-----------------------------|---------------------------|
| Rounded gravel           | 10                        | 2.7                    | 0.5          | 1742                        | 1656                      |

Figure (1): Grading curve for fine aggregate

Figure (2): Grading curve for coarse aggregate
Water: Ordinary drinking (tap) water was used for all concrete mixes.
Limestone Powder: Limestone powder (CaCO₃) was used as a filler material, the particles passing from sieve No. 100 (0.150 mm), in the present research three ratios of limestone powder are used 20, 30, and 40%.
Chemical Admixture: Sikament-NN a high range water reducing (HRWR) was used in this work to get the necessary workability, stability and flowability. The main properties as recommended from factory are shown in Table (5).

| Table (5): The Properties of HRWR |
|-----------------------------------|
| **Type** | Naphthalene formaldehyde sulphonate |
| **Color** | Dark brown |
| **Density** | 1.2 kg/L |
| **Dosage** | 0.8-3% by weight of cement depending on desired workability and strength |

Mix Proportion:

The initial outcome of an experimental program aimed at producing and evaluating SCC made with high-volumes of limestone powder (LSP). Three SCC mixtures were investigated in this study. The tested mixtures were proportioned with the same initial slump flow consistency of 650±15mm. The content of the cementitious materials was maintained constant at (450 kg/m³), while the water/cementitious material ratio is constant at 0.33. The self-compacting mixtures had a cement replacement(of limestone filler) at (20, 30, and 40%), for comparison purposes of the three batches, one of them made with Portland cement only and it had a similar slump flow, and the other two batches had ratios of added limestone powder of 20,30%.

Tests were carried out on all mixes to find out the effect of a variable percentage of limestone powder on some mechanical properties of SCC. The proportions of the concrete mixtures are summarized in Table (6). For all the mixtures, the coarse and fine aggregates weights were taken at room dry condition.

| Table (6): Proportions of the concrete mixes |
|--------------------------------------------|
| **Mix No.** | **W/C+LSP** | **Water kg/m³** | **Cement kg/m³ O.P.C** | **Limestone powder %** | **Fine agg. kg/m³** | **Coarse agg. kg/m³** | **SuperPlasticizer %** |
|-------------------------------------------------|----------------|----------------|-------------------|------------------------|---------------------|---------------------|------------------------|
| 1 | 0.33 | 149 | 450 | 0 | 756 | 743 | 1.75 |
| 2 | 0.33 | 149 | 360 | 20 | 90 | 756 | 743 | 1.6 |
| 3 | 0.33 | 149 | 315 | 30 | 135 | 756 | 743 | 1.625 |
| 4 | 0.33 | 149 | 270 | 40 | 180 | 756 | 743 | 1.63 |

ORDINARY PORTLAND CEMENT

There is no single test that can adequately measure the filling, passing and segregation also there were no standardized test methods or equipments adopted by ASTM. Below is a list of test methods for workability properties of SCC that had been employed previously. These equipments and Test methods have been employed by many researchers and agencies to investigate SCC rheology with good success. It is further expanded these equipments will be standardized without serious dimensional alterations [6].
Slump-flow and $T_{50}$ time for SCC:

The slump-flow and $T_{50}$ time is a test to assess the flowability and the flow rate of self-compacting concrete in the absence of obstructions.

Procedure

The equipment consists of one slump cone and one flow base plate made of a flat plate with a plane area on which concrete can be placed. The plate should have a flat, smooth and non-absorbent surface with a minimum thickness of 2 mm. The surface shall not be readily attacked by cement paste or be liable to rusting. The construction of the plate shall be such as to prevent distortion. The centre of the plate shall be scribed with a cross, the lines of which run parallel to the edges of the plate and with circles of 200 mm diameter and 500 mm diameter having their centers coincident with the centre point of the plate, see Figure (3).

The slump cone is filled with concrete while pressing the slump cone to the table. Next, the slump cone is lifted vertically and time measurement is started. Time for the concrete diameter to reach 500 mm ($T_{50}$) is recorded. When the concrete stops flowing, the final diameter ($d_1$) of concrete is measured. Then measuring the diameter of the flow spreads at right angles to $d_1$ recorded as $d_2$. The slump-flow is the mean of $d_1$ and $d_2$ expressed to the nearest 10 mm. The $T_{50}$ time is reported to the nearest 0.1 s [7]. The concrete spread for segregation is checked. The cement paste/mortar may segregate from the coarse aggregate to give a ring of paste/mortar extending several millimeters beyond the coarse aggregate. Segregated coarse aggregate may also be observed in the central area.

V-funnel test: The V-funnel test is used to assess the viscosity and filling ability of SCC. The equipment consists of V-shaped as shown in Figure (4). The V-funnel is filled up to its upper level with concrete. After the concrete rests one minute in the V-funnel, the gate is opened. Time for concrete to flow out of the V-funnel (Flow-time) is recorded. The concrete is observed while it flows out and any blocking leading to total stoppage of flow or temporary stops is noted.
**L-Box test:** The principles of the L-shaped box are shown in Figure (5). With the L-shaped box, it is possible to measure different properties, such as flowability, blocking and segregation. The vertical part of the box, with the extra adapter mounted, is filled with concrete. After the concrete has rested in the vertical part for one minute, the sliding gate is lifted. The concrete will now flow out of the vertical part into the horizontal part of the L-box.

On its way, it has to pass the layer of reinforcement. After the sliding gate is removed, the time for the concrete front to reach (200mm) marking ($T_{20}$), and the time for the concrete front to reach (400mm) marking ($T_{40}$) are recorded. When the concrete has stopped, the distance $H_1$ and $H_2$ at (200mm) and (400mm) mark are measured. Acceptable values of the so-called blocking ratio, $H_1/H_2$, can be 0.8-1.0[8]. Both blocking stability can be detected visually. If the concrete builds a plateau behind the reinforcement layer, the concrete has either blocked or segregated. Blocking usually displays itself by coarse aggregates gathered between the reinforcing bars.

![Figure (5): L-box apparatus](image)

**Testing specimens:**

All concrete specimens have been cast and cured according to ASTM C192-95[9], and ASTM C496-96[10]. The moulds were oiled properly for easy demolding. Since this is a SCC, the concrete will flow under its own weight; therefore, the molds were not vibrated. After casting and finishing, the specimens were covered with plastic sheet to avoid loss of water due to evaporation. The specimens were demolded after 24 hours of casting and then they were transferred to a curing tank placed at laboratory temperature. The specimens were cured in the water tank for 28 days.
Results and Discussion

Compressive Strength:

Results of fresh self-compacting and strengths tests conducted on four mixes are presented in Table (7).

| Mix       | Fresh Self-Compacting properties | Compressive Strength(MPa) At indicated "age" days | Splitting Strength (MPa) at 28 days | Flexural Strength (MPa) at 28 days |
|-----------|----------------------------------|--------------------------------------------------|------------------------------------|-----------------------------------|
| Mix1 (0%) | 640                              | 3.30, 7.78, 0.84                                 | 26.2, 36.65, 44.6, 56.4.           | 4.995, 5.066                      |
| Mix2 (20%)| 660                              | 3.38, 9.81, 0.88                                 | 18.2, 29.4, 40.7, 53.3.            | 3.667, 3.67                       |
| Mix3 (30%)| 640                              | 3.67, 6.4, 0.82                                  | 16.5, 25.35, 30.4, 38.             | 3.43, 3.2                         |
| Mix4 (40%)| 650                              | 3.67, 11, 0.9                                    | 14.8, 20.26, 28.5, 37.             | 2.809, 2.75                      |

*Flow table value should be in the range of 650 to 800 mm [8].
**T50 value should be in the range of 3 to 5 sec [8].
*** V-funnel value should be in the range of 6 to 12 sec [8].
**** L-box value should be in the range of 0.8 to 1 [8].

The values of compressive strength of each mix at different curing ages, as presented in Table (7), were plotted as shown in Figure (7) to show the progress of compressive strength with curing period. Like traditionally consolidated concrete, SCC also continues to gain strength with curing time. The 28-day compressive strength of SCC is approximately 20-40% higher than the 7-day strength.

The highest 28-day compressive strength of 40.7 MPa was achieved in mix2 and the lowest value of 28.55 MPa was noted in mix4. As seen from Table (7) the variations in compressive strength for mix1 and mix2 are not obvious, but when the percentage of limestone filler increased the compressive strength decreased to reach 28.55 MPa at 40%. Generally speaking the effect of added limestone on the compression strength is noticeable from figure (7) i.e. the addition causing a reduction in the compression strength as compared to the reference mix at all the percentages tried. Fig (8) shows the relation between percentage of LSP and compressive strength at 28 days.
As observed from Table (7), all the mixes satisfied the self-compactibility criteria. By visual examination of concrete it was found out that there were no signs of segregation as seen from Fig.(9). It may be observed that the T-50 times, which provide an indication of the relative viscosity of the SCC [9], increase with an increase in the limestone filler ratio. The increase in viscosity will help to minimize the risk of segregation during and after placement. Using of LSP in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow as for concrete made with Portland cement only as seen in Table (6).
Splitting and Flexural Tensile Strength: Table (7) presents the splitting tensile strength and flexural strength for each mix. It can be seen that the tensile and flexural strength decreases as limestone powder ratio is increased and the largest value of strength is for mix2 which had 20% of limestone powder as replacement of O.P.C with respect to mix3 and mix4. Figures (10) and (11) show the relation between splitting strength and percentage increase in LSP ratios and the percentage decrease of splitting strength with respect to mix1 at an increasing LSP ratio.

![Figure (9): Measurement of slump flow (mix2)](image)

![Figure (10): Relation between Percentage of LSP and splitting strength at 28 day](image)
All specimens showed a linear mode of fracture and the same relief (surface shape) on the fractured faces. Fig. (12) Shows the specimens after failure and surface shape of the fractured faces of concrete cylinders, a uniform distribution of aggregates over the full cross section can be seen.

Figures (13) & (14) show the relation between flexural strength (modulus of rupture) and percentage increase in LSP ratios.
Comparison between the addition and the replacement of limestone powder to the SCC:

Table (8) shows the constituents materials comprising the same ratios of Cement, Sand, Gravel and water/powder as used previously. The sole variable in these mixes was the way of adding the limestone filler. In mixes 2,3, the limestone filler was added as percentage replacement of cement; in the mixes 4,5 the same percentage of limestone filler (20,30%) is added to the cement in order to see the difference between the replacement and addition of limestone powder.

![Graph of Relation between Percentage of LSP and Flexural Strength at 28 days](image1)
![Graph of Percentage drop in Flexural Strength with respect to mix1 with Increasing LSP ratio](image2)
Table (8): Proportions of the concrete mixtures

| Mix No. | Water Content kg/m³ | Cement Content kg/m³ | Limestone filler kg/m³ | Total cementitious material kg/m³ | Fine agg. kg/m³ | Coarse agg. kg/m³ | SP % | T50 (sec) | Densiy kg/m³ |
|---------|---------------------|----------------------|------------------------|----------------------------------|-----------------|-----------------|------|-----------|-------------|
| No Filler |                     |                      |                        |                                  |                 |                 |      |           |             |
| Mix1    | 149                 | 450                  | 0                      | 450                              | 756             | 743             | 1.75 | 3.3       | 2106        |
| Ratio   | 0.33                |                      |                        |                                  |                 |                 |      |           |             |
| Mix2    | 149                 | 360                  | 90 20                  | 450                              | 756             | 743             | 1.6  | 3.38      | 2105        |
| Mix3    | 149                 | 315                  | 135 30                 | 450                              | 756             | 743             | 1.625| 3.67      | 2105        |
| Ratio   | 0.33                |                      |                        |                                  |                 |                 |      |           |             |
| Mix4    | 178                 | 450                  | 90 20                  | 540                              | 907             | 891             | 1.72 | 3.25      | 2525        |
| Mix5    | 178                 | 450                  | 135 30                 | 585                              | 983             | 965             | 1.74 | 2.68      | 2721        |
| Ratio   | 0.33                |                      |                        |                                  |                 |                 |      |           |             |

*Limestone Filler as a replacement |

*Limestone Filler as an addition |

*SP: Superplasticizer

From the results of table (8) the quantity of superplasticizer (SP) needed by those mixes to attain a flow equal to 650±15mm was larger than the quantity used by mixes 2,3 because the filler content is larger and the W/(C+LSP) was kept constant at 0.33. Also it can be noticed that with the filler mixes the time needed to reach T50 was less than with respect to mixes without the filler. The mixes that had the filler as a replacement of cement are more fluid, due to increase the fine materials.

After testing the specimens, the results were clarified in Table (9). The table shows the density, compressive strength and splitting strength of these mixes. It can be noticed that the density of these mixes in the fresh and hardened state is greater than that of mixes with no filler or when the filler is used as a replacement to cement and the compressive strength increased with the time similar to conventional concrete without filler.

Table (9): Mechanical Properties of Mixes

| Mix | Mix1(0%) | Mix2(20%) | Mix3(30%) | Mix4(20%) | Mix5(30%) |
|-----|----------|-----------|-----------|-----------|-----------|
|     | Limestone Filler as a replacement | Limestone Filler as an addition |
| Density kg/m³ at fresh state | 2400 | 2385 | 2381 | 2430 | 2438 |
| Density kg/m³ at hardened state | 2430 | 2428 | 2425 | 2448 | 2450 |
| Compressive Strength(MPa) at 3days | 26.2 | 18.2 | 16.5 | 17.1 | 15.2 |
| Compressive Strength(MPa) at 7days | 36.65 | 29.4 | 25.35 | 29.3 | 24.6 |
| Compressive Strength(MPa) at 28days | 44.6 | 40.7 | 30.4 | 39.8 | 27.6 |
| Compressive Strength(MPa) at 56days | 56.4 | 53.3 | 38 | 52.9 | 37 |
| Splitting Strength(MPa) at 28days | 4.995 | 3.667 | 3.43 | 3.78 | 2.96 |
Figure (15) shows the relationship between compressive strength and age for mixes containing 20, 30% limestone filler as cement replacement and mixes containing 20, 30% limestone filler as an additive. It can be seen that the compressive strength of mixes having 20% of limestone filler has rather similar values. A similar conclusion applies for mixes having 30% of limestone filler. This means that the use of limestone filler as a replacement or an additive material has no effect on the compressive strength except for the fact that using the limestone filler as an additive is not economical because more Plasticizer material is needed although it gives the mix more fluidity, as fine material leads to increasing fluidity of SCC.

![Graph showing relationship between compressive strength and age for mixes containing limestone filler](image)

**Figure (15):** Relationship between Compressive Strength and age for mixes containing (20, 30%) of limestone filler as cement replacement and mixes containing (20, 30%) of limestone filler as an additive

Table (9) presents the splitting tensile strengths for each mix. It can be seen that the tensile strength for mixes containing the filler as an additive material decreased as the limestone powder ratio increased. Figure 16 shows the percentage decrease of splitting strength with respect to mix 1 (which had no filler) at an increasing LSP ratio. Approximately, the splitting tensile strength is about 10% of the compressive strength.

![Bar chart showing percentage decrease in splitting strength](image)

**Figure (16):** % Percentage drop in Splitting Strength with respect to mix 1 as Increasing LSP ratio
Conclusions

1. The use of limestone filler helps successfully in producing SCC, but increasing the percentage of limestone filler does not necessarily lead to increasing mechanical properties.
2. Increasing the limestone ratio as replacement of O.P.C leads to a decrease in compressive, splitting, flexural strength.
3. Using the limestone filler as replacement of cement is more economical because the use of LSP in SCC reduces the dosage of superplasticizer needed to obtain similar slump flow as for concrete made with Portland cement only.
4. Using the limestone filler as an additive material needs greater amount of plasticizer with respect to using limestone filler as replacement of cement, but it gives more fluidity for SCC.

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