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DEVELOPMENT OF DRY MIX MORTARS FOR FLOOR ELEMENTS

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Dry mix mortars are widely used in construction projects for the implementation of construction works in new construction, reconstruction, and repair. The improvement of properties of dry mix mortars for the installation of floor screeds is relevant. The purpose of such mortars is to equalize the differences in the thickness of the floor surface, to create an intermediate layer characterized by the necessary strength, durability, and even surface with the possibility of decoration with various types of flooring. A step-by-step design of the composition of dry mix mortar for the installation of floor screeds was carried out. The ratio of fine aggregates and limestone filler was optimized according to the maximum packing density criterion, the required amount of plasticizer was selected according to the consistency index of the fresh mortar, and the minimum amount of Portland cement was selected to ensure the required strength.

Key words: dry mix mortar; floor screed; packing density criterion; consistency; compressive strength; shrinkage.

Introduction

Modern trends in the development of new construction, as well as the reconstruction and repair of existing building objects, require the availability of high-quality and multifunctional building materials, which are characterized by increased technological and strength properties to ensure durability and reliability of operation. Nowadays, one of these materials is dry mix mortars, which have become widely used in modern construction technologies of many construction projects. Their use makes it possible to carry out construction work quickly and qualitatively with the use of machine units and a minimum of human resources. Dry mortar is also an environmentally friendly material, as its use reduces water consumption and waste generation during construction work.

Dry mixes are becoming increasingly popular in the global construction materials market, which is due to the increase in the volume of construction. According to forecasts, by the end of 2027, the volume of the world market of dry mix mortars will grow by 5.5 % compared to 2022 (Dry Mix Mortar Market Overview) and in Europe by 3 % in the forecast period 2024–2029 (Europe Dry-Mix Mortar Market Size & Share Analysis Source). An increase in the production of dry mix mortars was also observed in Ukraine. Thus, in 2021 the volume of produced products was 4557.2 thousand tons, which was 1.86 times more than in 2018 and corresponded to the indicator of 110 kg per person (Oficijnyj sajt Derzhavnoi' sluzhby statystyky Ukrai'ny).

In the modern construction industry, dry mixes are among the most versatile materials. In the market, consumer demand is focused on such dry mix mortars as cement plasters, screeds, tile adhesives and repair mixtures (Poluha, Zolotarova & Komakha, 2020). The advantages of dry mixes are the stability of strength and other properties; reduced mixing time; machine application; reduction of sand and cement losses due to the stability of the mixture composition; ease of transportation; improvement of industrial working conditions; they are sold ready-to-use, conveniently packaged and, if properly stored, retain their properties for a long time (Poluha, Zolotarova & Komakha, 2020; Kwan, Wong, & Fung, 2015; Cheng et al., 2023; Leopolder, 2010). Besides this, dry mortar is also an environmentally friendly material. Using the cradle-to-gate life cycle assessment (LCA) method, it was established that cement dry mix mortars have a relatively low impact on most of the analyzed environmental indicators (Czernik et al., 2020).

An important structure in residential and public buildings is the floor, which consists of several layers – a base, a screed, a finishing layer. The intermediate layer between the rough screed and the finishing coating (ceramic granite tiles, laminate, vinyl coatings, parquet, etc.) during floor installation plays an important role in obtaining a high-quality and durable surface. Depending on the finishing material, the intermediate layer of the easy-leveling screed should be characterized by good adhesion to it, the possibility of equalizing differences in thickness, and sufficient strength, which in total will ensure the high quality of the coating and its long-term operation. In this regard, the use and research of dry mix mortar for floor installation, which provides the necessary properties, is of great practical interest.

One of the main indicators of the quality of lightweight screeds is the compressive strength, which depends on several factors, including the consumption and dispersion of the binder and the content of quartz aggregates of the selected particle size distribution (Sanytsky, Marushchak, Olevych & Novytskyi, 2020; Han, Ros & Shima, 2013; Stechshyn, Sanytsky & Poznyak, 2015; Sydor, Maruchchak, Braichenko & Rusyn, 2020; Parashchuk et al., 2020). During construction and repair work, careful leveling of the floor surface is essential. Therefore dry mix mortar for floor elements must be characterized by a good flowability index using a small amount of water to level the surface with special equipment that allows performing a huge amount of work in a short time and with low labor costs. In addition, to ensure high-quality and long-term operation, the screed must be characterized by good adhesion to the base layer. Therefore, the dry mixture is a multi-component material consisting of a binder, fillers, aggregates and modifiers, which provide mortars with the necessary properties, and the main principle of its design is to establish the optimal ratio between the components (Sanytsky et al., 2020; Rudenko et al., 2016; Moskalova et al., 2023).

The most important modifiers of dry mixes are cellulose esters, superplasticizers (Lei & Zhang, 2022), defoaming agents (Shunxiang et al., 2023; Li et al., 2021), setting agents and other chemical admixtures. The function of water-retaining admixtures is to prevent uncontrolled moisture loss into porous substrates. The cellulose esters dominate in industrial products due to their environmental friendliness, good compatibility, and cost-effectiveness (Kovalenko, Tokarchuk & Poliuha, 2020; Bülichen, Kainz & Plank, 2012; Shi, Zou & Wang, 2020). To improve such characteristics as strength, adhesion, water retention, water permeability, and deformation ability, redispersed polymer powders are introduced into the mixtures. The presence of polymers makes the mortar more fluid, which makes it easier to apply. Polymers can also be used to improve the mechanical and physical properties of cement-based materials, as they have good flexibility and compatibility with cement materials, good elastic deformation capacity, and resistance to alkaline and acid corrosion (Balagopal et al., 2023). Research on reducing the cement content in mixtures to meet the specified technological strength characteristics and durability requirements of the cement-based material to reduce carbon dioxide emissions and energy consumption, promoting the sustainability of such materials is relevant (Tayebani, Said & Memari, 2023). For this purpose, mineral additives are used, in particular, carbonate fillers are effective due to their wide availability and low cost. The mechanism of action of the limestone filler is determined by physical (compaction of the structure of the mortars due to the packing density model) and chemical (the ability to stabilize calcium hydroaluminates with the formation of calcium hydrocarboaluminates and to accelerate the hydration of calcium silicates due to the nucleation) effects (Wang et al., 2018; Sanytskyi, Kropyvnytska & Gev'yuk, 2019; Panesar & Zhang, 2020).

Target of this article – to select the optimal granulometry of aggregates and limestone filler, to study the effect of cement and plasticizing additive amount on the rheological parameters, strength and shrinkage of floor screed.

Materials and Methods

The cement CEM II/A-S 32.5R was used in the investigation. The specific surface of CEM II/A-S 32.5R is 330 m^2/kg, the residue on sieve 008 is 8.5 %, and the initial and setting final time is 70 and 150 min respectively. Two different natural quartz sands were used as an aggregate. The fineness modulus of Nova Skvaryava aggregate (A1) and Davydiv aggregate (A2) is 1.9 and 1.26 respectively.

According to the requirements, the maximum size of fine aggregate particles in mixtures for installation of floor elements should not exceed 1.25 mm. Therefore, fine aggregates A1 and A2 were sifted through a 1.25 sieve. Mineral powder (MP) of class I from the Ternopil quarry as a fine limestone filler was used. A void at compaction of 40 MPa of MP is 26 % by volume, and its bulk density is 993 kg/m^3.

The superplasticizer MELFLUX 2651 F produced by BASF was used to adjust the consistency of fresh mortars as a plasticizing admixture. In the technology of dry building mixes a water-retaining additive is a mandatory component that prevents the mortar mixture from drying out during the installation of flooring and the formation of cracks. Therefore, a water-retaining additive based on cellulose ether Walocel MKX 15000 PP20 in the amount of 0.1 wt. % was used for the research.

After weighing a certain amount of aggregates, additives and cement, they were thoroughly mixed in a laboratory mixer in a dry state, and then water was added. After the consistency testing of the ready fresh mortar, it was poured into a mold for forming samples 40×40×160 mm. The samples were used to determine strength after 3 and 28 days, as well as shrinkage. The consistency of fresh mortar, the strength and shrinkage of the mortar were determined by standard test methods.

Results and Discussion

One of the main factors affecting the strength of screeds with high flowability is the optimized particle size composition of the components to achieve maximum compaction of grains. To establish the optimal ratio between fine aggregates and limestone filler to ensure minimal voids of the grains of the dry mix mortar, six mixtures of aggregates and filler were studied, the compositions of which are given in Table 1. The amount of finely dispersed limestone filler did not change, since the total amount of filler together with a binder to obtain optimal characteristics in terms of flowability and water-solid ratio should not exceed 25–32 %.

Table 1

Component proportion and physical properties of aggregate-filler mixture

Component	Ratio of components in aggregate-filler mixture, mass part					
	M1	M2	M3	M4	M5	M6
A1	9	8	7	6	5	4
A2	4	5	6	7	8	9
MP	1	1	1	1	1	1
Properties						
Bulk density, kg/m^3	1422	1426	1430	1445	1425	1420
Voids, %	46.1	46.0	45.8	45.2	46.0	46.2

The cumulative curves of the granulometric composition of all mixtures are continuous and differ in the area of grain sizes of 0.315–1.00 mm (Fig. 1, *a*). Meanwhile, the analysis of particle size distribution showed that the dispersion curves of compositions M3 and M4 are smooth, closest to the normal Gauss distribution curve (Fig. 1, *b*). The results of the loose bulk density and voids allow to determine that the mixture M4 has an optimal ratio between fine aggregates and it is characterized by a maximum bulk density of 1445 kg/m^3 and a minimum void of 45.2 % (Table 1). Mixture M4 is the most favourable for the preparation of dry mix mortar.

To ensure the quality of the finished floor covering, modifiers of various functional purposes are added to the composition of the dry mix. The plasticizers increase the flowability of binding materials and due to the water-reducing effect the water amount, which is needed to achieve necessary flowability, is decreased as a result, the physical and mechanical characteristics of cementing materials are improved. To reduce the water-solid ratio (*W/S*) the effect of a plasticizing additive on the consistency of the mortar mixture was investigated. The consistency of the mortar according to the requirements of the current standard should be at least 8 cm. The amount of superplasticizer varied in the range of 0.0–0.15 % to ensure $W/S = 0.15$. The amount of water-retaining additive was 0.1 wt. %. The results of experimental studies are shown in Table 2.

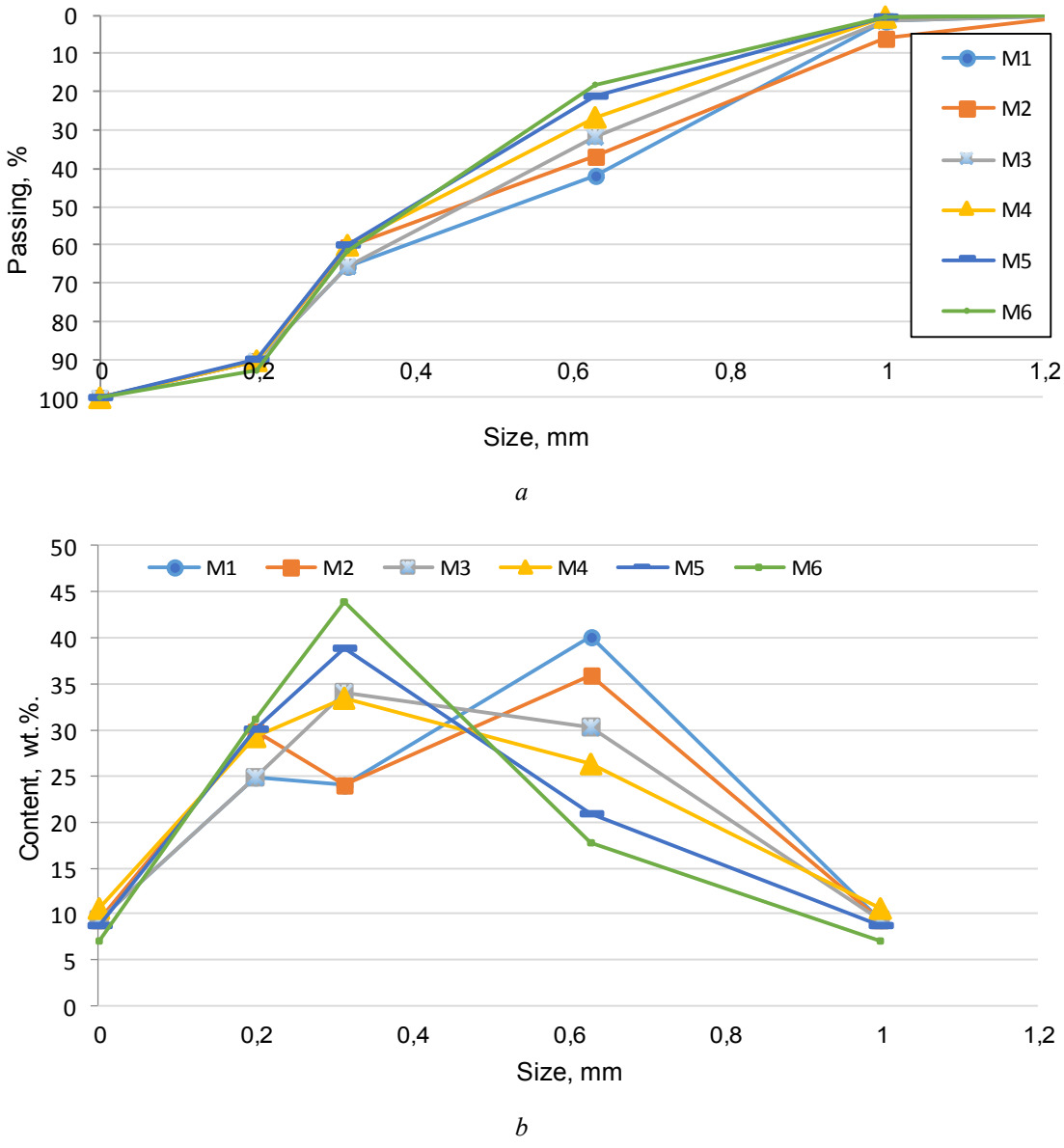

Fig. 1. Particle grading curve of aggregate-filler mixtures: a – cumulative; b – differential

The mixture without plasticizer is characterized by a low consistency index. This will cause the mortar mixture to be difficult to install the floor covering, and will not allow it to be placed by machine. When a plasticizer with an amount of 0.1 wt. % was added, the consistency of the mixture met the requirements of the standard for floor element mixtures and allowed for optimal rheology of the mixture when placed by machine. The increase in the plasticizer amount provides an increase in the consistency of the mortar mixture but leads to the effect of sedimentation (bleeding), which negatively affects the quality of the finished floor element coating.

In addition to the optimal particle size distribution of aggregates and fillers, the binder content has a significant impact on the strength of the mortar, shrinkage, and water-solid ratio. According to the requirements of the standard, for a screed of group CT1, the compressive strength should be at least 5.0 MPa after 3 days of curing and at least 15 MPa after 28 days. The dry mixes with a Portland cement content of 20, 23, 26 and 29 wt. % were tested (Table 3). The quantity of water was taken according to the optimal consistency of the fresh mortar 85±2.0 mm. It should be noted that an increase in the content of fine components in the mixture leads to an increase in the water-solid ratio, which negatively affects the performance characteristics of the finished floor coating.

Table 2

Influence of plasticizer amount on the consistency of mortar mixtures

Component	Content, %			
CEM II/A-S 32.5R	29	29	29	29
M4	71	71	71	71
MELFLUX 2651 F	0.00	0.05	0.10	0.15
Walocel MKX 15000 PP20	0.1	0.1	0.1	0.1
Property				
W/S	0.15	0.15	0.15	0.15
Consistency, mm	58	66	85	106

Table 3

Influence of Portland cement amount on the properties of fresh mortar and mortar

Component		Content, %			
CEM II/A-S 32.5R		20	23	26	29
M4		80	77	74	71
MELFLUX 2651 F		0.1	0.1	0.1	0.1
Walocel MKX 15000 PP20		0.1	0.1	0.1	0.1
Properties					
W/S		0.14	0.145	0.15	0.155
Consistency, mm		82	83	85	86
Compressive strength, MPa, after	3 days	3.9	4.3	5.1	5.7
	28 days	9.8	12.7	15.3	17.7
Shrinkage, mm/m		0.50	0.57	0.65	1.15

The analysis of the results showed that mortars with amount of Portland cement of 20 and 23 % don't meet the requirements of the standard for strength indicators after 3 and 28 days, while an increase in cement an amount to 26 and 29 wt. % ensures the achievement of standard strength indicators (Table 3). Regarding the shrinkage of the hardened mortar, it was found that mortars with a shrinkage rate of 0.6–0.8 mm/m are more resistant to cracking, and at shrinkage values of more than 0.8 mm/m, the risk of cracking increases, although the standard allows a shrinkage value of no more than 2 mm/m. Therefore, to achieve the standard values of strength and shrinkage the optimal consumption of Portland cement is 26 wt. %.

Conclusions

Dry mix mortars for floor elements are widely used to create a high-quality and reliable floor covering. The research has established the optimal ratio of the fine aggregates and carbonate filler, the amount of plasticizing additives and Portland cement. The packing density model was employed to optimize the ratio between fine aggregates and carbonate filler. The developed dry mix mortar for floor screed is characterized by a strength of 5.1 and 15.3 MPa after 3 and 28 days of curing, shrinkage of 0.65 mm/m with satisfactory rheological characteristics of the fresh mortar.

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РОЗРОБЛЕННЯ СУМІШЕЙ БУДІВЕЛЬНИХ СУХИХ МОДИФІКОВАНИХ ДЛЯ ВЛАШТУВАННЯ ЕЛЕМЕНТІВ ПІДЛОГИ

Сухі будівельні суміші все ширше використовують у будівельних проєктах для здійснення будівельних робіт під час нового будівництва, реконструкції та ремонту. До переваг сухих будівельних сумішей порівняно з комерційними будівельними розчинами належать мінімум кінцевих технологічних операцій для приготування робочого розчину, економія дорогого та енергоємного портландцементу за рахунок використання пластифікаторів та водоутримувальних добавок, стабільність складів сухих будівельних сумішей у результаті точного дозування компонентів і ефективного їх змішування, підвищення продуктивності праці за рахунок поліпшення пластичних властивостей готових розчинів, зниження транспортних витрат. Для виконання робіт із вирівнювання підлогової поверхні для влаштування оздоблювального шару під час нового будівництва та ремонтів використовують сухі будівельні суміші для влаштування підлог, які повинні забезпечити необхідну міцність, довговічність, рівність поверхні стяжки. У статті подано результати із розроблення складів будівельних сухих сумішей модифікованих для влаштування стяжок підлог. Здійснено оптимізацію зернового складу дрібних заповнювачів та карбонатного наповнювача, що забезпечує максимальну щільність упакування зерен у суміші. Показано, що у разі використання суміші заповнювачів на наповнювачах оптимізованого складу та введенні суперпластифікатора у кількості 0,1 мас. % досягається необхідна рухомість розчинової суміші для влаштування стяжки машинним способом. З метою мінімізації витрати портландцементу досліджено вплив кількості в'яжучого на рухомість та фізико-механічні властивості розчинів. Встановлено, що за вмісту портландцементу 26 % досягаються показники міцності затверділого розчину 5,1 та 15,3 МПа через 3 та 28 діб відповідно, а також показники усадки 0,65 мм/м, що задовольняє вимоги чинного стандарту.

Ключові слова: суха будівельна суміш; стяжка; щільність упаковки; рухомість; міцність на стиск; усадка.