Impact Resistance of Limestone Cement Self Compacting Concrete Reinforced by Locally Available Grids

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Abstract. Impact strength of self-compacted concrete is a field of interest, mostly when the concrete is produced from sustainable materials. This research's main objective is to clarify the ability to use two types of Portland limestone cement (Karasta and Tasluja) in self compacted concrete under impact loading, further to the economic and environmental benefits of the limestone cement. The impact loading was applied by a low-speed test, using the drop ball on concrete. Moreover, the study reveals the resistance of the grids reinforced concrete to impact loading by using polymer grid, and steel grid reinforced concrete slabs. Mixes reinforced by steel mesh had the highest results, indicating that the steel mesh was more robust because it had absorbed more energy till it reached failure.

Keywords: Limestone; cement; impact resistance; self-compacting concrete.

1. Introduction
Concrete is a common material used in the construction field. The overall properties of the concrete mixture depend on the properties of the materials made. A lot of studies were related to the addition of materials to cement and/or replacement of the cement with other materials to reach the target behavior of concrete. One of these replacements is limestone. Limestone, which is the subject of this study, can be replaced with cement-producing limestone Portland cement. The use of this kind of cement is increased in the decades due to the benefits that can be gained from the limestone Portland cement in the economic and technique fields [1]. Limestone is used to improve the flow efficiency of self-compacting concrete. It is used as a partial replacement for cement in most masonry cement. This is due to considering the limestone as inert filler [2]. Blended cement these days is desirable because of its economic and technical benefits.

Moreover, decreasing CO\textsubscript{2} emissions when clinker production is reduced reduces pollution either [3]. The limestone effect blended with cement in 0, 5, 10, 20, and 40 percent by weight was also studied [3]. This study's main goal was to investigate the optimum percentage of limestone when blended with cement to gain the most preferred durability properties of cement mortars and concrete. Investigation [4] on the effect of limestone on the water demand of blended cement was conducted. However, it was concluded that the critical factor that affects the limestone influence on water requirement is the clay content in limestone powder. Limestone powder's existence in cement mixture improves the viscosity and physical properties of the mix. Limestone powder has a large amount of calcium carbonate, which works, in addition to silica or nanocarbon materials, as filler materials. Concrete production with limestone containing a high organic percentage is not preferred. This is due to the effects of the organic materials on concrete's overall properties [5]. Low-velocity testing methods used to explore the dynamic performance include pendulum impact test and drop-weight test. Pendulum test can give the impact
number leading to the material's complete failure, but it is hard to obtain other data [6,7]. On the other hand, the drop weight test usually provides more detailed results than the pendulum test, such as the impact force, specimen deflection, and impact energy [8,9].

2. Materials and mix design

The properties of materials and the tests were carried out in the laboratories of the Civil Engineering Department/University of Baghdad and the Center for Building Research laboratories.

2.1 Cement

Two types of Portland limestone cement were used in this study for comparative purposes. The first is Karasta limestone Portland cement produced by Lafarge Co., and the second is Tasluja limestone Portland cement produced by Tasluja Factory. Physical and chemical tests were carried out in the Building Research Center, as shown in tables below:

| Table 1. Chemical properties of Karasta and Tasluja limestone Portland cement IL. |
|-------------------------------|-----------------|-----------------|-------------------------------|
| Oxides and phases, %          | Karasta test results | Tasluja test results | Specification limits ASTM C-595/15 |
| L.O.I                         | 7.44             | 6.21             | Not more than 10               |
| SiO2                         | 18.39            | 17.81            | -                             |
| Al2O3                        | 4.63             | 4.19             | -                             |
| Fe2O3                        | 4.77             | 4.91             | -                             |
| SO3                          | 2.35             | 2.44             | Not more than 3               |
| CaO                          | 62.11            | 62.22            | -                             |
| MgO                          | 1.83             | 1.95             | -                             |
| Cl                           | 0.01             | 0.011            | -                             |
| LSF                          | 1.04             | 1.02             | -                             |
| I.R                          | 0.9              | 0.47             | -                             |

| Table 2. Physical properties of Karasta and Tasluja limestone Portland cement IL. |
|-------------------------------|-----------------|-----------------|-------------------------------|
| Test                          | Tasluja test results | Karasta test results | Specification limits ASTM C-595/15 |
| Finance (blain) m²/kg          | 310.5            | 365             | -                             |
| Setting time (min)             | Initial          | 90              | 75                            |
| Compressive strength (MPa)     | 3 days curing   | 14              | 17                            |
|                               | 7 days curing   | 21              | 25                            |
|                               | 28 days curing  | 34              | 43.5                          |

2.2 Sand

Ekhaider natural sand was used as fine aggregate in this study. The physical and chemical properties of fine aggregate are shown in Table 3. The sieve analysis shows that the sand lies in (zone 2) from the tests that were carried out according to the requirement of Iraqi specification (IQS No.45/1984), as shown in Table 4.

| Table 3. Physical and chemical properties of fine aggregate. |
|-------------------------------|-----------------|-----------------|
| Property                      | Test result     | I.Q.S.45: 1984 Limits |
| Specific gravity              | 2.6             | -               |
| Absorption, %                 | 0.72            | -               |
| density (kg/m³)               | 1580            | -               |
| Sulphate content (SO₃)        | 0.2             | 0.50% (max)     |
Table 4. Sand analysis according to the requirement of (IQS no.45/1984), Zone II.

| Sieve no. | Passing % | Limits of Iraqi specification no.45/1984 |
|-----------|-----------|----------------------------------------|
| 10 mm     | 100       | 100                                    |
| 4.75 mm   | 93.3      | 100-90                                 |
| 2.36 mm   | 77.7      | 100-75                                 |
| 1.18 mm   | 66.6      | 90-55                                  |
| 600 µm    | 54.4      | 59-35                                  |
| 300 µm    | 26.3      | 30-8                                   |
| 150 µm    | 3.1       | 100                                    |
| Passing from sieve 75 | 2.6 | Max 5 |

2.3 Gravel
Crushed gravel was used of (14 mm) max size as shown by the sieve analysis conducted according to the requirement of Iraqi specification (IQS No.45/1984), see Table 5.

Table 5. Sieve analysis results.

| Sieve No. | % Passing | Iraqi specification (IQS No.45/1984) for max size agg. of 14 mm |
|-----------|-----------|---------------------------------------------------------------|
| 14 mm     | 100       | 100                                                           |
| 10 mm     | 99.7      | 85-100                                                        |
| 5 mm      | 23.8      | 0-25                                                          |
| 2.36 mm   | 1.8       | 0-5                                                           |
| Passing sieve 200% | 0.2 | 3                |
| Sulfate content (SO₃) | 0.6 | Maximum 1%         |

2.4 Lime dust
Limestone powder is used with a cement mixture to improve the viscosity and physical properties of the mix. Limestone powder has many calcium carbonate (98%), and silica works as filler materials. Table 6 shows the properties of the lime dust used.

Table 6. Properties of lime dust.

|           | SiO₂ | Fe₂O₃ | Al₂O₃ | CaO | MgO | SO₃ | L.O.I | CO₃ |
|-----------|------|-------|-------|-----|-----|-----|-------|-----|
|           | 0.21 | 3.36  | 0.03  | 48.28 | 3.97 | 0.08 | 42.48 | 0.19 |

*The material was tested at the laboratories of the Iraqi Geological Survey

2.5 Water
Normal tap water was used.

2.6 Super plasticizer
BETONAC-1030 was used, which is a high range water reducer, high extended workability superplasticizer, and conforms with the specifications of ASTM-C494 Type F. in addition to improve workability and cohesion. It also increases the high early strength due to the reduction of W/C ratio, which means less mixing water used. Hence a better homogenous mix is produced.

2.7 Mix design
The mix proportions that have been used in this research are (1: 1.71: 1.9) for (cement, sand, and gravel) respectively, with W/C ratio of 0.42 conforming to the ACI-211. The superplasticizer has been added to the mix (1.4%) by weight of cement, where the lime dust replacement was (20%) by weight of cement.
3. Tests and results

3.1 Fresh concrete tests
The results of conducted fresh concrete tests are given in Table 7.

3.2 Slump flow test
The slump flow test is the ability of the mixture to free flow horizontally. The diameter of the concrete circle is the measure of concrete filling ability. This test is implemented according to (EFNARC 2002). The time required for concrete to reach (50 cm) is measured. A slump cone, baseplate, and stopwatch are required to conduct this test, as shown in Figure 1.

3.3 V-Funnel Test
This test is used to assess the viscosity and filling ability of self-compacting concrete. The test is not suitable for aggregate that exceeds the maximum size of 20mm. The V-shaped funnel is filled with fresh concrete, and the time of concrete to flow out of the funnel is recorded (EFNARC 2002). Details of the tests are shown in Figure 1.

![V-Funnel test and slump flow test.](image)

3.4 L-Box Test
This test is used to assess self-compacting concrete’s passing ability to flow through tight openings like spaces between reinforcement bars and other obstacles without segregation or blocking. There are two ways in this test: using two bars, and the second is by using three bars. The three bars test imitates more congested reinforcement, which has been used in this study according to (EFNARC. 2005. Figure 2 gives the details of the L-Box test.

![L-Box test details.](image)
Table 7. Fresh concrete results.

| Method          | Unit | Karsat L.P.C | Tasluja L.P.C | Typical range of values (EFNARC) |
|-----------------|------|--------------|---------------|----------------------------------|
| T-50 Slump Flow | mm   | 4            | 4.3           | 2-5                              |
| V-Funnel        | sec  | 9            | 10            | 6-12                             |
| L-Box (H2/H1)   |      | 0.9          | 0.86          | 0.8-1                             |

3.5 Hardened concrete tests

The conducted hardened concrete tests are:

3.5.1 Compressive strength test

Compressive strength is considered as an index to assess the overall quality of concrete. It is generally assumed that an improvement in the compressive strength results in the improvement of all other physical properties like impact strength. Which an average of three cubic specimens (10×10×10 cm) dimensions for (28, 56, and 90) age was tested for two types of limestone portland cement according to BS 1881-116:1983. The average results are shown in Table 8 and Figure 2.

Table 8. Results of compressive strength tests.

| Mix   | 28 days | 56 days | 90 days |
|-------|---------|---------|---------|
| Karasta | 51 |
| Tasluja | 46 |
| 58 | 60 | 55 |

It's noticed from Table 8 above that both Karasta and Tasluja had close results in the compressive test due to the similarity in both cement components, which lead to overall good compressive results. With the current focus on sustainable effect in the industry of construction, the use of lime dust eco-friendly material which reduces the CO2 emissions by reducing the amount of cement used, which also reduces cost. The effect of adding lime dust which works as inert fillers to produce a more dense mixture, hence; increase in strength.

3.5.2 Impact resistance test

Impact test represents the object's ability to resist high-rate of loading. Impact resistance is one of the most important properties for a designer to consider. The object to repetitive blows by falling weight (iron ball of a standard weight of 3.4 kg) and the number of blows at which the failure occurred is the impact resistance. In this study, the iron ball was dropped from 1.5 m high. The number of blows at

![Figure 3. Compressive strength with age.](image)
which the first crack appeared was recorded and the number of blows to cause failure. An average of three specimens of (50×50×10 cm) dimensions was tested at age (28, 56, and 90) for two types of limestone portland cement according to ACI C-544, which were reinforced by plastic and iron mesh of square opening size (0.5 in.) and (0.2 mm) in diameter. The steel mesh was of a welded one. The test results are illustrated in Table 9 and Figures 4 to 6.

Table 9. The results of the impact test.

| Mix          | Type of Reinf. | Dimensions (cm) | Impact Resistance |
|--------------|----------------|-----------------|-------------------|
|              |                |                 | No. of blows to cause 1st crack at age (days) | No. of blows to cause failure at age (days) |
|              |                |                 | 28    | 56    | 90    | 28    | 56    | 90    |
| Karasta L.P.C| Plain          | 50×50×10        | 3     | 6     | 6     | 7     | 8     | 8     |
|              | Steel          | 50×50×10        | 6     | 9     | 15    | 15    | 22    | 26    |
|              | Polymer        | 50×50×10        | 6     | 8     | 14    | 13    | 14    | 23    |
| Tasluja L.P.C| Plain          | 50×50×10        | 3     | 4     | 6     | 7     | 7     | 8     |
|              | Steel          | 50×50×10        | 5     | 9     | 12    | 13    | 20    | 23    |
|              | Polymer        | 50×50×10        | 4     | 7     | 10    | 12    | 13    | 22    |

As shown in Figure 4, all results start to develop impact resistance with age, and steel mesh had the highest readings, then the plastic, and finally the plain concrete had the lowest. As shown in Figure 5, the results of the mix reinforced by steel mesh had the highest value of impact resistance, unlike the plain mix, which had the lowest. At the same time, the mix reinforced by plastic mesh had the middle value of results. This behavior may be attributed to the high tensile strength of the steel grid compared to the other. The bond between the concrete and the reinforcement grids has a key role in impact resistance, where the number of blows required to cause the first crack and failure increased. It can be attributed to reinforcing grids that helped to absorb more of the impact energy [10].
4. Conclusions

The following points can be concluded from the results of the tests:

- Specimens were tested for both Karasta and Tasluja PLC, and results had shown general development in compression strength with the increase of time. That behavior is due to the increase of curing time, leading to a rise in the overall hydration reactions, hence increasing strength.

- The impact resistance of both Karasta and Tasluja PLC indicated an increase with time of curing, which contributed to concrete gaining more strength as the hydration continued. As shown in the results, the mixes reinforced by steel mesh had the highest results, which indicate that the steel mesh was more robust because it had absorbed more impact energy till it reached failure, which leads to an increase in impact resistance. While the mixes reinforced by the plastic mesh had a satisfying result but still lower than the mixes reinforced by steel mesh, which indicates that the plastic mesh endurance to absorb impact energy was lesser than the iron mesh.

- From the point of sustainability, it is possible to use Portland Limestone Cement locally manufactured in producing self-compacting concrete and exposed to impact loading reinforced with locally available grids.

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