Fine-grained limestone concrete with improved dissipative properties

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Abstract. Crack propagation in concrete is known to be partially stipulated by the process of energy dissipation. In this study the usage of complex admixture including limestone fines and superplasticizer which enhance crack propagation energy dissipation rate is discussed. Energy dissipation rate and crack propagation are assessed by comparing cracking strains and stress intensity ratios for two sets of specimens, with and without limestone fines. Limestone semi-inert filler acting in a synergetic way with superplasticizer is revealed to enhance crack propagation energy dissipation rate and cracking strains, which makes fine-grained limestone concrete the effective crack-resisting material.

1. Experiment

1.1. Introduction
Rather few experimental studies consider crack-resisting mechanism in quasi-brittle material like concrete in view of crack propagation energy dissipation rate [1]. Failure of concrete specimens is mainly assessed by the loss of rigidity and strength due to structure damage incurred from microcracks development [2]. Energy can dissipate by either way – upto the very failure due to fracture development in elastic field or into plastic zones which appear at the peak of trunk crack and deprive the latter the energy to further growth thus providing the whole mechanism of energy dissipation. Physical and chemical compatibility of limestone fines with cement as a partial replacement [3] for it promotes good distribution of plastic micro-zones evenly within the volume [4], reinforcing a mineral skeleton of concrete [5] and widening its dissipation areas.

1.2. Materials
Tests on crack propagation energy dissipation were performed at Tver state technical university. Limestone filler was manufactured from fine-sewed product of jaw-crushed limestone gravels. Aggregates were limestone grains ranging from 5 to 0.05 mm. Fifteen concrete cubes of 10x10x10 sm. have been tested in compression. Five cubes had basic concrete composition without limestone filler. Ten specimens contained limestone filler. Basic concrete composition to be compared to is given in table 1.
### Table 1. Basic mixture composition, kg per 1 m³.

| Composition | Cement | Sand | Water | W/C ratio |
|-------------|--------|------|-------|-----------|
| Basic       | 650    | 1460 | 286   | 0.44      |

1.3. **Technics**

Physical explanation of the cracking energy dissipation in the paper is approved by experimental data concerning standard concrete and a concrete enriched by adding to the mixture a filler constituted of limestone micro-particles which are assumed to improve the dissipative behavior of the material.

The cracking process of concrete involves mechanisms with various energy dissipation levels. The cracking stresses are detected by the electric sensors. Crack resistance was assessed by stress intensity ratio

\[
K_r = \left(1 - \mu^2\right) \times \sigma^2 \times \pi \times l / E
\]

\(l\) – trunk crack half-width, \(\mu\) - Poisson coefficient, \(\sigma\) – cracking stress, \(E\) – elasticity modulus.

Test mixture compositions is presented in table 2.

### Table 2. Two test mixture compositions, kg per 1 m³.

| Compositions | Cement | Aggregates | Water | Limestone filler | SP-1 | W/C ratio |
|--------------|--------|------------|-------|------------------|------|-----------|
| Test №1      | 472    | 1528       | 295   | 200              | 5.04 | 0.44      |
| Test №2      | 336    | 1528       | 333   | 336              | 2.52 | 0.5       |

Two test mixture compositions were used to assess the dissipation properties. Specimens were tested on a special frame-device. Axial loading was applied in compression, as regards of volumetric stress-strain state with stretching tensions along the orthogonal planes of specimens.

2. **Test results**

The following is test results indicating properties of concrete grouped in table 3.

### Table 3. Test results indicating properties of concrete.

| Concrete compositions | \(R_{\text{cub}},\) MPa | Density, \(\text{kg/m}^3\) | General porosity | Capillary porosity | \(K_r\) |
|-----------------------|--------------------------|-----------------------------|------------------|-------------------|--------|
| Basic                 | 33.6                     | 2310                        | 21.8             | 12.3              | 0.00055|
| Test №1               | 34                       | 2260                        | 22.04            | 12.7              | 0.00085|
| Test №2               | 25.7                     | 2240                        | 24.8             | 13.1              | 0.00115|

Measured data show quite a good fit with theoretical predictions by the presented parameters and ensure a sound basis for further developing the theoretical and practical methods to study the phenomena in question.

The more limestone filler is in the paste the better dissipative properties concrete seems to possess. The values of stress intensity ratio \(K_r\) for limestone containing specimens are greater than for the specimens without limestone filler. Limestone fines and superplasticizer act synergetically and produce plastic zones at the main trunk crack and depriving it of the energy to propagate, micro-cracks being distributed smoothly throughout the volume and contributing to higher rate of crack propagation energy dissipation.

The following is the diagram of relations between cracking strains, amount of limestone fines and superplasticizer (Figure 1).
The values of the cracking strains indicate the better strain capacity of the specimens with limestone addition, as compared to that of specimens without it. Limestone fines are considered to enhance the rate of dissipation of cracking energy and thus crack-resistance and vitality of limestone fine-grained concrete. Regarding this, the main dissipation phenomena have been taken into proper account in presenting tests results, such as concrete micro-damages of developing fracture, cracking strains and micro-zones of plasticity constituted by tiny amount of complex additive of limestone filler and superplasticizer, evenly distributed over composite volume. Among these possibilities, the kind and level of cracking strains and micro-zones of plasticity herein considered plays a significant role, as it is linked to the very cracking energy dissipation rate, stress intensity ratio values $K_I$ in table 3 being compared with one another to testify this conclusion. The experimental results herein shown were intended as good evidence in support of the proposed explanation of the cracking energy dissipation mechanism.

3. Summary and prospects
Limestone filler manufactured from local quarries reveals good crack resistance via high crack propagation energy dissipation rate. Easily ground limestone fines has a wide range of particle size distribution which promotes best infilling micro-voids between the cement particles in a matrix, reducing the water demand and improving the homogeneity of cement paste, enriching it with plastic micro-zones. This results in improved dissipation features and crack-resistance of concrete, which is shown through greater values of stress intensity ratio $K_I$ for limestone containing specimens. Cracking strain values are somewhat greater for these specimens too. Improved dissipation properties of limestone fine-grained concrete also come from better and smoother packing of particles within the concrete matrix. Pores are viewed to be filled by micro-globules of limestone paste ensuring dissipation process being transferred from air to capillary areas and gel zones, having rather plastic than elastic features. All this make limestone fine-grained concrete a composite with improved dissipative properties.

Energy dissipation process in concretes still has quite a number of questions to be resolved via experiments. These questions naturally entail the possibility to investigate concrete mixtures with newly introduced and effective additives. For example, the possibility to reach an optimized and well modified dissipation from mechanical to internal energy as to achieve damping effect in concretes, is nowadays very crucial scientific topic. The way of modifying the dissipation rate investigated in present paper is related to the usage of admixtures with limestone micro-disperse filler in civil engineering, and in particular in cases of large building structures, working under cyclic and dynamic loads, like shells, domes and large spanned frames. Challenges on this way are to thoroughly explore the dissipative modification phenomena of such additions to concrete as mixtures of limestone filler with hyperplasticizers of different chemical compositions, plasticity being taken into proper account as largely contributing to facilitating the crack propagation energy dissipation process. These phenomena remain open for further scientific discussions. As for other possible future lines of investigation, a
special attention would have to be granted to designing of the limestone fine-grained compositions concerning a more detailed description of the cracking energy dissipation rate under various external conditions with applying different techniques of its assessment.

References
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