Designing of special concretes for machine building

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Abstract. Based on transdisciplinarity research, using the provisions of the geonics, modern composite materials have been developed that can effectively replace steel parts in mechanical engineering. The composite material was prepared by the joint grinding of cement (55%), ash of acid composition (40%) and limestone (5%) to a specific surface area of 550 kg/m², with an activity of 70.2 MPa. It was found that the combined effect of mechanical and chemical activation promotes an increase in the pozzolanic activity of acid ash, has a catalytic effect on the reaction activity of the fly ash the Ordinary Portland cement and the limestone crushed waste surfaces during machining in a vario-planetary mill. Thus, in the process of operation of equipment with concrete and reinforced concrete elements, their significant production advantages, determined by the improvement of the precision, strength and other parameters of the machines, due to the use of new materials, will be revealed.

1. Introduction
The task of mechanical engineering is to improve the quality, accuracy and high-speed performance of machinery and equipment, while reducing their cost, labor intensity of manufacturing and increasing the unit capacity. The use of polycrystalline composite materials opens up new possibilities for improving and regulating the characteristics of structures in operation, in comparison with single-crystal materials, whose capabilities are in some cases exhausted. In the US mechanical engineering industry, the share of such materials is approximately 15-20%, in Japan - about 50%, in Germany - up to 30%. In Russia, it is only about 2%, and the trend of its growth largely depends on the absence of a theoretically grounded methodology.

The current level of development of construction technology and structures allows us to successfully solve the problem of improving engineering products through the use of special concretes and reinforced concrete, both conventional and uniaxial, biaxially or volumetrically prestressed. The purpose of this study is to develop a special concrete that can maintain performance in the specific operating conditions of machinery and equipment.

2. Results and Discussion
To achieve the purpose, composite binder, obtained by the joint grinding of Ordinary Portland cement (OPC), superplasticizer (SP), fly ash (FA) and limestone crushed waste, was developed. The OPC of this study was type I (Spassky cement CEM I 42.5N). The physical properties of Spassky Portland
The physical properties of Spassky Portland cement are presented in Table 1.

| Compressive strength [MPa] | Setting time [min] | Fineness, passed through sieve [008 [%] | Surface area [m²/kg] | Normal density [%] |
|---------------------------|-------------------|------------------------------------------|----------------------|-------------------|
| 24 hours                  | 3 days            | 28 days                                  | Start                | Finish            |
| 30.2-32.6                 | 40.0-42.2         | 50.2-52.7                                | 112                  | 256               |
|                           |                   |                                          | 91.8-93.0            | 290               |
|                           |                   |                                          | 27                   |                   |

The fly ash obtained from Vladivostok thermal power plants was used as components of composite binders (Figure 1).

In the course of thermal studies it was revealed that in the low temperature interval physically bound water is removed from the FA sample [1–3]. The exothermic effect with a maximum of about 400°C indicates the burnout of organic substances, and the endothermic effect at 712°C is the dissociation of calcite into CaO and CO₂, which was confirmed by X-ray fluorescence analysis (Figure 2).
The limestone crushing waste (LCW) was obtained through pre-drying of carbonate rocks to about 1% moisture content of the raw material and then crushing to 300 microns in the centrifugal mill "Tribokinetika".

PANTARHIT PC160 superplasticizer (Ha-Be Betonchemie, Germany) was used in the mixtures in order to enhance the fresh properties.

The raw materials were dry mixed in various compositions [4]. The mixture was ground by a vario-planetary mill as is more energy-efficient than by either conventional ball mills or vibratory mills. In addition, due to the joint action of shock, centrifugal shock and abrasive forces, it becomes possible to achieve a higher powder dispersion using vario-planetary mill [5]. The movement and the trajectory of the grinding balls can be influenced by varying the gear ratio, so that the balls strike horizontally on the inner wall of the grinding jar (high impact energy), approach tangentially (high friction) or simply roll over the inner wall of the grinding jar (centrifugal mills) [6-7]. The rotational speed of the grinding jars and the support disc was set independently to optimally use high impact energy and high friction, respectively. All intermediate stages and combinations between pressure friction and impact can be freely set (Figure 3). The vario-planetary mill "Pulverisette 4" is controlled by integral software, in which up to 9 programmes can be saved and then loaded quickly and easily via the mill display.

Figure 3. Schematic operating principle of a vario-planetary mill

The raw components were milled and mixed in various proportions (OPC 30-100%, FA 0-50%, LCW 0-20%, superplasticizer 0.3%) in a vario-planetary mill for one hours. The materials mixing was carried out using cyclic and continuous flow dispensers with automatic control with a maximum weighing cycle duration of 45-90 s, with a weighing accuracy of 1-3% [8-10]. All raw materials were dosed by mass, with the exception of water and liquid additives (if any) that dosed by volume. In this research, there were no liquid additives (the super plasticizer is added dry). Water was added at the last stage, during the mortar preparation.

The control samples were made from a composite paste without addition of sand and fiber. Number of specimens was fabricated to determine the optimum composition of the binder.

3. Results and discussion

To reduce the water requirement of fine-grained cement-sand concrete mixture, while maintaining its required flowability, it is expedient to use a superplasticizer. In the paper, a choice was made of six
powdered superplasticizers, the most common in the Russian Far East building materials market [11-12]. For the formation of the raw mix of binder used CEM I 42.5N at a water-cement ratio of 0.3. The dosage of the superplasticizer into the binder mixture was 0.3%. The time for the beginning of the measurement of the slump flow was fixed after the end of the mixing of the cement paste. The mixing time of the cement paste was 6 minutes. Compared to other samples of superplasticizers, the attainment of the highest values of the cone spread was experimentally detected on a binder raw mix using a dry polycarboxylic superplasticizer PANTARHIT PC160.

Table 2. Spreading of cement paste with various superplasticizers

| Time of measurement start, min | Melflux 1641 F (Germany) | Melflux 5581 F (Germany) | PANTARHIT PC160 (Germany) | FOX™-8H (Russia) | PC-1030 (China) | JK-04 PPM (China) |
|-------------------------------|--------------------------|--------------------------|---------------------------|----------------|----------------|-----------------|
| 0                             | 290                      | 350                      | 370                       | 250            | 240            | 130             |
| 5                             | 380                      | 390                      | 400                       | 260            | 280            | 120             |
| 30                            | 390                      | 350                      | 390                       | 240            | 190            | 98              |

Seven binder composites were developed for further research. The "binder: sand" ratio is 1 to 3. To determine the optimal dosage of components in the "cement-limestone-ash" system it was grinded them to specific surface of 600 m²/kg at various ratios (Table 3).

Table 3. Compositions and properties of composite binders

| Mix No. | OPC, wt. % | FA, wt % | LCW, wt % | Compressive strength, MPa |
|---------|------------|----------|-----------|---------------------------|
|         |            | Vladivostok TPP | Artem TPP | 3 days | 7 days | 28 days |
| 1       | 100 (no milling) | –          | –         | 17 | 32.5 | 47.5 |
| 2       | 30         | –          | 50        | 20 | 30.2 | 40.1 | 50.4 |
| 3       | 35         | 45         | –         | 20 | 34.2 | 43.1 | 53.2 |
| 4       | 40         | –          | 45        | 15 | 36.6 | 48.2 | 56.6 |
| 5       | 45         | 45         | –         | 10 | 39.2 | 50.1 | 59.2 |
| 6       | 50         | –          | 40        | 10 | 45.1 | 54.9 | 65.8 |
| 7       | 55         | 40         | –         | 5  | 47.2 | 54.1 | 70.2 |
| 8       | 100 (milling) | –          | –         | –  | 60.3 | 81   | 103.2 |

Note: reference specimen (no milling); specimens No. 2-8 milled to S_p=600 m²/kg

In order to determine the optimum particle size the Portland cement (55% wt.), the superplasticizer (less 1% wt.), the fly ash (40% wt.) and the limestone (5% wt.) were ground to different specific surface area (S_p): 500, 550, 600, 700, 800, 900 m²/kg.

This fineness of grinding was chosen based on the results of previous studies, which showed that further reduction of the particle size is economically unprofitable. Positive dynamics of strength growth of the composite binder under the joint influence of the ash fine constituents, limestone crushing screenings and superplasticizer with maximum increase in the activity of the binder at 62% was found. Active mineral components of the composite binder contribute to the binding of Ca(OH)2 produced during cement hydration which results in formation of additional amount of hydrosilicate neoplasms. At the same time optimizing the process of structure formation is achieved by composite polydispersed components. Highly dispersed spherical ash particles act as crystallization centers, and used as filler at the nano- and micro- levels. In conjunction with the larger particles of the mineral component denser filling of intergranular spaces is noted in concrete cement structure with reduction in number of pores and microcracks. This is confirmed by micrographs of composite cement paste derived by joint grinding of clinker and industrial wastes of the Russian Far Eastern region. Cement
stone structure is very dense packing of small grains in the crystalline neoplasms total mass (Fig. 6). The additional amount of hydrated crystalline phases contribute to filling of the voids at the micro level in the crystalline matrix of calcium hydrosilicates at the boundary of the contact area, increasing degree of adhesion binder with filler.

4. Conclusion

1. The composite material was prepared by the joint grinding of cement (55%), ash of acid composition (40%) and limestone (5%) to a specific surface area of 550 kg / m², with an activity of 70.2 MPa.
2. It was found that the combined effect of mechanical and chemical activation promotes an increase in the pozzolanic activity of acid ash, has a catalytic effect on the reaction activity of the FA, the OPC and the LCW surfaces during machining in a vario-planetary mill.
3. It has been revealed that the addition of fly ash and limestone crushed waste to the composite binder at all dosages increases the strength characteristics of special concretes. Thus, a clear relationship between the properties of concrete and the features of the structure of cement stone is revealed - an increase in the number of hydrosilicate neoplasms, with a complex decrease in gel- and capillary porosity, especially at the molecular and submicroscopic levels, which predetermines the growth of strength and increase in the performance characteristics of concrete.
4. Thus, in the process of operation of equipment with concrete and reinforced concrete elements, their significant production advantages, determined by the improvement of the precision, strength and other parameters of the machines, due to the use of new materials, will be revealed.

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