

INFLUENCE OF METAKAOLIN ON PROPERTIES OF CONCRETE MODIFIED WITH POLYCARBOXYLATE ADMIXTURE FOR RIGID PAVEMENT REPAIR¹**Kryzhanovskiy V.O.**, Engineer,

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Abstract. The effect of partial cement replacement with high-activity metakaolin on the strength, frost resistance, shrinkage and abrasion resistance of concrete modified with polycarboxylate admixture MasterGlenium SKY 608. Portland cement CEM II/A-S 42.5 (III II/A-III-500) with partial metakaolin replacement 15 kg (3.75 %) and 30 kg (7.5 %) was used for concrete preparation. The amount of superplasticizer in all studied compositions was 1.2% of cement weight. Slump of concrete mixtures was 6...7 cm.

It was found that with increasing amount of metakaolin W/C ratio of mixtures increased slightly. The early compressive and flexural strength (at the age of 2 days) of the composition without metakaolin was higher than similar indicators with partial cement replacement with the active mineral admixture. It is worth noting the positive effect of increasing the metakaolin amount on early strength, because the composition with 30 kg metakaolin had strengths higher at 2 days of in difference to the composition with 15 kg metakaolin.

It is necessary to note high frost resistance of all obtained concretes. Its grade of frost resistance reached F200 (evaluated according to the method for road concrete), which is equivalent to the grade F600 for structural concrete. Abrasion resistance was in the low range (0.30-0.31 g/cm²), total shrinkage does not exceed 0.28 mm/m, which in combination with high frost resistance has a positive effect on the durability of concrete mixtures for rigid pavements repair.

Keywords: rigid pavement, repair, early strength, shrinkage, frost resistance, abrasion resistance, metakaolin, superplasticizer.

Introduction. Concrete technology is constantly evolving. Today classic three-component concretes are practically not used. Concrete mixtures modification takes place using superplasticizers and active mineral admixtures, one of which is metakaolin [1-7]. Environmental pollution is acute issue in cement production [8]. It led to the use of pozzolanic products, including metakaolin, as a partial replacement for clinker.

Metakaolin is a heating product of purified kaolinite clay at a temperature of 600-900°C. When Al₂O₃·2SiO₂·H₂O (kaolin) is heating the crystal structure is deformed due to the evaporation of bound water. The result is a non-hydrated reactive form consisting of an amorphous aluminosilicate – metakaolin.

The investigation introduces results of a complex concrete mixture modification with the polycarboxylate admixture BASF MasterGlenium SKY 608 and high-activity metakaolin.

Analysis of recent researches and problem statement. The characteristics of concrete are determined by its strength and properties that determine its durability under typical operating conditions. With the advent of various types superplasticizers and a more complete exposure of the high-activity metakaolin reactivity, it became feasible to obtain high performance concretes [3, 9, 10], with high early strength (minimum 30 MPa on the 2nd day) and grade strength (minimum 60 MPa). High frost resistance (minimum F200 for pavement concretes and F600 for structural concretes) and low abrasive resistance (no more 0.4 g/cm²) ensure high durability of the material. The lifetime of

structures made of such concrete reaches 200 years. This allows them to be used as a repair material for rigid pavements repair.

Ukraine occupies one of the leading places in the world of industrial kaolin reserves, their volume exceeds 300 million tons [11]. Metakaolin was first used as a pozzolanic admixture for concrete mixtures in Brazil (1962) for the dams' construction [12]. In addition, the metakaolin manufacture, in comparison with Portland cement, requires a much lower calcination temperature, as a result, less CO₂ emissions. According to [3, 6] for each ton of cement produced, 0.82-1 ton of CO₂ is emitted.

Depending on the type and cement dosage used in the concrete, the optimal amount of its replacement with metakaolin is up to 20% [2-7, 11-14]. The pozzolanic properties of metakaolin improve the physical and mechanical properties of concrete due to the formation of additional calcium hydrosilicate (C-H-S) as a result of the interaction of cement hydration products (Ca(OH)₂) with a mineral filler, which has a smaller specific surface area in contrast to cement. It should be noted that the W/C of concrete mixtures with metakaolin increases with raise in its amount. It is necessary to use water-reducing admixtures-superplasticizers to restore the mixture workability at a lower W/C.

Research objective is to study the effect of cement replacing with high-activity metakaolin on early and grade strength, frost resistance, wear resistance and shrinkage of concrete modified with BASF additive MasterGlenium SKY 608.

Materials and research methods. The following source materials were used in research. Portland cement III/II-A-III-500 (CEM II/A-S 42.5), manufactured by PJSC "Dyckerhoff Cement Ukraine". Metakaolin obtained by heat treatment of enriched natural kaolin from the Dermankovskoye field of the Rivne region, manufactured by Ltd "Western Kaolin Company". Granite crushed stone of the Gorikhovsky quarry with nominal maximum size 20 mm and quartz sand of the Nikitovsky quarry (Voznesensky district) were used as aggregates. Sieve analysis of aggregates is presented in Fig. 1. Modifying admixture MasterGlenium SKY 608 based on polycarboxylate ether was used in an amount of 1.2% by weight of cement. This dosage has been selected based on past research [15]. The cement replacement with metakaolin was 15 and 30 kg/m³ (3.75% and 7.5% of the cement mass). The concrete mix preparation process and sample testing were carried out in accordance with current requirements.

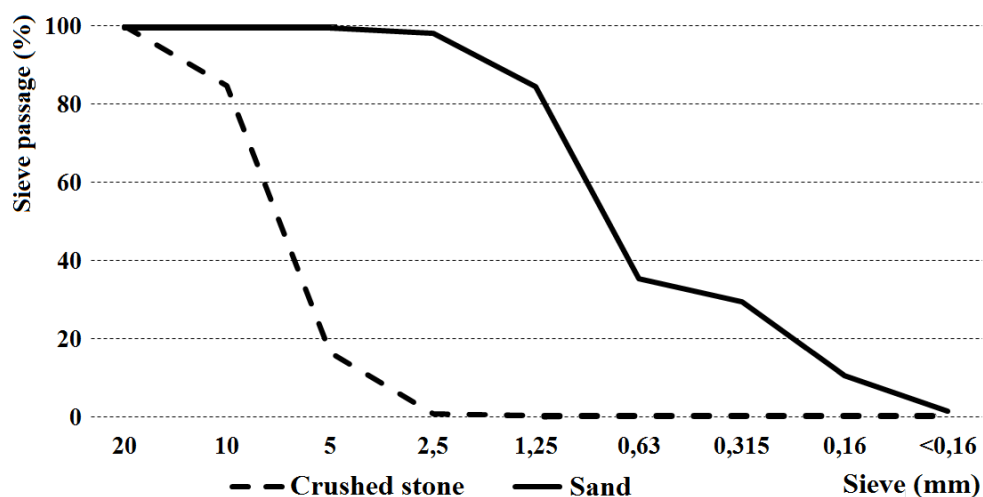


Fig. 1. Coarse and fine aggregates gradation

Research results. 3 batches of concrete samples were fabricated (in each batch 18 cubes 10×10×10 cm and 8 beams 40×10×10 cm). The compositions of the investigated concretes and W/C are shown in Table 1. Slump of concrete mixtures was (6...7 cm), which meets the workability requirements for rigid pavement repair concrete mixtures.

Table 1 – Concrete mixtures and W/C

No	Cement, kg/m ³	Crushed stone, kg/m ³	Sand, kg/m ³	Metakaolin, kg/m ³	Admixture MasterGlenium SKY 608, %	Water, l/m ³	W/C
1	400	1195	830	0	1.2	115	0.288
2	385		825	15		124	0.322
3	370		820	30		126	0.341

The average density of the investigated concretes ranged from 2480 to 2580 kg/m³. Compression and flexural strength tests were carried out for each batch at the age 2 and 28 days. The obtained data are shown in Fig. 2, 3.

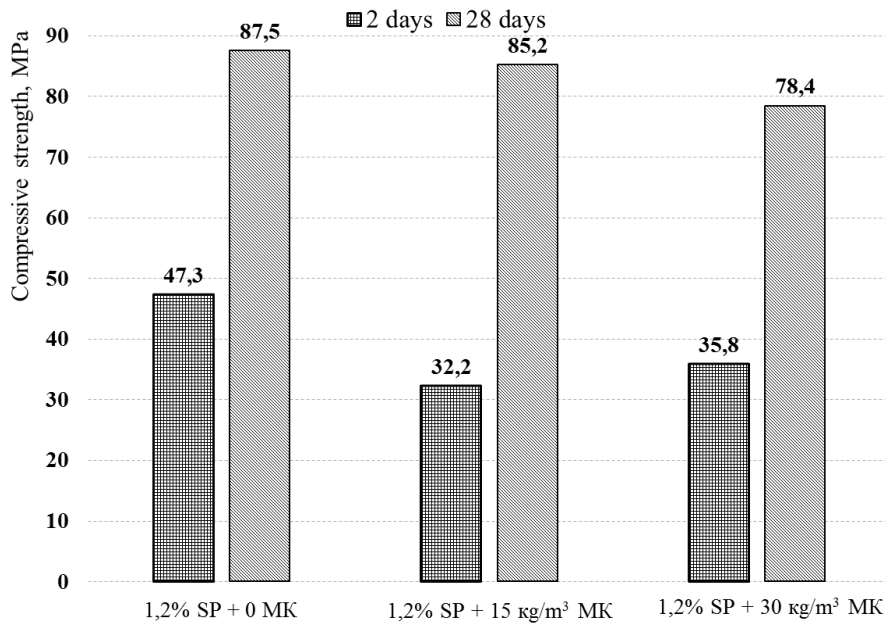


Fig. 2. Compressive strength of the investigated concretes at the age of 2, 28 days

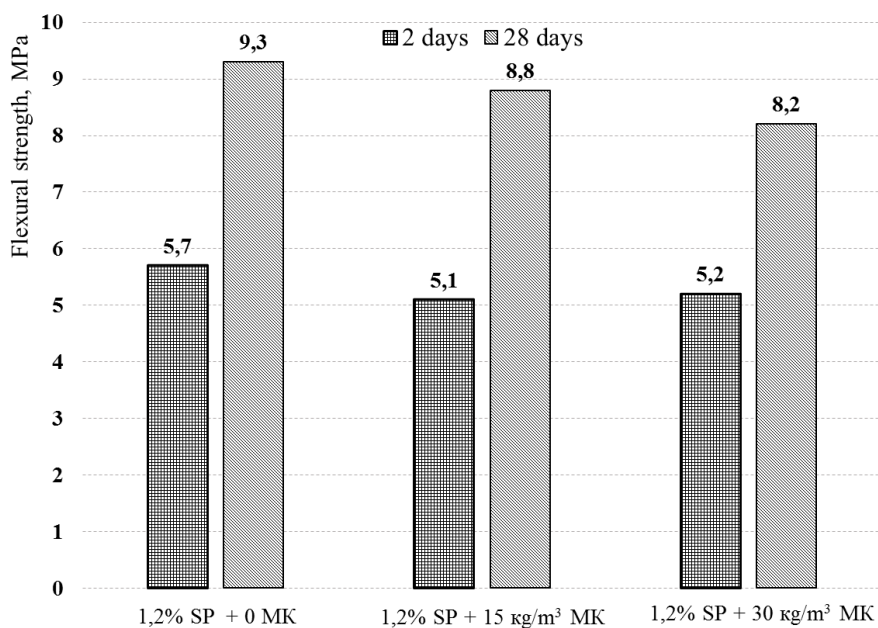


Fig. 3. Flexural strength of the investigated concretes at the age of 2, 28 days

Data analysis in Fig. 2, 3 show that the early and grade compressive and flexural strength of modified concrete without metakaolin addition ($f_{ck, cube, 2} = 47.3$ MPa, $f_{ck, cube, 28} = 87.5$ MPa, $f_{c, tf, 2} = 5.7$ MPa, $f_{c, tf, 28} = 9.3$ MPa) is slightly higher than similar strength indicators of concrete with partial cement replacement with metakaolin. This is caused by the water demand increase of concrete mixtures due to the greater dispersion of metakaolin relative to cement. It should be noted that the compressive and flexural of composition № 3 at 2nd day age (30 kg metakaolin) with a higher W/C was 5.9% higher than the strength of composition № 2 (15 kg metakaolin). This is due to increase in the amount of (C-H-S) in the early ages [11] with an increase of the metakaolin content. Probably, this trend can persist with a further increase of the metakaolin content. In this case, the increase of the mixture W/C must be compensated by adjusting of the superplasticizer amount.

On the basis of Portland cement III/II/A-III-500 (CEM II/A-S 42.5) with an amount of BASF MasterGlenium SKY 608 additive 1.2% of its mass, high-performance concrete with compressive strength 87.5 MPa was obtained, which approximately corresponds to the grade C50/60. 15 kg replacement of cement with metakaolin made it possible to obtain concrete of the same grade C50/60 with strength 85.2 MPa, and after 30 kg cement replacement, concrete grade C45/55 with strength 78.4 MPa was obtained.

Early strength is an important parameter of the concrete quality for the rigid pavement repair. Compressive strength of the investigated modified concretes at 2nd day age was 54%, 38% and 46% of the grade for compositions 1, 2 and 3, respectively. Flexural strength at 2nd day age for these compositions was 61%, 58% and 63% of the strength at 28th day. Strength features of the obtained concretes allow them to be used as a repair material since main indicator of the mechanical properties for pavements is the early flexural strength, which was more than 5 MPa on the 2nd day of hardening for all researched compositions.

Frost resistance of the concretes was determined according to the Ukrainian building state code DSTU B V.2.7-49-96, 3rd accelerated method. The obtained values for all compositions corresponded to the frost resistance of the F200 grade for road concretes, which is equivalent to the F600 grade for structural concretes. High frost resistance of the compositions with metakaolin is explained by the fact that with an increase in its amount, a greater number of new formations (C-H-S) are formed [4, 14, 16-20] that reduce the average pore size.

Abrasion resistance for road concrete is an important and integral characteristic of its durability. The most important factors affecting on the wear resistance of concrete are its strength, the nature and amount of aggregate, defined as the cement/aggregate ratio, and its maximum size [21-23]. Tests were carried out according to DSTU B V.2.7-212:2009. The results showed high abrasion resistance of all investigated concretes – 0.30...0.31 g/cm², which ensures their durability under the influence of road transport.

For rigid pavement repair compositions, an important indicator of the quality of concrete is its shrinkage, which largely determines the joint work of new and old concrete. Deformations of fresh concrete can be caused due to the following reasons [24-27]: plastic shrinkage, chemical shrinkage, which is an integral part of autogenous shrinkage and may not be considered in practice, drying shrinkage, carbonation shrinkage develops over a long period of time and constitutes an insignificant value that can be neglected. Additional factors causing shrinkage deformations can be stresses caused by unacceptable temperature fluctuations in massive structures and the highly reactive ability of mineral additives with cement alkalis. Drying shrinkage is at least studied. It causes the main shrinkage deformations of the cement stone and depends on the type and cement content, its specific surface area and W/C ratio, which determines moisture content of the cement stone. According to researches [25, 28] increasing metakaolin content reduces shrinkage over time with the same W/C mixtures and equal workability.

In our study, we measured the total shrinkage, consisting of autogenous and drying shrinkage for mixtures with different W/C. Measurement of shrinkage deformations was carried out on prisms of 40×10×10 cm according to DSTU B V.2.7-216:2009. Measurements started 24 hours after concrete forming, directly after sample stripping. The measurements were carried out using a dial indicator with a graduation of 0.01 mm after 3 hours, 6 hours, 1, 2, 3 and 7 days. The results are shown in Fig. 4.

Conclusions and prospects for further researches. Partial replacing of the cement with metakaolin entails the need to increase W/C ratio of the concrete mixture. However, this does not significantly affect the compressive and flexural strength of concretes modified with the BASF MasterGlenium SKY 608 polycarboxylate admixture. Control concrete and concrete with metakaolin in the amount of 15 kg/m^3 correspond to grade C50/60. 30 kg of cement replacing with metakaolin, concrete grade C45/55 was obtained. Total shrinkage of concrete with partial replacement of cement with metakaolin, does not exceed 0.28 mm/m , all investigated concretes had high frost resistance (F200 for road concrete, equivalent F600 for structural concrete) and low abrasion resistance – $0.30\text{-}0.31 \text{ g/cm}^2$. Such physical and mechanical properties ensure high concrete durability for rigid pavements.

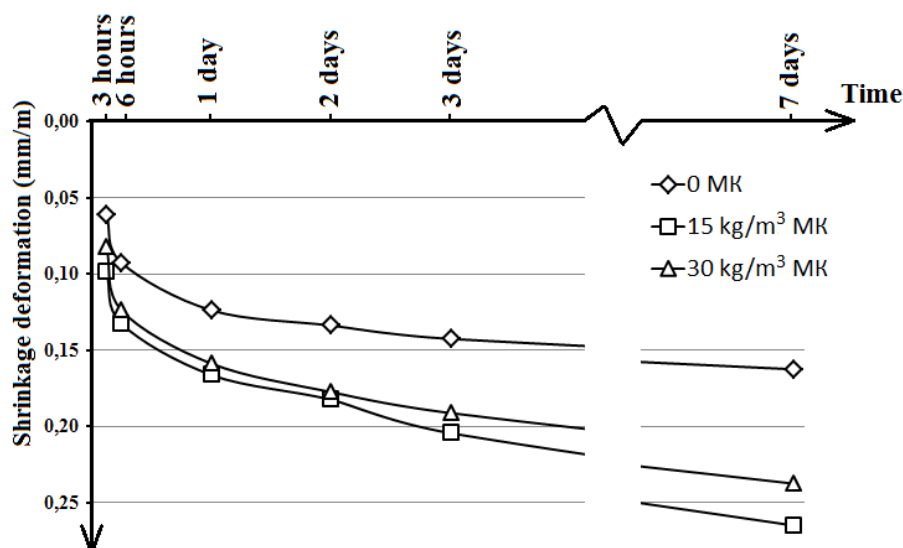


Fig. 4. Total shrinkage of investigated concretes at early ages

Further research should be directed to optimizing the dosage of various types of plasticizers, depending on the amount and cement type used in conjunction with metakaolin. It is also necessary to attend to a more detailed study of shrinkage deformations in compositions with metakaolin, since, according to [29], it is theoretically possible to reduce shrinkage by replacing cement with metakaolin and adding gypsum.

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ВПЛИВ МЕТАКАОЛІНУ НА МОДИФІКОВАНИЙ ПОЛІКАРБОКСИЛАТНОЮ ДОБАВКОЮ БЕТОН ДЛЯ РЕМОНТУ ЖОРСТКИХ ПОКРИТТІВ ДОРІГ

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Анотація. Досліджено вплив часткової заміни цементу високоактивним метаксоліном на міцність, морозостійкість, усадку і зносостійкість модифікованих полікарболілатною добувкою MasterGlenium SKY 608 бетолів. Для приготування бетолів використовувався цемент ПЦ II/A-III-500 (СЕМ II/A-S 42,5) з частковою заміною метаксоліном: 15 кг (3.75%) і 30 кг (7.5%). Кількість суперпластифікатора у всіх досліджуваних композиціях складала 1,2% від маси цементу. Марка рухливості бетолних сумішей Р2.

Встановлено, що з підвищенням кількості метаксоліну В/Ц сумішей незначно підвищувалося. При цьому рання міцність (у віці 2-х діб) на стиск і розтяг при згині складу без метаксоліну була вище аналогічних показників з частковою заміною цементу на активну мінеральну добувку. Варто відзначити позитивний вплив підвищення кількості метаксоліну на ранню міцність, тому що склад з більшою кількістю метаксоліну (30 кг) мав показники міцності вище на 2 добу твердіння на відміну від складу з 15 кг метаксоліну.

За рахунок використання добувки MasterGlenium SKY 608 на основі портландцементу ПЦ II/A-III-500 був отриманий високоміцний бетон для ремонту жорстких дорожніх покриттів з міцністю 87,5 МПа, що приблизно відповідає класу С50/60. Заміна 15 кг цементу на метаксолін дозволила отримати бетон того ж класу С50/60 з міцністю 85,2 МПа, а при заміні 30 кг цементу був отриманий бетон класу С45/55 з міцністю 78,4 МПа. Середня густина досліджених бетолів становила від 2480 до 2580 кг/м³.

Необхідно відзначити високу морозостійкість всіх отриманих бетолів. Їх марка по морозостійкості досягла F200 (при оцінці за методикою для дорожніх бетолів), що еквівалентно марці F600 для конструкційних бетолів. Показники зносостійкості були в низьких межах (0,30-0,31 г/см²), усадка до 0,28 мм/м що в сукупності з високою морозостійкістю робить позитивний вплив на довговічність ремонтних складів жорстких дорожніх одягів.

Ключові слова: жорсткі дорожні покриття, ремонт, рання міцність, усадка, морозостійкість, зносостійкість, метаксолін, суперпластифікатор.

**ВЛИЯНИЕ МЕТАКАОЛИНА НА МОДИФИЦИРОВАННЫЙ
ПОЛИКАРБОКСИЛАТНОЙ ДОБАВКОЙ БЕТОН ДЛЯ РЕМОНТА ЖЕСТКИХ
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Аннотация. Исследовано влияние частичной замены цемента высокоактивным метакеаолином на прочность, морозостойкость, усадку и износостойкость модифицированных поликарбоксилатной добавкой MasterGlenium SKY 608 бетонов. Для приготовления бетонов использовался цемент ПЦ П/А-Ш-500 (СЕМ П/А-S 42,5) с частичной заменой метакеаолином: 15 кг (3.75 %) и 30 кг (7.5 %). Количество суперпластификатора во всех исследуемых композициях составило 1,2% от массы цемента. Марка подвижности бетонных смесей P2.

Установлено, что с повышением количества метакеаолина В/Ц смесей незначительно повышалось. При этом ранняя прочность (в возрасте 2х суток) на сжатие и растяжение при изгибе состава без метакеаолина была выше аналогичных показателей с частичной заменой цемента на активную минеральную добавку. Стоит отметить позитивное влияние повышения количества метакеаолина на раннюю прочность, т.к. состав с большим количеством метакеаолина (30 кг) имел прочностные характеристики выше на 2е сутки твердения в отличие от состава с 15 кг метакеаолина.

За счет использования добавки MasterGlenium SKY 608 на основе портландцемента ПЦ П/А-Ш-500 был получен высокопрочный бетон для ремонта жестких дорожных покрытий с прочностью 87,5 МПа, что примерно соответствует классу C50/60. Замена 15 кг цемента на метакеаолин позволила получить бетон того же класса C50/60 с прочностью 85,2 МПа, а при замене 30 кг цемента был получен бетон класса C45/55 с прочностью 78,4 МПа. Средняя плотность исследованных бетонов составляла от 2480 до 2580 кг/м³.

Необходимо отметить высокую морозостойкость всех полученных бетонов. Их марка по морозостойкости достигла F200 (при оценке по методике для дорожных бетонов), что эквивалентно марке F600 для конструкционных бетонов. Показатели износостойкости были в низких пределах (0,30-0,31 г/см²), усадка до 0,28 мм/м что в совокупности с высокой морозостойкостью оказывает положительное влияние на долговечность ремонтных составов жестких дорожных одежд.

Ключевые слова: жесткие дорожные покрытия, ремонт, ранняя прочность, усадка, морозостойкость, износостойкость, метакеаолин, суперпластификатор.

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