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The effect of pre-setting pressure applied flexural strength and fracture toughness of reactive powder concrete during the setting phase

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ABSTRACT

In this study, the effect of pre-setting pressure on reactive powder concrete (RPC) was examined. The fresh (plastic) concrete samples were filled in a specified beam mould and six different pre-setting pressure values (control-without pressure, 5, 10, 15, 20, 25 MPa) were applied. Flexural strength was improved by 34% with very low amounts (5 MPa) of pre-setting pressure. Also, toughness was increased more than thrice. In this study, the maximum flexural strength of 36.4 MPa and toughness of 116.960 N m were obtained under 25 MPa pre-setting pressure. Volume of sample was decreased 7.9% by pre-setting pressure.

1. Introduction

In recent years, high-performance concrete is being assessed not only in terms of high strength, but also in terms of specifications such as strength and ductility. Although high-strength concretes are favourable also because they are impervious, a significant issue with these concretes which emerges as their strength increases has been the problem of fragility. Although the capacity of axial deformation increases in high-strength concretes, once the peak point is reached, stress relaxation is instantaneous and the fragility leads to crashes. Since the beginning of 1960s, in order to resolve the issue of fragility in concrete, it has been a common practice to work fibre into it to ensure its ductility capacity. In order to improve the mechanical features such as tensile strength, resistance to cracks, endurance to wearing and shocks and toughness of plain concrete, it is mixed with steel, glass and polypropylene fibres. The fibres used in concrete increase tensile and flexural strength and also decrease shrinkage cracks [1,2].

Unlike the high performance concrete, reactive powder concrete (RPC) has been produced by working fibre into concrete, replacing aggregates with microgranules, arranging granule distribution so as to form minimum void in concrete, increasing pozzolanic activity and exposing the materials to different production and treatment. Although it was discovered in the first half of 1990s, the RPC has started to be developed and used all over the world [3–5].

RPC is a cement-based ultra high performance concrete with superior mechanical and physical specifications and excellent ductility and durability characteristics. Compression strength of RPC is 150–800 MPa, while its tensile strength changes between 25 and 150 MPa. Its fracture energy, on the other hand, changes between 1200 and 40,000 J/m^2. The durability properties of RPC are better than current high performance concrete in terms of magnitude [3–12].

Fine powders such as crushed quartz (100–600 μm) are used instead of coarse aggregate in order to make RPC more homogeneous. The water/cement ratio of RPC is reduced to less than 0.20 by using superplasticizers (SP). Silica fume addition to RPC reduces the total pore volume of the cement paste and the average diameter of the pores. Also, researcher's reports that application of different heat cure processes improves the mechanical properties of RPC to a great extent after the application of 50 MPa pre-setting pressure to fresh RPC [3]. Besides, pressure application to fresh RPC during the setting phase of 6–12 h can eliminate some amount of pores caused by autogenous shrinkage. Pre-setting pressure applied during setting stage causes microcracks in the sample. These microcracks are improved as a result of expansion of aggregate after discharging the applied pressure.

Pre-setting pressure trials were carried out also in the previous studies [3,6,13,14]. However, no study has been encountered so far where the effect of pre-setting pressure on beam samples are examined. The effects of pre-setting pressure on compressive

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strength have been examined by some researchers. In the study carried out by Dugat et al. [6], they applied a pre-setting pressure of 60 MPa onto the RPB800 concrete during the setting and hardening stages. Also, they applied 90 °C hot water and then heat curing process at 250 °C onto RPB800 samples for 4 days. Moreover, they examined the effect of the fibre content on the fracture energy. In their experiments, they increased the fracture energy up to 40,000 J/m^2 and found out the optimum amount of fibre content to be between 2% and 3%. Another study has been carried out by Teichman and Schmidt [13]. In that study, they applied 50 MPa constant pre-setting pressure onto the RPC samples while they are fresh and achieved strength of 487 MPa at the end of the experiment. The last study has been the one performed by us [14]. In this study, the effects of pre-setting pressure on compression strength, the elastic modulus and unit weight have been examined in details. For that purpose, six different pre-setting pressure amounts of control-without pressure, 25, 50, 75, 100, 125 MPa have been applied onto RPC and the compressive strength characteristics of the samples have been examined. Eventually, as the pre-setting pressure increased, compression strength and elastic modulus increased and the unit weight decreased. When compared to control-without pressure, 100 MPa pre-setting pressured had twice better compressive strength.

Generally, concrete properties are influenced by placement and compression factor. It is well known that reducing voids positively affect the mechanical and durability properties of hardened concrete. Concrete must be placed with minimum voids [15]. During the application of vibration to RPC, as the samples are examined, the increment in air volume due to air-entrainer property of SP is clearly observed. The RPC workability is similar to self-compacting concrete. In this study, T_{50} value of the mixture of RPC measured 4 s in slump-flow test. Workability can be brought to a desired level due to high ratio of SP whereas RPC has low water cement ratio. However, water and compressed air of closed pockets were found in the RPC. It was observed that the air bubbles in concrete caused swelling overflow from mould or forming of bubbles at the surface. The voids were formed between fibre and the concrete interface. In such condition, adherence between fibre and concrete interface was affected negatively and consequently the strength was reduced.

Because the steel fibres used in RPC is hookless and 0.16 mm in diameter and in order to make these fibres achieve a favourable adherence with concrete, it is mandatory to cover it with a fine-grained paste. This necessity stems from the fact that all the materials which compose RPC are at micron level. However, there are voids in the fine-grained paste as compared to normal concrete, even in the least. By reducing the voids to a minimum, there will be achieved more adherence between the fine-grained paste and the micron-sized hookless fibre. In order to increase the adherence between the paste and the fibres and to minimize the voids in the paste, it was decided to apply pre-setting pressure onto the RPC in fresh form. In this study, the effects of pre-setting pressure on RPC's, unit weight, flexural strength, fracture parameters and cost were investigated. For this purpose, a special moulding system was designed and the mixture in fresh form was filled in these moulds where it was applied pre-setting pressure of six different

Table 1
Properties of cement and silica fume.

Component	Chemical composition (%)	
	Cement	Silica fume
CaO	64.47	0.50
SiO_2	20.09	96
C	–	1.50
Al_2O_3	5.01	0.70
Fe_2O_3	2.73	0.25
MgO	1.72	0.60
K_2O	0.66	0.85
Cl	0.01	0.10
Na_2O	0.21	0.25
P_2O_5	–	0.10
SO_3	3.03	0.50
H_2O	–	0.80
Fever loss	2.11	1.50
pH value	–	5.0–8.0
C_3S	60.7	–
C_2S	11.8	–
C_3A	8.6	–
C_4AF	8.3	–
Silicate modulus	2.6	–
Alumina modulus	1.8	–
Hydraulic modulus	2.3	–
Total alkaline	0.58	–
	Physical properties	
	Cement	Silica fume
Blaine specify surface	5162 cm^2/g	200,000 cm^2/g
Unit volume weight	–	0.650 g/cm^3
Specific gravity	3.14	2.26
Initial setting time	154 min	–
Final setting time	191 min	–
Volume expansion Genleşmesi	0.8 mm	–
	Compressive strength of cement (MPa)	
2 days	39.8 MPa	–
7 days	54.2 MPa	–
28 days	61.8 MPa	–

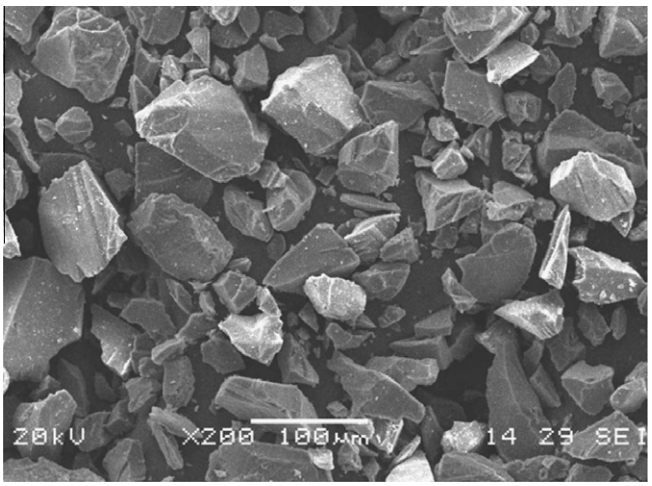

Fig. 1. Granule structure of the quartz powder [14].

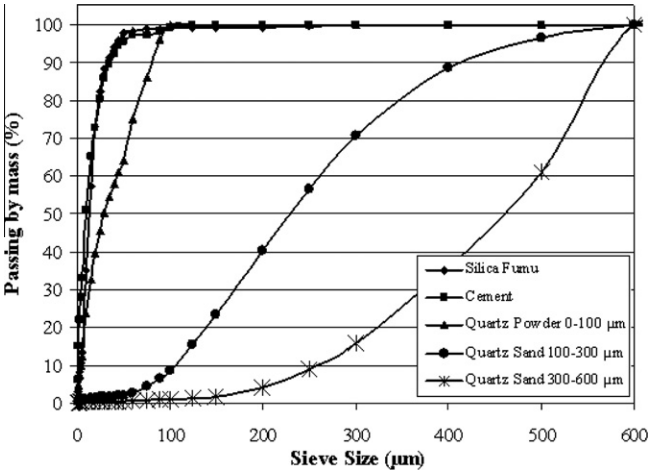

Fig. 2. Particle size analysis of granule materials [14].