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Effect of modification of cement mortar with selected nanoparticles on abrasion and subsurface tensile strength

Wpływ modyfikacji zaprawy cementowej wybranymi nanocząstkami na ścieralność i przypowierzchniową wytrzymałość na rozciąganie

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Abstract. The article presents an analysis of the impact of selected nanoparticles on selected mortar overlay parameters in concrete floors. The tests were carried out for 13 series of mortars differing in the type of additive and its amount. It was shown that the addition of each of the tested nanoparticles had a positive effect on the overlay properties, such as abrasion and subsurface tensile strength, and the optimal amount of the additive for each type of nanoparticles was indicated.

Keywords: overlays; nanoparticles; concrete floors; abrasion resistance; subsurface tensile strength.

Streszczenie. W artykule przedstawiono analizę wpływu wybranych nanocząstek na określone parametry zaprawy warstwy wierzchniej podłogi betonowej. Badania zostały przeprowadzone na 13 seriach zapraw różniących się rodzajem dodatku oraz jego ilością. Wykazano, że dodatek każdej z badanych nanocząstek wpływa korzystnie na takie właściwości warstwy wierzchniej, jak ścieralność i przypowierzchniowa wytrzymałość na rozciąganie oraz określono optymalną ilość dodatku w przypadku każdego rodzaju nanocząstek.

Słowa kluczowe: warstwy wierzchnie; nanocząstki; podłogi betonowe; ścieralność; przypowierzchniowa wytrzymałość na rozciąganie.

Concrete floors are commonly used in residential, public and industrial construction. Floors are most often layered systems, which means that they are made of at least two layers, i.e. an overlay and a substrate. A cross-section showing a typical set of layers in a concrete floor is shown in Figure 1.

Layered systems can be newly built, existing or created as a result of repair work. Overlays can be made of many materials and can be divided into: cement, magnesia, anhydrite, asphalt and synthetic resins. The optimal selection of the material used depends on the conditions in which the overlay will be used and on financial conditions. However, the most common are cement overlays or those made as a cement composite consisting of a cement matrix, sand and additives. Due to the durability and requirements for the overlay, it is assumed already at the design stage that this layer will have a number of properties at the appropriate level [1, 2]. These properties can be divided into the properties of the fresh mortar (such as consistency, bulk density, setting time) and the properties of the hardened mortar, including, among others: compressive strength, tensile strength, pull-off adhesion, abrasion and subsurface tensile strength [3]. Various methods are used to improve these properties. In order to improve pull-off adhesion between overlay and the substrate, the following methods are possible: mechanical processing of the substrate before applying the overlay [4], using bonding agents between the overlay and the substrate [5], removing cement laitance from the substrate surface, surface exposure of aggregate of the substrate [6], the use of additives in the mortar of the overlay [7]. In order to improve the mechanical parameters of the hardened mortar of the overlay, possible methods include: strengthening the mortar of the overlay with dispersed reinforcement (fibres), surface hardening of the overlay (e.g. with using mineral or metallic hardeners), surface impregnation of the overlay and modifying the structure of the overlay by using additives [8]. Over time, additives with progressively smaller fractions have been used in cement composites, starting from micro-additives (various types of powders, fly ash, or fine-grained mineral additives) to nano-additives [9, 10]. The literature indicates that one of the additives that can be particularly used for overlays in floors is nanoparticles. However, the knowledge in this area is incomplete and mainly concerns the strength properties of

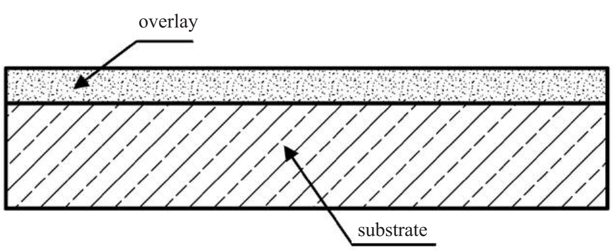

Fig. 1. Cross-section of typical concrete floor
Rys. 1. Przekrój przez typową podłogę betonową

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overlays [11, 12]. Bearing this in mind, the article presents an analysis of the modification of the cement mortar of the surface layer using the addition of four types of nanoparticles in order to improve their selected properties (abrasiveness and subsurface tensile strength of the overlay).

Sample preparation

In order to carry out the research, compositions of 13 mortars were designed: one without the addition of nanoparticles as a reference mortar and three series of mortars with the addition of SiO_2, Al_2O_3, TiO_2, SnF_2 nanoparticles in the amount of 0.5%, 1% and 1.5% of the cement mass. The detailed specification of the nanoparticles used was presented in articles [13, 14, 15]. The substrate was designed with C30/37 class concrete and 12.5 cm thick. To make the substrate, a concrete mixture was used consisting of 352.0 kg/m^3 of Portland cement CEM II A-LL 42.5R, 40 kg/m^3 of fly ash, 724.4 kg/m^3 of fossil quartz sand with a grain size of up to 2 mm and a density volume 2.62 g/cm^3, 1086.6 kg/m^3 of natural quartz pebble aggregate with a grain size of up to 8 mm and a bulk density of 2.60 g/cm^3. Moreover, in order to obtain the appropriate consistency of the concrete mix, 2.0 l of a superplasticizer based on polycarboxylates with a density of 1.07 g/cm^3 was used. The composition for the concrete mixture of the overlays was presented in [15, 16]. The cement mortar of the overlay was designed as a mortar of C60 compressive strength and F10 bending strength class. CEM-I 42.5R cement, dried quartz sand (maximum grain diameter up to 2 mm) and Y superplasticizer based on polycarboxylates in the amount of 0.5% of the cement mass were used to make the mortars. The composition of the mortars is presented in Table 1.

Composition of cement mortars modified with nanoparticles
Skład zapraw cementowych modyfikowanych nanocząstkami

Nanoparticles addition [%]	Sand	Cement	Water	Superplasticizer	Nanoparticle type			
	[g]				SiO_2	Al_2O_3	TiO_2	SnF_2
0	4000	2932	880	14,8	0	0	0	0
0,5	4000	2932	880	14,8	14,8	0	0	0
1	4000	2932	880	14,8	29,2	0	0	0
1,5	4000	2932	880	14,8	44	0	0	0
0,5	4000	2932	880	14,8	0	14,8	0	0
1	4000	2932	880	14,8	0	29,2	0	0
1,5	4000	2932	880	14,8	0	44	0	0
0,5	4000	2932	880	14,8	0	0	14,8	0
1	4000	2932	880	14,8	0	0	29,2	0
1,5	4000	2932	880	14,8	0	0	44	0
0,5	4000	2932	880	14,8	0	0	0	14,8
1	4000	2932	880	14,8	0	0	0	29,2
1,5	4000	2932	880	14,8	0	0	0	44

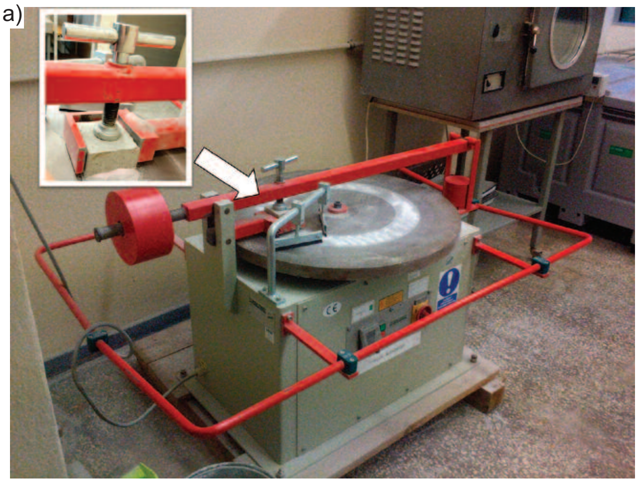
The procedure for preparing fresh cement mortar consisted of adding and mixing nanoparticles with mixing water and a superplasticizer. Then cement was added and the mixture was mixed for 45 seconds with an automatic mixer at a speed of 140 rpm. Then sand was added and the mixture was mixed for another 45 s at a speed of 140 rpm. Then the whole mixture was stirred for 18 s at a speed of 285 rpm. The concrete of the substrate and the cement mortar of the overlay cured naturally, at an air temperature of +20°C (±3°C) and a relative air humidity of 60% (±5%). After 28 days, abrasion tests were carried out on the Boehme abrasion wheel in accordance with [17].

For each series of mortar, three samples with dimensions of 71 x 71 x 71 mm were made to determine the abrasion on the Boehme disc in accordance with the PN-EN 13892 standard [17]. Before starting the study, the samples were dried and placed in desiccators. Before each abrasion cycle on the Boehme disc, the disc was cleaned and 22 g of abrasive material (corundum) was evenly spread on the abrasive path. Then the sample was mounted in a holder and loaded with a force of 294±3 N and subjected to 16 abrasion cycles. Each abrasion cycle consisted of 22 revolutions of the disc, and after each 4 cycles the sample was weighed and rotated 90° in relation to its previous position in the holder. Abrasion was determined as the loss of mass and volume of the sample after 16 abrasion cycles. A view of the test stand during the abrasion test is shown in Photo a.

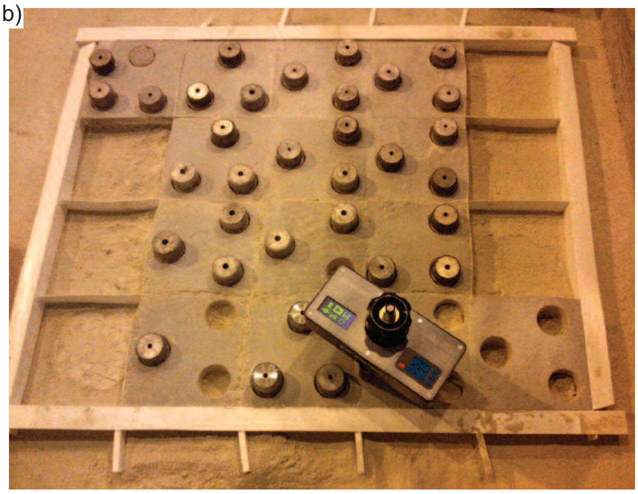
After 28 days from the placement of the cement overlay on the concrete substrate, the subsurface tensile strength test of the cement mortar overlay was conducted in accordance with PN-EN 1542 [18]. To conduct the tests, a model element representing the floor was designed and constructed. The element consisted of a 12.5 cm thick concrete substrate and overlays with dimensions of 20 cm x 20 cm (for each series of mortar). Next, the subsurface tensile strength test of the overlay was carried out using the pull-off method at least three times for each series of mortar. For this purpose, holes with a diameter of 50 mm and a depth of about 5 mm were drilled in the overlay using a core drill. Steel discs with a diameter of 50 mm were glued in these drilled holes. After the adhesive cured, the discs were pulled off using a Proceq DY 216 automatic pull-off tester with a constant stress increase rate of 0.05 MPa/s, and the tensile strength values were calculated. A view of the test stand during the subsurface tensile strength test of the overlay mortar is shown in Photo b.

Research results and their analysis

Figure 2 presents the relationship between the abrasion of mortars with the addition of selected nanoparticles and the percentage content of the nanoparticles (relative to the mass of cement). As shown in Figure 2, the addition of each type of nanoparticle tested reduces the abrasion of the overlay mortar compared to the reference mortar. The most beneficial decrease in abrasion was observed with the addition of 0.5% SiO_2 nanoparticles. In this case, the abrasion decreased by approximately 39.2%. The improvement in abrasion resistance with the addition of SiO_2 nanoparticles (with fractions of 12, a)



b)



View of the test stand during the tests: a) abrasion; b) subsurface tensile strength

Widok stanowiska badawczego w trakcie badania: a) ścieralności; b) przypowierzchniowej wytrzymałości na rozciąganie zaprawy warstwy wierzchniej

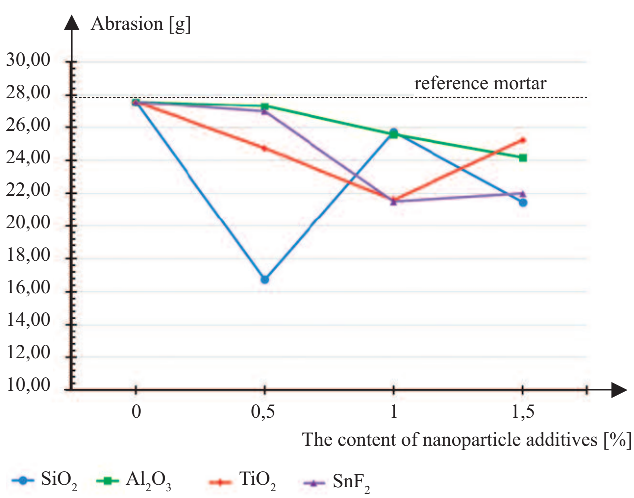


Fig. 2. Function of abrasiveness of mortars with the nanoparticles on the percentage of its content in relation to the mass of cement

[Fig. based on 13 ÷ 15; 19]

Rys. 2. Zależność ścieralności zapraw z nanocząstkami od ich procentowej zawartości w stosunku do masy cementu

[Rys. opracowanie własne na podstawie 13 ÷ 15; 19]

20, 40, and 100 nm) to the cement mortar of the overlay is also described in the literature [20]. For Al_2O_3 nanoparticles, the optimal addition is 1.5%, which reduces abrasion by approximately 12.2%. In the case of TiO_2 nanoparticles, the optimal amount is 1%, where a decrease in abrasion of approximately 21.5% and 22% was observed, respectively.

Figure 3 shows the relationship between the subsurface tensile strength of the overlay mortar with the addition of nanoparticles and the percentage content of nanoparticles relative to the mass of cement.

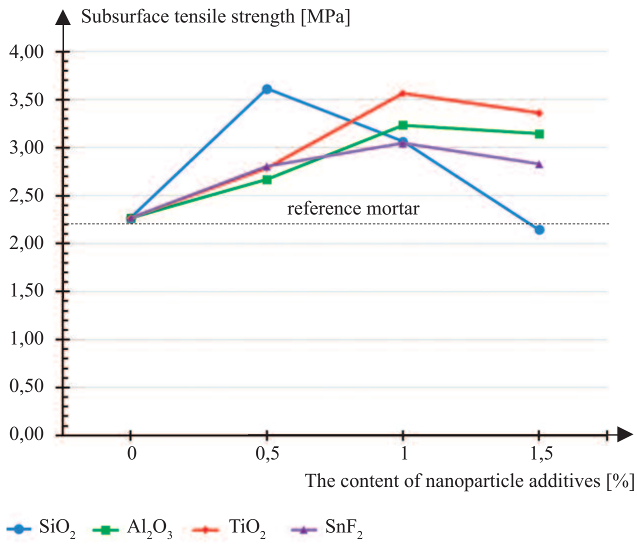


Fig. 3. Function of subsurface tensile strength of the mortar overlay with the nanoparticles on the percentage of nanoparticles in relation to the mass of cement *[Fig. based on 13 ÷ 15; 19]*

Rys. 3. Zależność przypowierzchniowej wytrzymałości na rozciąganie zaprawy warstwy wierzchniej z nanocząstkami od ich procentowej zawartości w stosunku do masy cementu

[Rys. opracowanie własne na podstawie 13 ÷ 15; 19]

Figure 3 shows that each type of nanoparticle used in the studies positively affects the subsurface tensile strength of the overlay (except for the addition of 1.5% SiO_2 nanoparticles, where a slight decrease in this strength is observed). The most significant increase in subsurface tensile strength was observed with the addition of 0.5% SiO_2 nanoparticles and 1% TiO_2 nanoparticles. For SiO_2, the strength increase is about 59.4%, and for TiO_2, it is about 57.4%. In the case of Al_2O_3 nanoparticles, the optimal addition is 1%, with a strength increase of 42.6%. For SnF_2 nanoparticles, the optimal addition is 1%, with a strength increase of 34.6%.

The mechanisms of action of nanoparticles used as additives in cement mortars and concrete are still the subject of intensive research. The literature indicates that nanoparticles can play a significant role in the hydration process and can function as a filler in the mortar structure [21, 22]. Additionally, they can be added to mortars and concrete to achieve special properties such as resistance to aging at high temperatures, self-cleaning, air purification, resistance to de-icing salt, and frost resistance [23, 24, 25, 26, 27]. Nanoparticles are used to improve the properties of mortars and concrete, as well as to achieve special characteristics. Due to their very small size (below 100 nm) and large specific surface area, they exhibit much higher reactivity compared to larger particle size additives such as silica fume or fly ash [28]. Considering both the high reactivity that positively affects the hydration process (leading to the reinforcement of the mortar structure) and the very small particle size (acting as a structural filler), nanoparticles significantly reduce the porosity of mortars [29, 30, 31].

Summary

The aim of this article was to present the impact of modifying the cement mortar overlay in floors with the addition of SiO_2, Al_2O_3, TiO_2 and SnF_2 nanoparticles on its selected properties such as abrasion and subsurface tensile strength. A total of 13 series of mortars were tested, differing in the percentage content of nanoparticles in the overlay mortar (0%, 0.5%, 1%, 1.5%) relative to the mass of cement. It was shown that, generally, the addition of each type of nanoparticle improves the abrasion resistance and subsurface tensile strength of the overlay.

In particular, for abrasion resistance, the most beneficial is the use of 0.5% SiO_2 nanoparticles, which reduces abrasion by approximately 39.2%. The optimal addition amount for Al_2O_3 nanoparticles is 1.5%, and for TiO_2 and SnF_2, it is 1%.

For subsurface tensile strength, the most advantageous is the use of 0.5% SiO_2 nanoparticles, which increases the subsurface tensile strength by approximately 59.4%, and 1% TiO_2, which increases it by about 57.4%. For Al_2O_3 and SnF_2 nanoparticles, the optimal addition amount is 1%.

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