Application of Self-Compacting Concrete in Precast Structure Technology

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Abstract. The present article contains research results on the influence of the water-cement ratio and the content of dolomite powder in blended cement; as well as the influence of the mortar excess ratio on the properties of the self-compacting concrete for the precast structure technology. Workability of concrete mix, strength and shrinkage of the concrete were examined. It was established that the content of dolomite powder and water-cement ratio produce an approximately equal impact on the strength of the self-compacting concrete. The workability of the self-compacting concrete mix at the consumption of the dolomite powder at the level of 30-40% depends only on the ratio of mortar excess in the concrete. Heat treatment of self-compacting concrete at the temperature of 50 °C over the period of 16-20 hours allows to achieve the concrete strength of 35 MPa. After the 24-hour exposure to room conditions, the strength of these concretes reaches 25-40 MPa. Concretes with the use of dolomite powder have a higher shrinkage at low dosages of superplasticizer.

1. Introduction

The application of the self-compacting concrete in the factory technology of the precast structures has significant advantages in comparison with the use of these concretes in in-situ structures [1-5]. In the context of the working conditions, a decrease in the noise and vibration levels within the conditions of an enclosed space have a particularly greater effect, than the sane decrease within the conditions of a construction site. Beyond that, a measurably lower transportation time of the concrete mixture at a factory in comparison with the time of its transportation from a concrete mixing station to a construction site lowers the risk of the concrete mixture slump loss or a significant dilution of the cement paste as a result of an increase in the plasticizing effect, which can occur when using polycarboxylate superplasticizers [6].

The reinforced concrete structure technology can benefit from using travelling formwork systems [7], which make it possible to forget the purpose-made forms and lower the production cost. Using travelling formwork with magnetic locks together with an additional wood or plywood formwork allows to produce an extended product range. At the same time the travelling formwork system technology has a number of drawbacks, including a high labor input during the framework installation, compaction of the concrete mix, and noticeable heat loss during the product heating. A high level of thermal energy losses is associated with a large formwork system area and ineffective methods of reducing heat losses, which mostly prevent only the loss of moisture from the concrete.

Reducing the labor input of the concrete work can be achieved by using the self-compacting concretes, whose technology is based on the introduction into the concrete of two additional components: highly effective superplasticizers and fine filler (inert mineral additive) or highly active pozzolanic additives (such as silica fume, fly ash and slag) [5, 8-10]. Dispersed waste produced as a result of rock crushing, including limestone and dolomite powder [8, 9, 11-13] are used as fine filler, substituting a part of the cement, reducing the shrinkage and increasing the crack resistance [14-19].

2. Methods and materials

An experimental assessment of the feasibility of using the self-compacting concrete in the formwork system technology under the conditions of low-temperature heating was performed on concrete mixtures made on the basis of Portland cement CEM I 42.5. The concrete was prepared using the following components: dolomite rubble (5-10 mm) with a density of 2840 kg/m^3 and a void ratio of 49%; sand with a fineness modulus of 1.51; dolomite screening dust (0.6-5 mm). Dispersed fraction of the dolomite screening dust with particle sizes not exceeding 0.16 mm was used as an inert mineral additive, and Glenium SKU 591 was used as the plasticizing additive. Specific surface area of dolomite powder was 335 m^2/kg.

To assess the consistency of the concrete's mortar component, the Hagerman's cone was used, and the workability of the concrete mix was estimated by the Abrams cone test.

Strength characteristics were determined using the samples with the dimensions of 40 × 40 × 160 mm. The samples were hardened using the following temperature settings: holding at 20 °C for 8 hours; heating up to 50 °C for 2 hours; holding at 50 °C for 5 or 9 hours, cooling for 1 hour.

Water-cement ratio (W/C), the proportion of dolomite powder in the blended cement and the excess ratio of mortar in the concrete were examined as the factors affecting the workability of the concrete mixture and the strength of concrete.

The first stage of the work included the analysis of two factors' impact on the properties of the concrete's mortar component. These factors were the water-cement ratio and the portion of cement substituted by the dolomite powder.

Compositions of mortar mixes are given in Table 1.

Table 1. Compositions of mortar mixes per 1 dm^3.

Composition of mortar	1	2	3	4	5	6	7	8	9
Portland cement (g)	739	749	760	610	614	629	488	498	493
Dolomite powder (g)	133	136	139	260	263	268	399	408	404
Sand (g)	1130	1142	1159	1121	1138	1167	1143	1168	1156
Superplasticizer (g)	6.2	6.3	6.4	6.2	6.3	6.4	6.3	6.4	6.5
Water (ml)	280	269	258	278	265	252	261	244	253

The second stage consisted of the workability research of a self-compacting concrete mixture and the concrete strength after heating at a temperature of 50 °C.

The properties of concrete mixture and concrete were examined depending on the content of dolomite powder and the excess coefficient of the mortar component, which was calculated as per the formula:

$$\alpha = \frac{1/m_{ca} - 1/\rho_{ca}}{1/\rho_b - 1/\rho_{ca}}$$

where m_{ca} – coarse aggregate content (kg/m^3);

ρ_{ca} – specific gravity of coarse aggregate (kg/m^3);

ρ_b – bulk density of coarse aggregate (kg/m^3).

Concrete mixes were prepared according to compositions shown in Table 2.

Table 2. Compositions of concrete mixes per 1 dm^3.

Composition of concrete	1	2	3	4
Dolomite rubble (g)	894	753	894	753
Dolomite screening dust (g)	102	110	102	109
Sand (g)	697	747	694	744
Portland cement (g)	426	457	334	358
Dolomite powder (g)	182	196	273	292
Water (ml)	182	196	182	195
Superplasticizer (g)	5.2	5.5	5.1	5.5

Shrinkage studies were carried out using the mortars with different workability values, in which the proportion of dolomite powder in blended cement and the consumption of superplasticizer were varied. When determining the shrinkage, the proportion of dolomite powder was at the level of 20 and 40% of the cement's weight, and the superplasticizer consumption amounted to 0.3 and 0.6% of the cement's weight.

3. Results and discussion

The flow of all studied mixtures exceeded 240 mm – the lower limit of mortar component spread for the self-compacting mixtures [20] (Figure 1). The only exception was the mixture with a low W/C and a high proportion of dolomite powder in the cement.

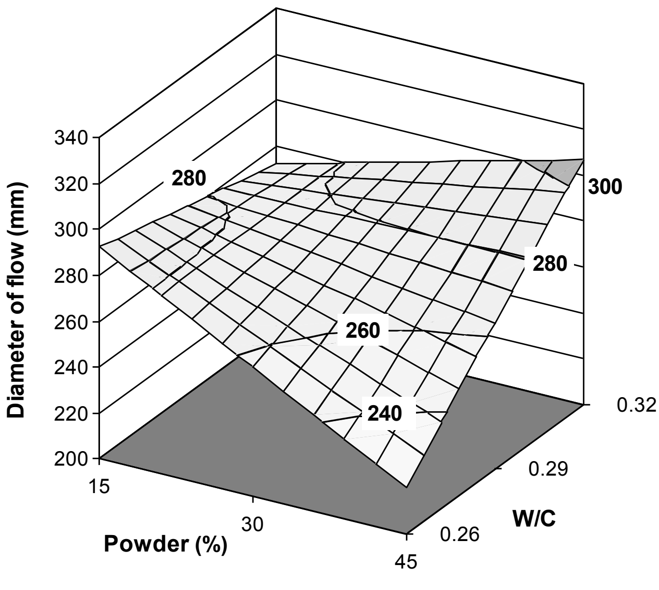

Figure 1. Dependence of the Hagerman's cone flow on the water-cement ratio and the content of dolomite powder in blended cement.

As can be seen from the graphs in Figure 2, the water-cement ratio and the proportion of dolomite powder exert an approximately equal influence on the mortar strength. The strength of almost all mortars after 16 hours of thermal treatment was in the range from 15 to 30 MPa, and, after 20 hours of heating, the mortar strength increased by 3-5 MPa. The increase in the mortar strength depends mainly on the water-cement ratio.

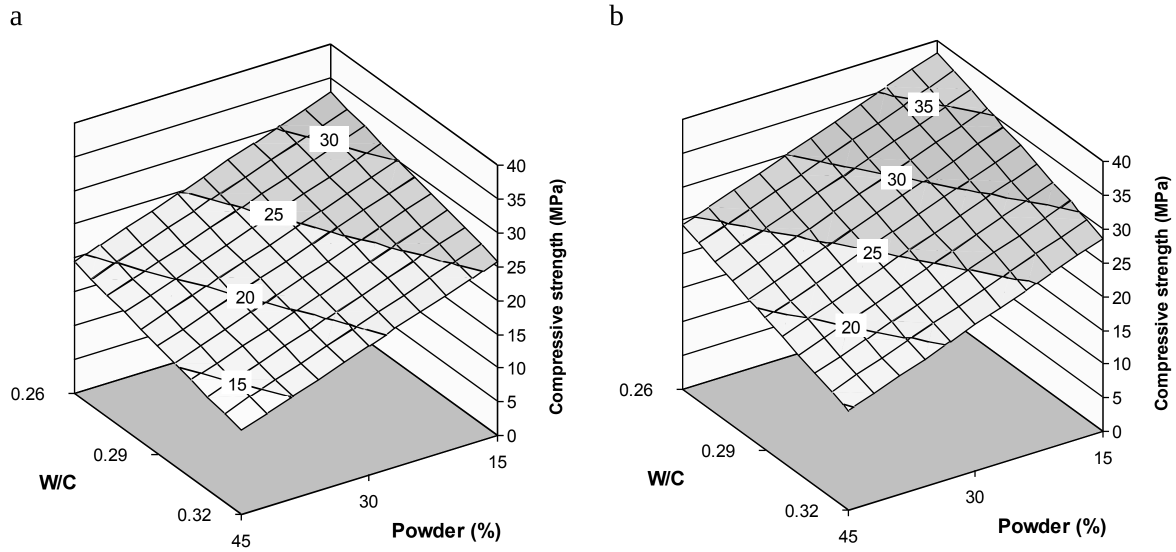

Figure 2. Influence of water-cement ratio and the content of dolomite powder in blended cement on the strength of the mortar after 16 hours (a) and 20 (b) hours of thermal treatment.

As can be seen from the graph in Figure 3, the diameter of the concrete mixture spread depends only on the coefficient of mortar excess in the concrete.

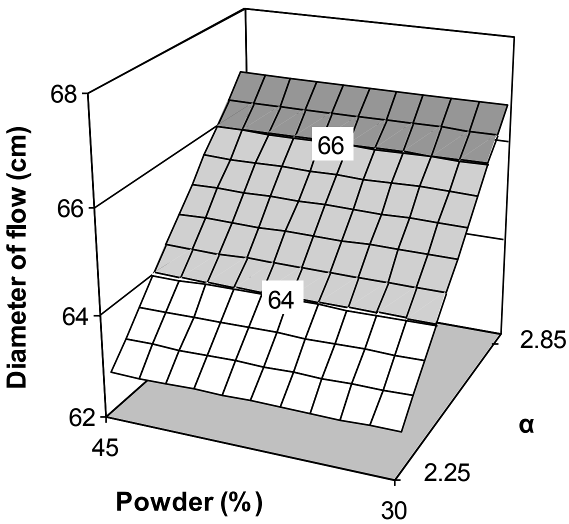

Figure 3. Influence of the coefficient of mortar excess in concrete and the content of dolomite powder in blended cement on the cone flow of the concrete mixture.

Evaluation of concrete strength after 16 and 20 hours of heat treatment shows that the investigated mixtures can achieve a strength of 20-35 MPa. As expected, the content of dolomite powder in cement has the greatest influence on the strength. However, mortar excess also affects the strength of concrete. An increase in the concrete heating duration from 16 to 20 hours leads to an increase in strength by 3-

5 MPa. The greatest increase in strength was registered in concretes with a high content of dolomite powder. Exposure of the investigated compositions at a temperature of 22-24 °C and a relative humidity of 70-75% ensures an increase in the strength of concrete by 6-14 MPa and a final strength of 25-40 MPa. At the same time, the strengths of the concretes that were subjected to thermal treatment with different durations were practically equalized.

The shrinkage of the mortar depends on the content of dolomite powder in the cement and the consumption of the superplasticizer (Figure 4). The introduction of 20% dolomite powder into the cement composition leads to decrease in shrinkage. Increasing the content of superplasticizer to 0.6% provides a noticeable reduction in shrinkage.

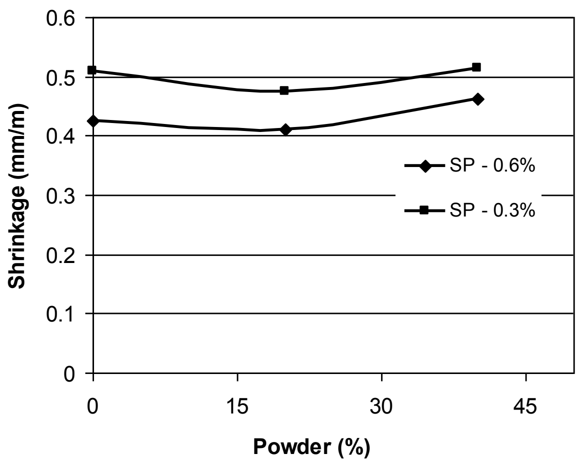

Figure 4. Influence of the content of dolomite powder and dosage of superplasticizer on the shrinkage of mortar.

This difference is associated with fact that with the introduction of the mineral additive at a low dosage of the superplasticizer results in an increase of the mixture water consumption, allowing to obtain the required consistency.

4. Conclusions

The results of the conducted study show that heat treatment of self-compacting concrete at the temperature of 50 °C over the period of 16-20 hours allows to achieve the concrete strength from 20 to 35 MPa. The use of such concretes in the manufacture of reinforced concrete products on travelling formwork systems can significantly improve the efficiency of this technology. The use of dolomite powder in mixtures with low consumption of superplasticizer leads to an increased shrinkage.

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