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Research of impact resistance of nanomodified fiberreinforced concrete

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Abstract. Effects of multilevel modification of concrete structure with complex nanomodifier at nano- and microlevel and polypropylene fiber at macro- and mesolevel on mechanical properties and impact resistance of concrete are presented. Nanomodification with complex nanomodifier, which consists of polycarboxylate ether superplasticizer, ultra- and nanofine mineral additives, provides early structure formation, higher strength at early and later ages. The increasing of the static hardness according to Brinell and Mayer of the nanomodified concrete was indicated the high energy of the bond between the structural elements in the surface layer of nanomodified concrete, as well as the ability of the structure to withstand elastic and plastic deformations under uneven compression load. Incorporating of polypropylene fibre to concrete was increased the impact resistance according to parameter of first crack strength and failure energy and changed the failure pattern from brittle to ductile mode.

1Introduction

Advanced construction technologies put forward a new level of requirements for technological and technical properties, as well as durability of concrete, which is associated with their use in structures of civil and military infrastructure, in structures of complex architectural forms, shells, reservoirs, roads, airfields, protective elements.Such structures work in extreme conditions, sothere is a growing trend to enhance their impact and crack resistancefor reliable exploitation throughout the life cycle.There are often high requirements set for the time allocated for construction and repair of building structures and need using of rapid-hardening concrete with necessary technical and technological properties. The disadvantage of high-strength concretes is low impact strength, increasing sensitivity to cracking and brittleness, which manifests itself by reducing plastic deformations under load.In addition, increasing of the loading velocity causes the transition of material to brittle state. Therefore, in the conditions of impact load concrete destructs at lower stresses compared with static loads, which can lead to previous destruction of structures [1].

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The ability of concrete to withstand dynamic load is largely solved by the formation of a multi-level structure of concrete due to complex modification at the nano-, micro- and macro-scale levels with superplasticizers of the new generation, nano- and ultrafine mineral additives, as well as reinforcement by fibres. Herewith structural conditions of braking of cracks, dissipation and absorption of external dynamic impact energy are created. The adding small amounts of different types of fibres into concrete can significantly reduce the damage due to impact load by arresting crack development and bridging of cracks [2, 3].

Changing of fibre reinforced concrete performance is based on the principles of composite development and associated with the joint work of materials with different physical and mechanical properties [4]. The presence of the boundary between the reinforcing elements and the matrix significantly enhances the cracking resistance of the material by increasing of area of load perception and distribution in all directions, which leads to increased ductile characteristics, deformation strengthening [5]. Such fibre reinforced concrete reveals the properties of ultraductile materials.

The improvement of deformation characteristics of cementing materials is associated with the elimination of initial defects at various scale levels, which are the initiators of stress at a load including an impact load. The formation of a low-defective structure on the micro- and nanostructural levels is monitored by the introduction of high effective polycarboxylatesuperplasticizers, energetically active ultra- and nanofine mineral additives [6, 7]. Conditions for the increasing of early strength of concrete due to provide an effect of the filler at the initial period, stimulation of nucleation processes in an intergranular space between cement grains and the early pozzolanic reaction with the formation of nanosized scale fibrous C-S-H phases are created in presence of nanoparticles [8, 9]. Fibrous hydration products provide additional micro- and nanoreinforcement of the cement matrix. The main objective of this paper is to study the impact resistance parameter of nanomodified fibre reinforced concrete.

2 Materials and methods

2.1 Materials

Ordinary Portland cement CEM I 42.5R PJSC Ivano-Frankivsk Cement (Ukraine) according to EN 197-1 standard was used in the investigations. Natural sand of Zhovkva quarry (MF=1.9) and granite crushed stone of 5–20 mm fraction as a coarse aggregate were used for concrete production. The mix proportion was 1:1.35:2.71 with the content of CEM I 42.5R 430 kg per 1 m^3 of concrete. Concrete modified with lignosulfonate plasticizer was used as reference (RC). Methakaoline was used as ultrafine supplementary cementitious materials and nanosilica (Aerosil-380) was used as nanofine admixture for nanomodified concrete (NC). A superplasticizer based on polycarboxylateeter polymer GLENIUM ACE 430 (PCE), which has a powerful dispersing effect on the cement particles, was used as a water reducing admixture for nanomodified concrete. The dosage of polycarboxylate ether superplasticizer which incorporated into nanomodified mixes was 1.0% by weight of cement. 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. The dosage of fiber in nanomodifiedfiber reinforced concrete (NFRC) was 1.0 wt.%.

2.2 Preparation of the specimens and testing

The coarse aggregate, sand and cement were first mixed in the dry state for one minute before adding the mixing water and 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 180-210 mm. Cubes (100 mm) were prepared from each batch for the compressive strength and hardness test and cubes (70.7 mm) – for impact test. The samples were cured in normal conditions for the hardening of concrete (90-100% RH at 20±2^{o}C). After 1; 2; 7 and 28 days the samples were testing for compressive strength and impact resistance.

The impact test was performed in accordance with the impact testing procedures recommended by ACI Committee 544. The test was carried out by dropping a hammer weighing 20 N from a height of 1000 mm repeatedly on a 30 mm diameter hardened steel ball, which is placed on the top of the centre of a cubical specimen. From this test, impact resistance was estimated as specific energy absorption capacity for initial visible crackand final crack (impact failure energy) of each specimen.

Static indentation tests of concretes at the age of 28 days were carried out by a Brinell testing device with ball diameter of 10 mm. Testing loads of 1000 kg were applied for 10-15 s on the concrete surfaces. Diameters of the residual impressions were measured by a hand microscope of 8× magnification.

3 Result and discussion

The compressive strength of nanomodified concrete NC after 2 and 28 days exceeds the strength of concrete modified with the lignosulfonate admixture - RC 1.8 and 1.4 times respectively (Fig. 1). The adding of fibres causes some decreasing of workability of concrete mixtures, which causes 7.9% increasing of water consumption compared with nanomodified concrete to achieve the required workability and 5-7% decreasing of strength. According to the specific strength parameter f_{cm2}/f_{cm28} = 0.52-0.57, nanomodified concrete and nanomodifiedfiber reinforced concretes are classified as concrete with a rapid strength development. The value of strength after 28 days (f_{cm28} = 98.7-104.5 MPa) of NC and NFRC concretes meet the requirements of high strength concrete (strength class C 80/95).

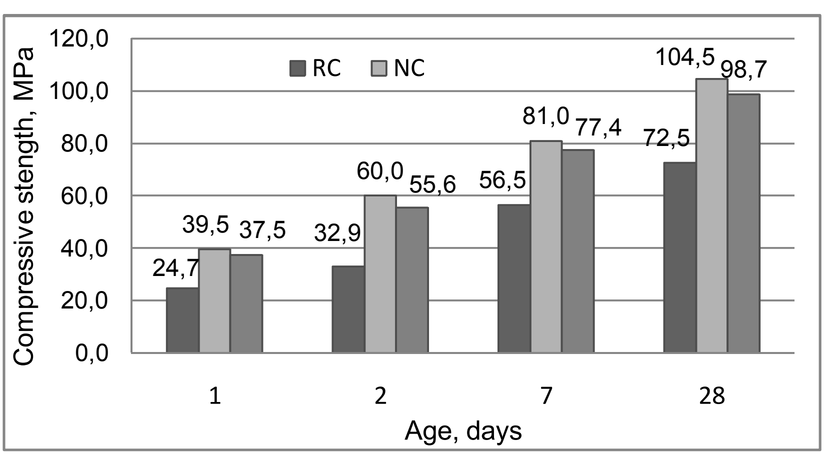

Fig. 1. The compressive strength of concretes.

Impact resistance of concrete is associated with the behaviour of its surface layer under mechanical action on the material, and is characterized by hardness.Brinell(HB) and Mayer (HM) hardness results plotted in Fig. 2 are shown that the use of complex nanomodifierprovides possibility to regulate the structural and energy state of the surface of concrete. The values of the static hardness according to Brinelland Mayerof the nanomodified concrete after 28 days are 812 and 851 N/mm^2 respectively, which is in 1.7-2.2 times exceeds the value of the hardness of reference concrete (390 and 493 N/mm^2). That indicates the high energy of the bond between the structural elements in the surface layer of nanomodified concrete, as well as the ability of the structure to withstand elastic and plastic deformations under uneven compression conditions.The hardness value for nanomodifiedfiberreinforced concrete is lower by 10.3% compared to nanomodified concrete, that indicate the relationship between compressive strength and hardness of concrete and the increasing of plastic deformations when polypropylene fibers are added.

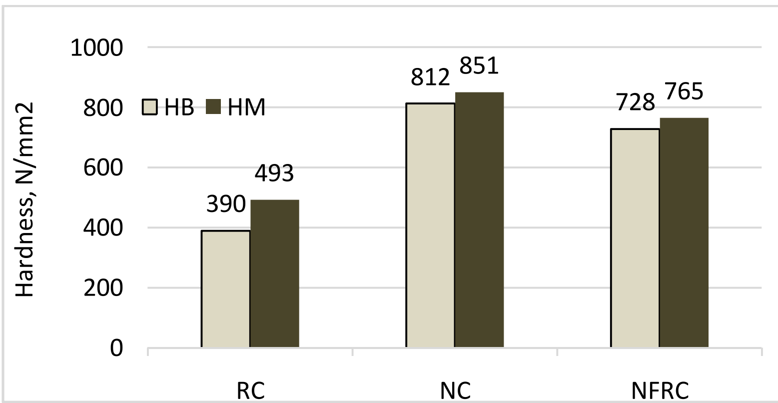

Fig. 2. The Meyer and Brinell hardness of concretes.

The formation of a dense structure of nanomodified concrete NC allowsto increase the impact resistance (specific impact energy to the appearance of the first visible cracks and final crack – impact failure energy) in 2.0-2.6 times compared with reference concrete RC at the early and the later age (Fig. 3).Significant increasing of impact strength occurs when structure of concrete is reinforced with polypropylene fibers. So, after 2 days of hardening, the specific energy of the impact for the first visible crack increases to 2.5 J/cm^3, and the impact failure energy is 3.89 J/cm^3, which exceeds the corresponding indices of nanomodified concrete in 5.0 and 6.7 times respectively.

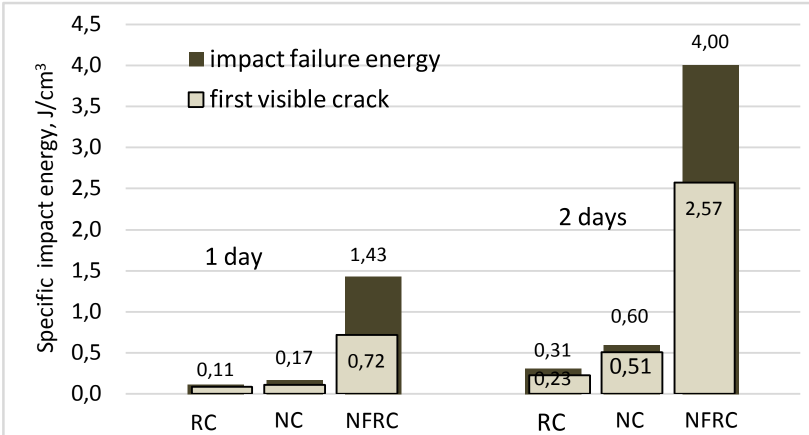

Fig. 3. Impact strength of concrete at early age.

The energy input necessary to cause the visibility of first crack of nanomodified fiber reinforced concrete after 28 days of hardening increases in 10.5 times compared to non-reinforced nanomodifiedconcrete(Fig. 4).The difference between impact energy for final crack and initial crack increased significantlywith adding polypropylene fiber. The energy necessary to cause failure of concrete specimen was increased by 11.8 time over the nanomodified concrete specimen (NC). This proves that the fibers act as an effective crack arrestor in case of NFRC, when an impact load is encountered. Thus the reference concrete exhibits an early brittle failure when compared to fiber reinforced which shows better ductile properties.

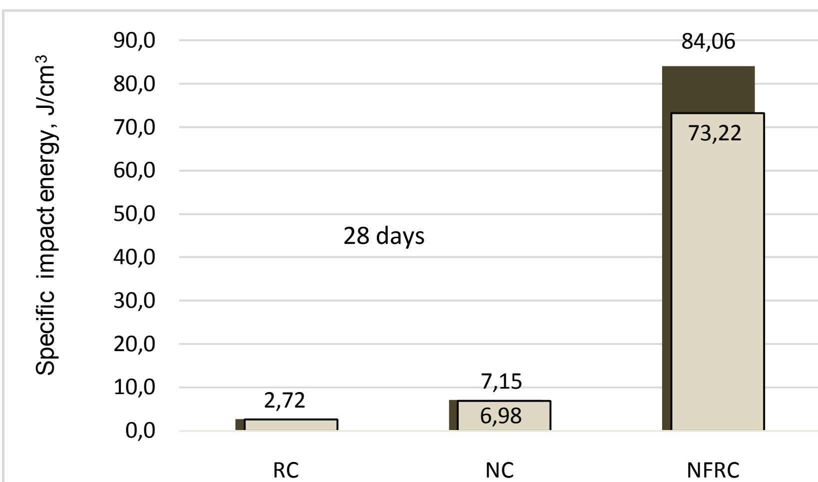

Fig. 4. Impact strength of concrete after 28 days.

The mode of failure of concrete depends upon the matrix strength, aggregate strength and bond strength of fiber with aggregate matrix. Brittle behavior was observed in RC and NFRC concrete specimens with formatiom trunk crackand it was broken into two pieces (Fig. 5, a, b).

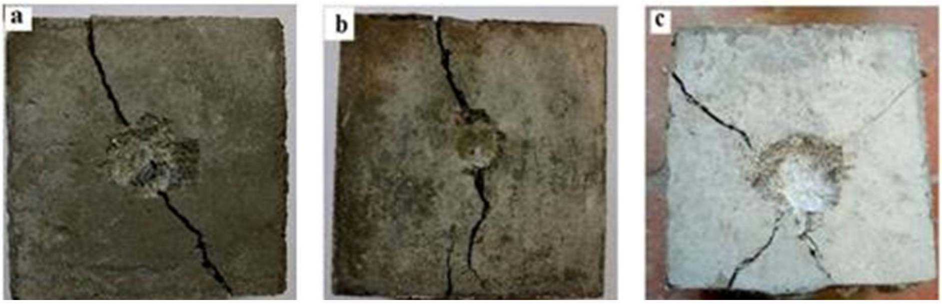

Fig. 5. Failure pattern of specimens after impact test: RC (a), NC (b), NFRC (c).

The NFRC specimens displayed different mode of failure (Fig. 5, c). The mode of failure was changed from brittle to ductile behavior. By incorporating fiber to concrete the cracking pattern was changed from single crack to large number of multiple cracks.When reaching the strength extremum such concrete does not lose integrity and is not accompanied by fragmentation of the material due to the set of reinforcing elements.Further deformation causes expansion of existing microcracks, which involves additional energy.

4 Conclusions

The nanomodification of concrete with organo-mineral additives based on metakaolin, nano-silica and polycarboxylate superplasticizer ensures obtaining nanomodified fiber-reinforced concrete relates to rapid-hardening high strength concretes with spesific strength parameterf_{cm2}/f_{cm28}=0.5-0.52 and strength after 28 days f_{cm28}=98.7 MPa.Reducing the structure defect, forming an increased number of hydrated products in the cement matrix when introducing elements of various scale levels, multilevel reinforcement provides a significant three-dimensional strengthening of nanomodified fibre reinforced concrete, which increases the energy intensity of the destruction process and impact resistance of the composite.By adding polypropylenefiber the energy required to cause the visibility of first crack and failure after 28 days was increased by 26.9 and 30.9 time, respectively over reference concrete, which displays effectiveuse of nanomodified fibre reinforced concretein structural engineering applications.

References

1. S. Fic, *Concrete under the influence of impact loads* (Politechnika Lubelska, Lublin, 2017)
2. A. Badr, A. F. Ashour, A. K. Platten, Int. J. Impact Eng., **32**, 1907 (2006)
3. U. Marushchak, M. Sanytsky, S. Korolko, Yu. Shabatura, N. Sydor. Eastern Eur. J. Enterprise Technologies, **6 (92)**, 34 (2018)
4. L. Dvorkin, O. Dvorkin, V. Zhitkovsky, Y. Ribakov, Mater. Des., **32 (6)**, 3254 (2011)
5. A. Plugin, T. Kostiuk, O. Plugin, D. Bondarenko, Y. Sukhanova, N. Partala, Int. J. Eng. Res. Afr., **31**, 59 (2017)
6. K. Pushkarova, K. Kaverin, D. Kalantaevskiy, Eastern Eur. J. Enterprise Technologies, **5 (5)**, 42 (2015)
7. U. Marushchak, M. Sanytsky, Yu. Olevych, MATEC Web Conf.,**116**, 01008 (2017)

8. O. Borziak, S. Vandolovskyi, V. Chajka, V. Perestiuk, O. Romanenko,MATEC Web Conf.,**116**, 01001 (2017)
9. U. Marushchak, M. Sanytsky, T. Mazurak, Yu. Olevych, Eastern Eur. J. Enterprise Technologies, **6 (84)**, 50 (2016)
10. E. Horszczaruk, E. Mijowska, K. Cendrowski,K. Mijowska, P. Sikora, Cem. Wapno Beton, **1**, 24 (2013)