Modified fiber reinforced concrete for industrial floors

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Abstract. The main requirements to gain of strength, impact resistance without increasing brittleness, durability of concrete for industrial floors are increasing. It has been shown that the strength of concrete at the impact loads can be increased by means of regulation of the macro-, micro- and nanostructure parameters of the concrete. The kinetics of hardening, peculiarities of pore structure and impact resistance of concrete reinforced with polypropylene fiber and modified by polycarboxylate ether superplasticizer, micro- and nanofine mineral additives are investigated. Nanomodified concretes are characterized by increased rate of early strength development (f<sub>cm2</sub>/f<sub>cm8</sub>=0.55) and strength after 28 days (101.5–104.9 MPa), which meets the requirements for rapid hardening high strength concrete. Impact resistance of modified fiber reinforced concrete is determined according to special procedure, which estimate parameter of maximum weight after which the residual impression depth on the surface from impact does not exceed the permissible value (2 mm). The impact resistance of concrete modified with polycarboxylate superplasticizer is 100 and 150 N after 28 and 360 days respectively. Nanomodified fiber reinforced concrete is characterized impact resistance 200 N after 28 and 360 days.

1. Introduction

All forms of activity in industrial object need a sound platform for operate and concrete floors almost invariably form the base for this aim. In recent years, there has been a steady growth warehousing operations, need for commercial garages, sports and other recreational to serve the needs of industry and society. The scale of such facilities, and the speed with which they are constructed, has also increased, with higher and heavier racking and storage equipment and transport being used. These all make greater demands on the concrete floor [1]. Innovative building technologies put forward new requirements for technological and technical properties, as well as the strength, corrosion resistance, durability of concrete, which is associated with increased requirements for reliable operation during the life cycle of buildings and infrastructure. In addition contemporary building sets high requirements concerning constructing works time due to application of rapid hardening concretes, which provide the ability of early structures loading, reducing of the production cycle.

High early strength of concrete is largely achieved by using nanotechnological principles of directed management of Portland cement hydration processes due to adding of ultrafine mineral additives, and polycarboxylate type superplasticizer [2-4]. Ultrafine particles of supplementary cementitious materials which are characterized by high values of specific interfacial area and surface energy provide directed formation of the microstructure of the cement matrix due to its compaction...
and pozzolanic reactions in unclinker part [5-7]. Introduction of high effective polycarboxylate superplasticizers, ultrafine mineral additives allows obtain necessary workability, strength kinetic and monitor of formation of low defective structure on the micro- and nanostructural levels of concrete [8, 9].

Recently there has been a tendency to increase the strength, impact resistance and crack resistance of industrial floor structures for reliable operation during their life cycle. But brittleness increases with increasing compressive strength of building composites. At that case the danger and limitation of high-strength concrete use for constructive purposes is created. Cracks can occur because of overloading or structural inadequacy, and some restraint-induced cracks could have structural implications because of their position in relation to applied loads, in particular impact load. Thus, requires to the development of measures to improve crack resistance and impact strength of concrete is increased [10, 11]. Therefore, more applications are made on the basis of fiber reinforced concrete with improved performance characteristics compared with traditional concrete. The technology of their production is based on the introduction of different type fibers [12-15].

Impact resistance is the ability of a material to absorb mechanical energy in the process of deformation and fracture under the action of dynamic loading. The ability of concrete to withstand dynamic load is solved by the formation of a multilevel structure of concrete due to complex modification at the macro-, micro- and nanoscale levels with superplasticizers of the new generation, ultrafine mineral additives, as well as reinforcement by fibers [16, 17]. The main objective of this paper is to study the strength and impact resistance parameter of nanomodified fibre reinforced concrete for industrial floors.

2. Experimental programs

2.1. Materials and mix proportions

Ordinary Portland cement CEM I 42.5R produced by PJSC Ivano-Frankivsk Cement (Ukraine) was used in the investigations. The specifications of the cement: specific surface area 370 m²/kg, initial setting time 140 min, compressive strength 26.9 MPa (after 2 days) and 47.8 MPa (after 28 days) are meeting the requires EN 197-1. Natural sand of Zhovkva quarry (MF=2.1) and granite crushed stone of 5–20 mm fraction as a coarse aggregate were used for concrete production. The composition of concrete mixtures is given in table 1. Concrete modified with lignosulphonate plasticizer Centrament N3 (LS) was used as reference. As supplementary cementitious materials of microlevel was used methakaoline. Nanosilica (Aerosil-380) was used for modifying of concrete at nanolevel. Polycarboxylate superplasticizer GLENIUM ACE 430 (PCE), which has a powerful dispersing effect on the cement particles, was used as a water reducing admixture for nanomodified concrete. For reinforcement at the macro- and the mesoscale levels was used polypropylene fiber (12 mm in length, 18 μm in diameter) to increase an impact resistance of nanomodified concrete.

| Component      | Number of composition |
|----------------|-----------------------|
|                | 1          | 2          | 3          | 4          |
| Cement         | 350        | 430        | 430        | 430        |
| Metakaolin     | -          | -          | 21.5       | 21.5       |
| Aerosil        | -          | -          | 2.15       | 2.15       |
| Sand           | 700        | 670        | 650        | 650        |
| Aggregate 5/20 | 1200       | 1200       | 1200       | 1200       |
| Water/Cement   | 0.50       | 0.46       | 0.38       | 0.40       |
| Fiber          | -          | -          | -          | 4.3        |
| PCE            | -          | 6.45       | 6.45       | 6.45       |
| LS             | 1.75       | -          | -          | -          |

Table 1. Composition of concrete mixtures (kg/m³).
2.2. Specimen preparation and measurement

The coarse aggregate, sand, Portland cement and mineral additives were first mixed in the dry state for one minute before adding the mixing water with plasticizing admixtures. Then the polypropylene fibers were added for prepared fiber reinforced concrete. Mixing was continued for further five minutes to achieve uniform distribution of the fiber. Workability of fresh concrete was determined by the slump test according to EN 12350-2. The slump values of fresh concrete were 140-150 mm. Cubes (100 mm) were prepared from each batch for the compressive strength test and slabs (500x500x100 mm) – for impact test. The samples were cured in normal conditions for the hardening of concrete (90-100% RH at 20±2°C). The samples were testing for compressive strength after 1; 2; 7, 28 and 360 days and for impact resistance after 28 and 360 days. Open porosity of concrete was determined according to water absorption test after 28 days.

The impact test of concrete was performed in accordance with the impact testing procedure for concrete floor. The test was carried out by dropping a hammer of different weight from a height of 1000 mm repeatedly on a 30 mm diameter hardened steel ball. At each designated point in the zone one impact is applied (Figure 1). The test begins with a weight of 5N. The following points are hit with weights of successively greater weight: 10, 20, 30, 50, 70, 100, 150 and 200 N. The depth of the residual impressions formed during impact was measured with accuracy to 0.1 mm. The impact resistance of concrete coating is determined by maximum weight from which the residual impression depth on the surface does not exceed the permissible (2 mm).

![Figure 1](image-url)

Figure 1. Scheme of location of impact points (a) and prepared concrete slab (b).

3. Results and discussion

The compressive strength of plasticized concrete 2 and nanomodified concrete 3 after 1 day exceeds the strength of concrete 1 modified with the lignosulfonate admixture in 1.5 and 2.4 times respectively (Figure 2). The dispersed reinforcement with polypropylene fibres (concrete 4) causes insignificant increasing of strength in 3-5%. According to strength ratio \( f_{cm2}/f_{cm28} \) to indicate the strength development nanomodified concrete 3 and nanomodified fiber reinforced concretes 4 are classified as concrete with a rapid strength development \( f_{cm2}/f_{cm28} = 0.55 \). At the same time, strength ratio for concretes 1 and 2 is 0.45 and 0.48 respectively that indicate the medium strength development of these concretes according to EN 206-1. The values of strength after 28 days \( f_{cm28} = 101.5-104.9 \) MPa of concrete 3 and concrete 4 meet the requirements for high strength concrete (strength class C 80/95). Compressive strength of concrete 2 after 28 days decreases 29.2% compared to concrete 3.
Compressive strength class of concrete 1 and 2 is C30/37 and C55/67, respectively. The compressive strength values after 360 days of all investigated concretes increase 11-14%.

![Figure 2. Compressive strength of modified concrete.](image)

The improved mechanical properties of rapid hardening nanomodified concrete is provided by lowering of capillary porosity by addition of ultrafine mineral additives. The porosity of designed rapid hardening concrete decreases by 16-32% in comparison with concrete 2, which modified superplasiticing monoadmixture. Hydration products of cement matrix of rapid hardening concrete fill up the empty space inside, block the capillary porosity. As result open porosity of nanodified concrete 3 and 4 decreases up to 2.68-4.26% and density of cement matrix increases. At the same time open porosity of concrete 1 is 6.75%. Increasing homogeneity, reducing defects (pores) of the surface layer structure, which are the initiators of stress leads at load, cause increase of stiffness of matrix component of nanomodified concrete and its impact resistance.

The results of impact test of concretes after 28 and 360 days are shown in figure 3 and 4 respectively. The residual impression depth on the surface of nanomodified concrete after 28 days does not exceed 3 mm for weight 200 N. This parameter is less than 1 mm when polypropylene fibers are introduced and impact resistance is 200 N. The increase of impact resistance of fiber reinforced concrete is caused by possibility of distribution and absorption of impact load evenly by volume. Ordinary concrete shows low impact resistance. Thus, maximum value of residual impression depth of reference concrete 1 is 4.9 mm.

![Figure 3. The residual impression depth on the surface of concrete after 28 days.](image)
Figure 4. The residual impression depth on the surface of concrete after 360 days.

The residual impression depth of nanomodified and fiber reinforced concretes after 360 days is 0.8 mm at impact weight 200 N (Figure 4), which doesn’t exceed the permissible value according to procedure. Impact resistance of reference concrete 1 is 100 N (residual impression depth is 1.8 mm).

4. Conclusion

Microsized particles of mineral additive due to effect of the filler at the initial period and nanoparticles of complex nano-modifiers due to seeding effect accelerate the formation of a hydroxilicate gel with a more homogeneous distribution of hydrates in a limited intergranular space. As a result, nanomodified concretes are characterized by increased rate of early strength development (after 2 days of hardening strength ratio $f_{cm2}/f_{cm28}$ is 0.55), which meets the requirements for rapid hardening concrete. The strength after 28 days of nanomodified and nanomodified fiber reinforced concretes is 101.5 and 104.9 MPa. These concretes meet the requirements for high strength concrete (strength class С 80/95). The early pozzolanic reaction with the formation of fibrous C-S-H phases is provided optimization of nanomodified concrete structure. As result open porosity of nanomodified concretes decreases up to 2.68-4.26 % and density of cement matrix increases. The impact resistance of concrete modified with polycarboxylate superplasticizer after 28 and 360 days is 100 and 150 N respectively. The impact resistance of nanomodified fiber reinforced concrete is 200 N after 28 and 360 days, which displays effective use of such concrete for industrial floor application.

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