Limestone filler as one of the cheapest and best additive to concrete

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Abstract. The purpose of obtaining effective building materials of high-density and high-durability is coupled with the development of implementation of different test-proven methods of modification of such materials on different levels, micro- and nanostructural included. Of late, of much significance is the application of finely-disperse ingredients in admixture compositions such as limestone filler produced from local raw resources and is considered to be one of the cheapest and best mechanical properties modifier, chemically and electrically relatively almost neutral. An efficiency of limestone filler to fine-grained carbonate concrete (FGCC) is proven in tests data obtained. Limestone filler in combination with superplasticizer enhances crack-resistance and reduces creep deformations thereby making FGCC the most effective and utilized. Besides, knowledge of the stress-strain distribution in concrete with limestone fine-grained additives under compression is crucial for the design of certain kinds of reinforced concrete structures, such as shells, membranes and domes. The latter preferably should be manufactured with addition of both limestone filler and superplasticizer which reveals synergetic effect and leads to narrowing boundaries of crack initiating stresses and strength in compression. An additional study must be performed as to replace superplasticizer with more progressive hyperplasticizer.

1. Introduction
The utilization of processed limestone to upgrade certain application properties of fine-grained concretes, such as crack-resistance and vitality has now become quite essential for construction industry [1]. Limestone fine grains are best filler to fine-grained carbonate concrete (FGCC). Limestone powder is considered to be one of the most effective modifier of mechanical, chemical and technological properties of FGCC and a purposeful replacement of a binder [2]. This occurs due to the ability of limestone powder to work conjointly with clinker ingredients in a concrete body [3] which consists of the fluid matrix of water, binder, various water-reducing additives and skeleton of inner structure filled with aggregates and fillers. Physical and chemical compatibility of limestone fine grains as the filler to FGCC and as a partial replacement to cement comes from the properties of limestone fine particles to facilitate distribution of the granular cluster more smoothly within the concrete volume, perform micro-reinforcement of a mineral skeleton of concrete and affect the hydration process by absorbing water which facilitates closest contacts with cement particles [4]. On the basis of previous researches [5], limestone filler is likely to improve strain capacity of concrete, reduce long-time creep and thereby contribute to crack-resistance and durability through densest grain placement and synergetic effect from using limestone fines with superplasticizer, which performs the FGCC best structure formation. This is why FGCC shows good practical efficiency.
2. Experiment

2.1. Apparatus

The experimental studies were performed in Tver Technical University (Russia) to show the compressive short and long-time creep and crack-resistance of FGCC as affected by water/cement ratio, cement/limestone filler ratio, an amount of superplasticiser. Five concrete cubes of 10x10x10 sm. have been tested in compression. Limestone filler is manufactured by milling the screened jaw-crushed limestone rocks. Aggregates are also limestone grains ranging from 5 to 0.1 mm.

To study crack-resistance and creep deformations of FGCC, a special device was used (Figure 1.).

![Test device with front and back clock-type indicators to compensate accidental non-axial loading due to bending the fixing frame, and dynamometer](image)

Figure 1. Test device with front and back clock-type indicators to compensate accidental non-axial loading due to bending the fixing frame, and dynamometer

2.2. Technics

Crack initiation has been fixed with electrical strain gauges and crack propagation has been pictured with a camera. Measurement accuracy amounted to $10^{-7}$. To estimate crack resistance, an appropriate newly-introduced crack coefficient was used, which took into proper account specific features of concrete as heterogeneous, composite material with conglomerate structure webbed through by tiny invisible cracks and having a big trunk crack. The coefficient is actually a ratio of strength in compression and cracking stress, both squared.

$$K_{cr} = \frac{\sigma_{crack}^2}{R_{compress}^2},$$

(1)

Creep deformations were assessed with clock-type indicators. Tests performed confirmed a hypothesis that FGCC displays a better crack-resistance and lesser long-term creep deformation as compared with ordinary concretes without limestone additive.

The following is the table with the test results.
Table 1. Compression test results

| No of mixes | w/c | Superplasticiser | Limestone filler/cement | Crack-stress and strength in compression |
|-------------|-----|-----------------|-------------------------|------------------------------------------|
|             |     | SP-1, % of cement mass |                      | σ_{crack} H/mm² | R_{comp}, H/mm² |
| 1           | 0.45 | 0                | 50                      | 23.3          | 27.8            |
| 2           | 0.34 | 1                | 0                       | 36.7          | 48.5            |
| 3           | 0.46 | 0.75             | 30                      | 24.2          | 35.6            |
| 4           | 0.39 | 0.75             | 17.8                    | 40.1          | 46.8            |
| 5           | 0.41 | 0.75             | 50                      | 30            | 37.1            |

As we may well see the gaps between crack-stresses and strength values are narrower for the specimens containing limestone powder. This is due to better distribution of the cement particles over the concrete volume and filling in air and capillary pores [6]. It enhances hydration, makes the paste more viscous and promotes uniform consolidation of the composite. This results in enhanced crack-resistance without any perceptible reduction in strength (see both table 1 and table 2).

Table 2. Values of crack coefficients

| No | Relative strain | Value of K_{cr} |
|----|-----------------|-----------------|
| 1  | 0.0087          | 0.70246         |
| 2  | 0.0019          | 0.5726          |
| 3  | 0.0021          | 0.6275          |
| 4  | 0.0021          | 0.73417         |
| 5  | 0.0028          | 0.65387         |

Limestone filler and superplasticizer showing synergetic effect give rise to plastic zones at the peak of the main trunk crack and in its vicinity depriving the crack of the energy to further propagation. Dynamic viscosity also increases. That is the essence of the conjoint mechanism of crack reduction by limestone and superplasticizer additive. The following figures illustrates correlation between strength in compression, crack coefficient(×1000), limestone finest grains content, limestone filler content and water-cement ratio.

Figure 2. Correlation between crack coefficient, amount of superplasticizer and limestone filler
Figure 3. Correlation between strength in compression, limestone finest grains content and limestone filler

Optimal amount of limestone finest powder as a partial replacement of cement is 17-18 %.
Although limestone powders insignificantly reduced the compressive strengths of concretes when they were used to replace cement without compensation of the amount of water, full strains are apparently lower for the specimens with limestone filler.
The use of limestone powders as a partial replacement of cement also require the use of a superplasticiser to compensate the loss of strength due to higher air-entaining and micro-porosity level [7]. In tests superplasticiser SP-1 was used in optimal amount of 0,75% of cement mass.
The following is the graph of compressive strength versus amount of superplasticiser SP-1 in paste.

Figure 4. Compressive strength versus amount of superplasticiser SP-1

An optimal amount of superplasticiser is to compensate a “puffing” effect of exceeding amount of superfine limestone particles that increase an air-entaining and slacken pore-free consistency of cement paste.
Increasing the amount of the finest limestone particles requires an increase in the superplasticiser amount for stabilizing hydration, which can conversely affect the short-term development of both strain and strength [8]. The following table contains the measured values of ultimate creep strains for five specimens.

| No of mixes | $S_e/(28)*10^{-5}$ |
|-------------|--------------------|
| 1           | 2                  |
| 2           | 5                  |
| 3           | 3                  |
| 4           | 1                  |
| 5           | 2.5                |

The values of the ultimate creep strains indicate the better strain capacity of the specimens with limestone addition in the long run, as compared to that of specimens without it. Positive role of limestone fines in enhancing durability, crack-resistance and vitality of FGCC is obvious.

3. Summary and prospects
Limestone filler to FGCC is proved to have a number of practical advantages.

It has been manufactured within local area to concrete plants from raw materials by, for instance, mechanical activation, thereby providing good efficiency and cheap replace for main binder. Easily ground limestone crushed rock usually has a wide particle size distribution that allows to fill the gaps between the cement particles, reducing the water demand, improving the stability of fresh concrete and densifying the microstructure of the hardening cement paste, thereby resulting in enhanced durability and crack-resistance, without loss in exploitation properties. Concrete expensive binder (cement) saving rates amount up to 50 % without any considerable loss in the concrete performance. Enhanced durability of FGCC also arises from denser packing of particles within the concrete matrix. Reduction in porosity is suggested to be caused by micro-cracks transference from air and capillary areas into gel zone. A superplasticiser is required to improve the strain-stress performance of FGCC. Notwithstanding, additional study must be performed as to replace superplasticizer with more progressive hyperplasticizer.

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