

EXAMINATION OF THE USABILITY OF BASALT AGGREGATE IN SIFCON

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ABSTRACT

In this study, the usability of the quartz and basalt rocks as aggregate in Slurry Infiltrated Fiber Concrete (SIFCON) has been examined. In the study, quartz aggregate has been taken as reference and basalt aggregate has been used as a substitute and separately. The aggregates have been ground and classified in the dimensions of 0-0.1 mm (powder) and 0.1-0.6 mm (sand). The physical properties of the aggregates have been determined and SIFCON slurry has been prepared. The samples produced by this slurry have been conducted to Compressive Strength, Flexural Tensile Strength, Fracture Toughness, Ultrasonic Pulse Velocity, Schmidt Hammer tests. Moreover, unit cost has been examined with the different aggregate usages. Consequently; the highest compressive and flexural strength being respectively 99.75 MPa and 32.01 MPa have been reached with the use of quartz aggregate. The compressive strength of the basalt aggregate is 14% lower than that of the quartz aggregate where, its flexural strength almost remained in the same value. It has been observed that basalt aggregate is more economical in terms of unit strength cost. It is suggested that basalt aggregate could also be used in SIFCON as an alternative to the quartz aggregate.

KEYWORDS

SIFCON, fiber, quartz, basalt

INTRODUCTION

Steel, polypropylene, and glass fibers are added into the concrete to develop its mechanical properties such as tensile strength, crack strength, abrasion, impact strength and toughness. The fibers used in the concretes decrease the shrinkage fractures and increase tensile and flexural strength [1]. As the fiber ratio increases, important workability problems occur in the concrete, therefore high ratios of fibers were not able to be incorporated into mixtures. Due to this problem, the idea of the addition of concrete to the fiber has occurred and SIFCON (Slurry Infiltrated Fiber Concrete) has been produced. SIFCON being in the fiber reinforced concrete class was firstly developed in 1983 by Lankard in New Mexico Engineering Research Institute (NMERI) [2, 3].

SIFCON is the new cement based composite material which is reinforced with 5-20% steel wire in high ratios in terms of volume in a matrix occurring from the hardening of a slurry consisting of cement, water, superplasticizer, silica fume, and very fine sand. Besides, its engineering properties are quite high [4].

SIFCON is a new material containing steel wire up to the ratios of 20% in volume with its characteristics of low permeability, high durability, strength, and ductility. One of the most important properties of SIFCON, different from the high strength concretes, is that it shows ductile behavior

during the fracture [1]. SIFCON provides an opportunity for using high ratios of fibers with the advantage of the production technique of filling the fiber into the mold and injecting the slurry in the fibers [5,6,7,8].

SIFCON is used in various applications such as industrial elastic ground and thin-walled elements where ductility is a problem. Thanks to superior performance against disintegration, it is also used in structures which are exposed to impact loads and built to store explosive materials [9,10].

The mixture ratios of the SIFCON slurry, the aspect ratio of steel fibers and embedding lengths were studied by Tuyana and Yazıcı. Improvement of sludge strength, fiber diameter and geometry has increased the adherence of the fiber [9].

Impact experiments were made in concrete plates by Rao et al. They compared SIFCON and reinforced concrete plates' behaviors in terms of the impact load. The highest impact strength was obtained from SIFCON plate which has 12% steel fiber [11].

When the literature is reviewed, it could be seen that the studies conducted related to SIFCON are limited and no studies examining the impact of the aggregates generally in different types on SIFCON have been encountered. Therefore; this study examined the issue of using basalt as aggregate in SIFCON concrete.

EXPERIMENT

Material

The largest one of the main components of SIFCON is cement in terms of amount. For this reason; cement type has a great importance. CEM I 42.5 R type cement produced by Bolu Cement Factory has been used in all of the conducted experimental studies. Chemical, physical and mechanical properties of the cement are given in Table 1. Silica fume with high pozzolanic properties and space filling performance has been used as pozzolana. Silica fume is a mineral consisting of shapeless, transparent silicium dioxide (SiO_2) spheres occurring as waste during the production of silicone or iron silicium [12,13]. In the experiments, Polycar 300 being a new generation polycarboxylate based, highly water reducer and superplasticizer have been used.

Quartz and basalt aggregates are the ones occurring as a result of the fracture of the rocks and they take their properties from the bedrock. The chemical and physical properties belonging to these aggregates are given in Table 1. Quartz rock is much harder and stronger than other rocks and because it is a very hard aggregate, its abrasion strength is known to be high. Generally, quartz aggregates are used in SIFCON concrete [6,14,15]. However; quartz aggregates are hard to attain and very valuable in terms of the reserve. Basalt is the rock which is equal to very dark colored gabbro and dolerite and consists of pyroxene and olivine crystals [16]. Basalt aggregates are the ones having great reserves in many places of the world and therefore, they are widely used in the concrete and asphalt production. The basalt aggregate to be used in the experiment has been ground via mill, sieved and brought to the dimensions of powder and sand. Because the quartz aggregate is widely used in the repair mortars, it has been supplied from the market in the desired dimensions and its gradation curve is as in Figure 1. The gradation curves of the granular materials used in the experiments are given in Figure 1.

Tab. 1 - Properties of cement, silica fume, quartz and basalt

Component	Chemical Composition (% by mass)			
	Cement	Silica fume	Quartz powder	Basalt powder
CaO	64.47	0.5	-	11.75
SiO ₂	20.09	96	99.50	50.40
Al ₂ O ₃	5.01	0.7	0.01	16.7
Fe ₂ O ₃	2.73	0.25	0.01	2.34
MgO	1.95	0.60	-	7.56
FeO	-	-	-	5.8
C	-	1.5	-	-
Na ₂ O+K ₂ O	0.87	1.10	0.37	4.95
SO ₃	2.65			
TiO ₂			0.07	-
LOI				
A.Z.				
Loss on ignition	2.34	1.50	0.40	0.35
Specific gravity	3.16	2.26	2.71	2.68
Physical Properties				
Blaine specify surface (cm ² /gr)	3830	200000	2142	2101
Moisture content (%)	-	-	0.08	0.16
Initial setting time (minute)	156			
Final setting time (minute)	198			
Volume expansion (mm)	1.1			
Compressive Strength of Cement (MPa)				
2 days compressive strength (MPa)	27.3			
28 days compressive strength (MPa)	55.3			

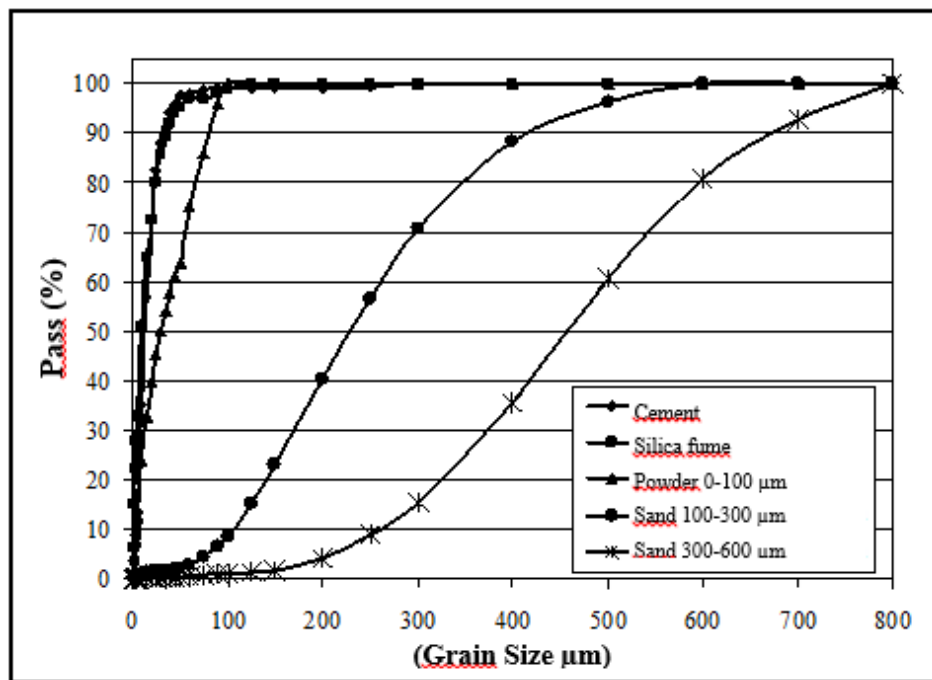


Fig. 1 – The gradation curves of the granular materials

Experimental procedures

Mixtures have been prepared by benefiting from the previous studies for SIFCON mixture and the one with the highest compressive strength has been selected and given in Table 3 [3,4,7,8]. The mixture ratios have been kept constant and the aggregates have been changed. Firstly; the quartz sand has been kept constant and the powder of basalt aggregate has been used instead of the quartz powder. At the second stage, Quartz powder has been kept constant and the sands of basalt aggregate have been used instead of the quartz sand. The third and last stage, the powder and sands of basalt aggregate have been used instead of the powder and sand of Quartz. Codes of the samples are given in Table 2.

Tab. 2 - Aggregate mixtures and sample codes

Aggregate mixture	Sample Code	Steps
Reference	REF	-
Basalt Powder+Quartz Sand	BPQS	First
Quartz Powder+Basalt Sand	QPBS	Second
Basalt Powder and Sand	B	Third

Tab. 3 - The mix proportion of SIFCON (kg/m³)

Materials	REF	BPQS	QPBS	B
Cement	900	900	900	900
Silica Fume	270	270	270	270
Quartz Powder	278	-	278	-
Basalt Powder	-	282	-	282
Quartz Sand	504	504	-	-
Basalt Sand	-	-	507	507
Water	270	270	270	270
Super plasticizer	36	36	36	36

The mixture process has been carried out by respectively filling the cement, silica fume, water additive, and aggregates in the mixer. Molds with the dimensions of 15 cubic centimeters have been used for the compressive strength and molds with the dimensions of 4x8x40 cm in rectangular prism shape have been used for the flexural strength. Fibers have been randomly filled in these molds and slurry has been injected on the vibratory table (Figure 2). Samples have been taken out of the molds after keeping for 24 hours in them and they have been subjected to the hot steam cure at 90 °C for 3 days. Following that, they have been kept in the curing pool at 20°C for 28 days.

Compressive strength tests have been conducted in the concrete tester with the capacity of 3000 kN and whose loading speed could be adjusted in accordance with TSE standards (Turkish standard) [17,18]. Test results have been assessed according to the standard and the mechanical properties belonging to the samples have been found.

Flexural tests have been conducted in the computerized bending test device that could draw the load-deflection graphs automatically (Figure 3). As specified in TS 10515, the loading speed of the test device has been adjusted in a way that it will make a deflection of 0.05-0.10 mm/min. in the middle point of the beam. 360 mm is the space between two supports has been divided into three equal parts and the beam sample has been loaded from two points [19,20]. As a

result of the test, load-deflection graphs have been drawn and the values of fracture toughness have been calculated [21].

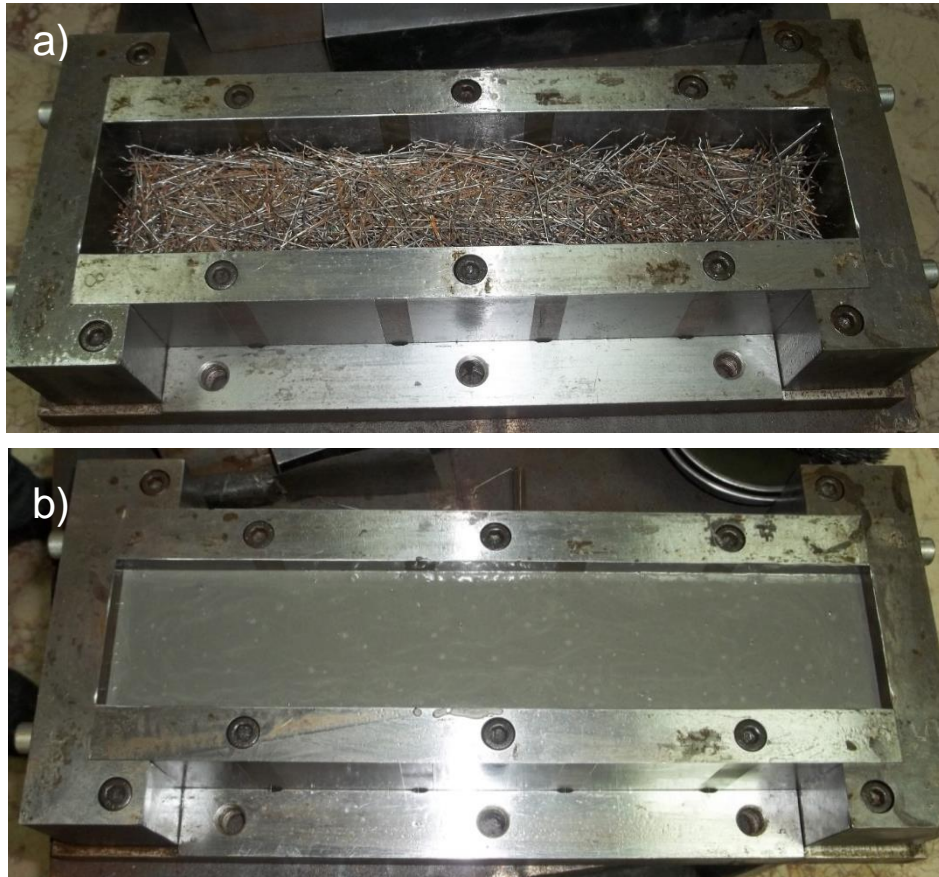


Fig. 2 - a) Filling the fibers into the mold, b) the fresh SIFCON



Fig. 3 - Flexural test apparatus

Ultrasonic pulse velocity test is one of the non-destructive experiments conducted to attain information about the quality of the concrete according to the speed of the sound transmission by taking the space amount in the concrete as the basis. Schmidt hammer test is a method developed to estimate the compressive strength of the sample by benefiting from the surface hardness. Ultrasonic pulse velocities of the samples and Schmidt hammer test reaction number are detected and the changes in other mechanical and physical properties of the samples are tried to be explained. For the test, ASTM C597-09 has been conveniently conducted in the cubic samples with the dimension of 15x15x15 cm (Figure 4) [22]. Sound transition period (t , μs) has been read from the screen and the proportioning to the distance between the probes (l , mm) and sound pulse velocity (V , mm/ μs) have been attained [6]. Schmidt Hammer Test has been conducted by fixing the concrete samples with the help of the concrete apparatus (Figure 5).



Fig. 4 - Sound pulse velocity experimental setup



Fig. 5 - Schmidt Hammer test setup

RESULTS AND DISCUSSION

The results attained from the test are given in Table 4 and Figure 6. The use of basalt aggregate instead of quartz powder has negatively affected the compressive strength and strength has decreased when compared to the REF sample. The compressive strength of the sample whose powder and sand aggregates consist of basalt is 14% lower than that of REF sample. This ratio has increased up to 30% on average with the use of basalt aggregate together with the quartz aggregate. Basalt aggregate has been ground from the rock and classification has been conducted only according to the minimum and maximum granular magnitude during the grinding. The distribution of the minimum and maximum grain interval has been checked and the gradation graphs in Figure 7 has been drawn. These graphs have been formed as a result of mixing the basalt aggregate in a certain ratio (35% powder+65% sand) as a result of its grinding as powder and sand. When Figure 7 is examined, quartz aggregate has been seen to be the closest one to the Fuller curve (assuming a Fuller exponential number of 0.50) accepted as the ideal curve [23,24]. Therefore, it is the aggregate with the highest composition. The highness of the composition has a positive impact on the increase in the compressive strength. The gradation curve of the basalt aggregate is different the gradation curve of Fuller and has an irregular curve. For this reason; the compressive strength of the basalt aggregate is lower. Schmidt hammer test results of the samples with high compressive strength are also high and show a little decrease in the REF sample. Because Schmidt hammer test conducts measurements depending on the surface hardness of the sample, it is possible for it to contain errors according to the real strength. No meaningful change has been observed in the ultrasonic pulse velocity values.

Tab. 4 - Mechanical properties of the sample

Sample Types	Compressive Strength (MPa)	Ultrasonic Velocity (km/sn)	Schmidt Test Hammer	Flexural Strength (MPa)	Fracture Toughness (Nm)
REF	98.89	3.42	61	32.44	70.61
BPQS	70.13	3.45	53	28.33	55.3
QPBS	71.87	3.47	52	29.21	59.62
B	88.40	3.41	62	32.05	69.77

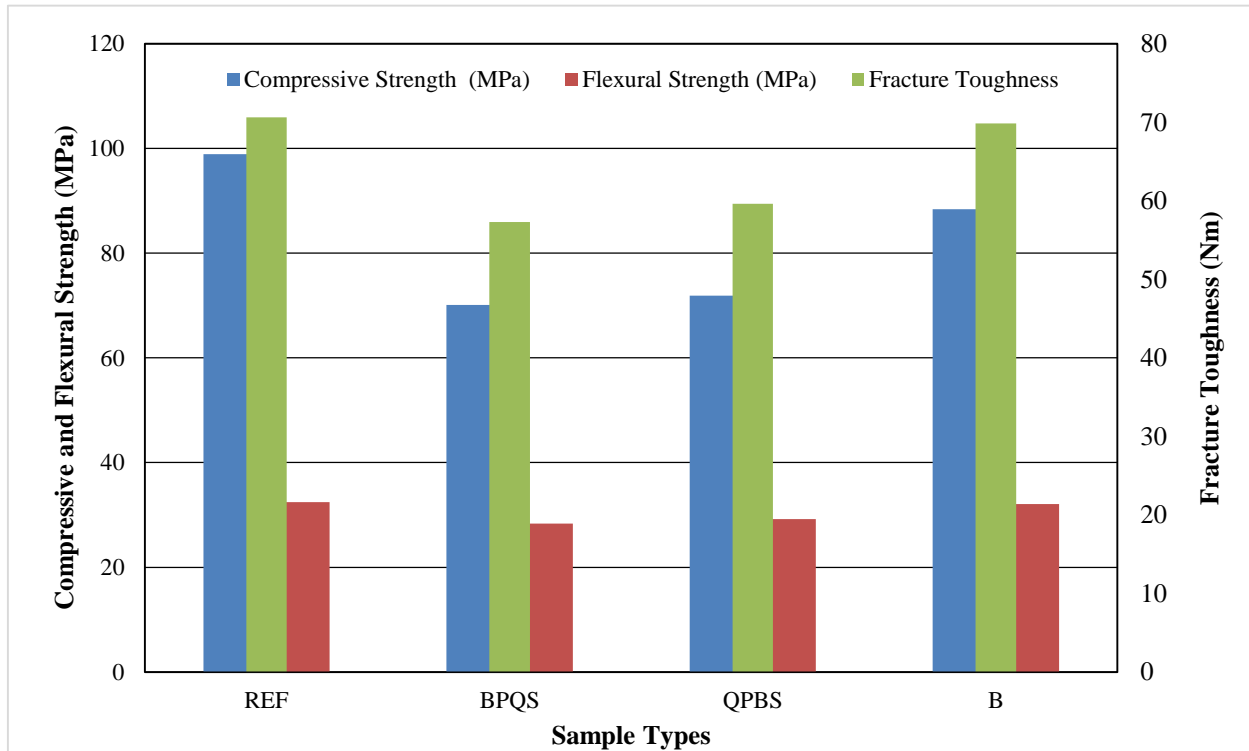


Fig. 6 - Compressive and Flexural Strength and Fracture Toughness graphics

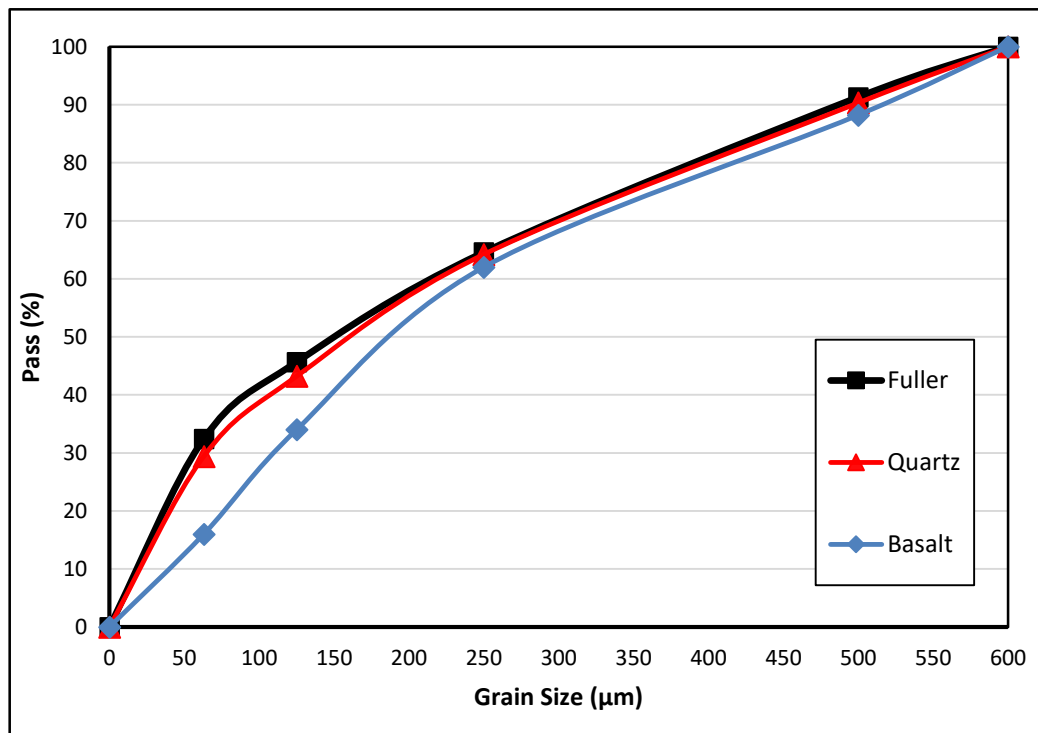


Fig. 7 – The gradation curves of the aggregate mixtures

It has been observed during the flexural test that the load has reached the peak point in a linear way and the fibers have started to debond after the maximum load. It has been seen that the sample has been broken by fracturing from almost the middle point (Fig. 8). It has also been observed that because the fibers are hooked, they break parts from the concrete during the debonding. Load-deflection graphs belonging to SIFCON samples as a result of the bending test is given in Figure 9-11. The strength and toughness results attained from the graphs are given in Table 4. While the flexural strength and fracture toughness values of the samples containing basalt aggregate have decreased when compared to REF sample, it has been seen that there has been a much higher decrease in the sample containing basalt powder (BPQS). A similarity is seen to be existent between the flexural strength and compressive strength. It is observed that the important factor decreasing the strength is basalt powder. When the aggregate gradation curves (Fig. 7) are examined, it is seen that basalt is 15% and quartz is 30% under 63 μm . The excessiveness of the fine material amount in quartz powder is very important in filling the spaces in micro dimensions and in cement paste. Filling the spaces in micro dimensions both affects the compressive and flexural strength.



Fig. 8 - Fracture sample as a result of the flexural test

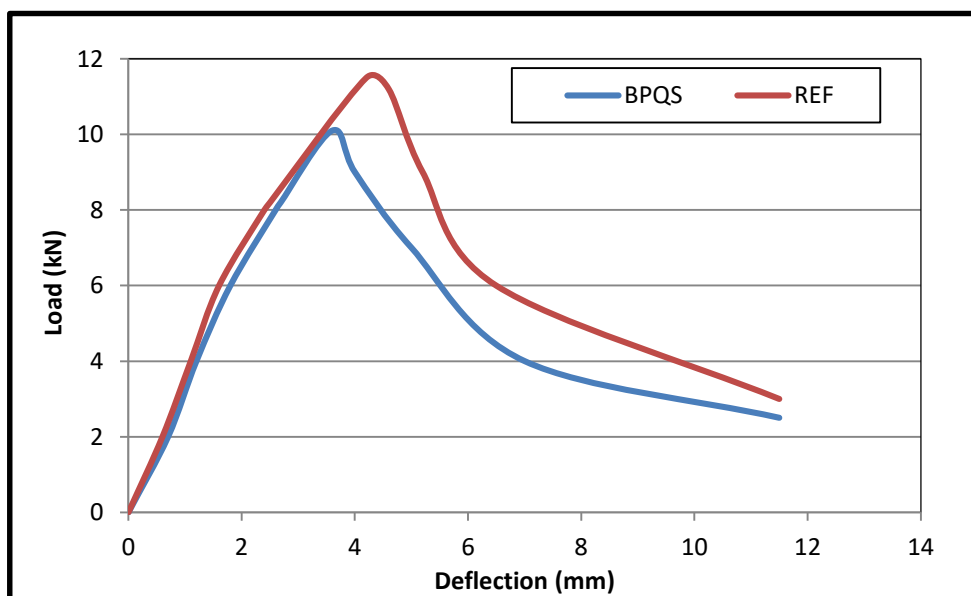


Fig. 9 - Load-deflection graphics of REF and BPQS sample

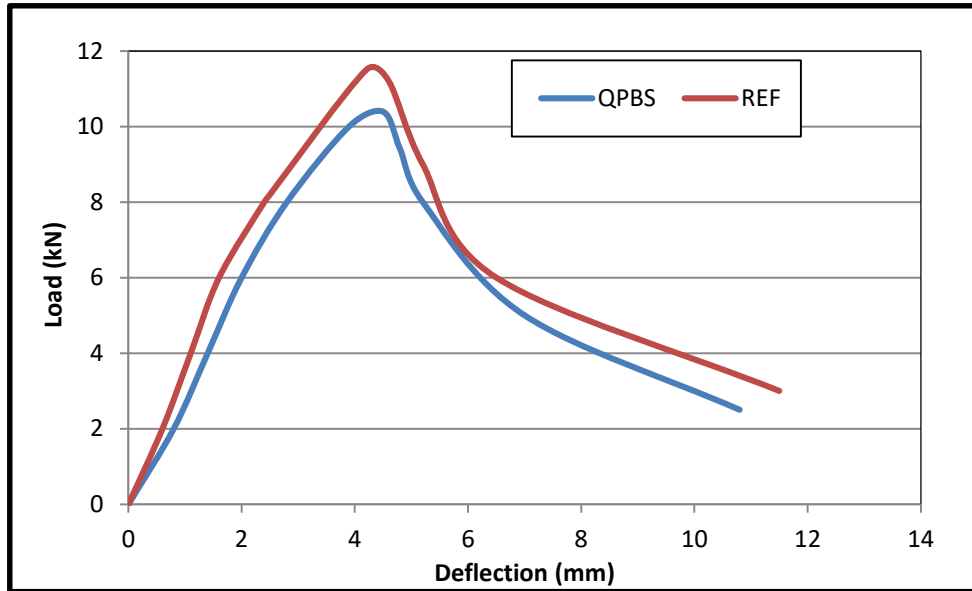


Fig. 10 - Load-deflection graphics of REF and QPBS sample

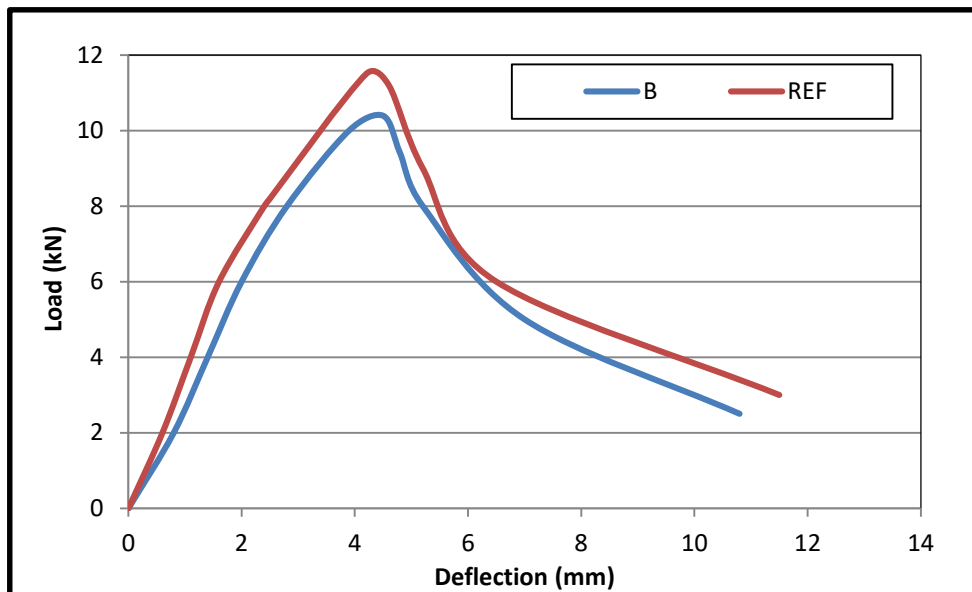


Fig. 11 - Load-deflection graphics of REF and basalt sample

Unit cost graphs of compressive and flexural strength are given in Fig. 11. The unit price of basalt aggregate in Turkey is approximately 75% cheaper than the unit price of quartz aggregate. Unit strength costs have been calculated by dividing the unit cost of SIFCON into strength. When Fig. 12 is examined, it is observed that the combined usage of quartz aggregate and basalt aggregate has increased the unit costs of compressive and flexural strength. However; there has not been any clear change in the compressive unit strength costs of the samples in which only basalt or quartz aggregates have been used and the unit cost of the flexural strength of the sample in which basalt aggregate has been used is approximately 7% lower.

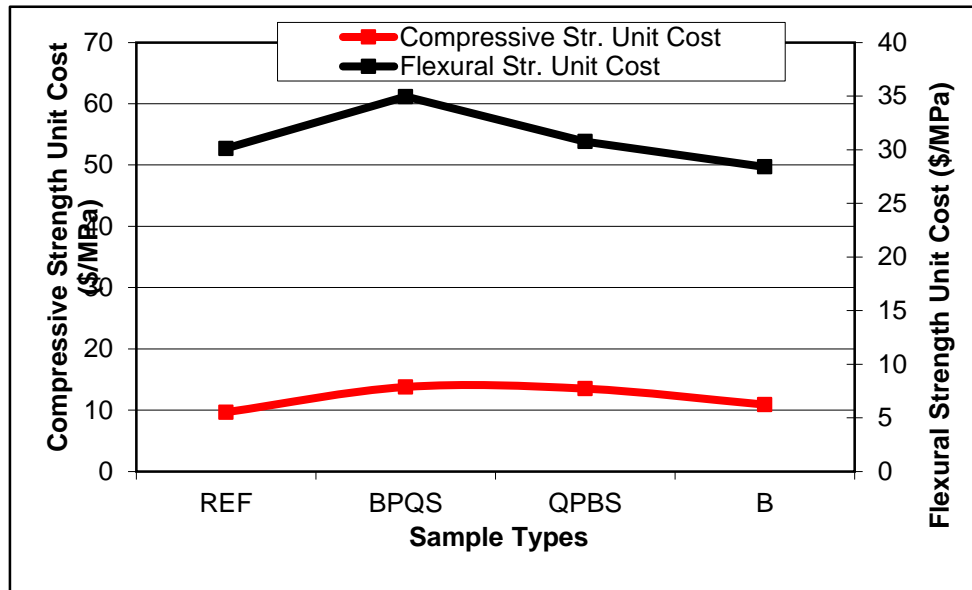


Fig. 12 - Unit cost graphics of the compressive and flexural strength of the samples

CONCLUSIONS

In the conducted study, the usability of the different rock types instead of the quartz powder used in SIFCON production and being in powder dimension has been examined.

The use of basalt aggregate instead of quartz powder has negatively affected the compressive strength and the strength has decreased when compared to that of REF sample. The decrease ratio in the compressive strength has increased by 30% together with the combined usage of the quartz and basalt aggregates. The gradation curve of the basalt aggregate is different from Fuller curve and it is irregular. Therefore; this may be the reason for the low compressive strength of the basalt aggregate. Schmidt hammer test results of the samples with high compressive strength are also high. However; no meaningful change has been observed in the values of ultrasonic pulse velocity.

According to the flexural test results, the flexural strength and fracture toughness values of the samples containing basalt aggregate have decreased slightly when compared to the values of the REF sample. The flexural strength and fracture toughness values of the sample in which quartz and basalt aggregates have been used in combination (BPQS) have decreased significantly. It has been observed that there is a similarity between the flexural strength and compressive strength results.

When the aggregate The gradation curves (Fig. 7) have been examined, it has been seen that the important factor decreasing the strength is basalt powder due to the fact that basalt is 15% and quartz is 30% under 63 μm .

The unit cost of SIFCON has been more economical because of the fact that the unit price of basalt aggregate in Turkey is as much as $\frac{1}{4}$ of the price of the quartz aggregate. Flexural strength unit cost has decreased by %8. However; no clear change has occurred in the unit compressive strength costs. It is suggested that the basalt aggregate could also be used as an alternative to the quartz aggregate in SIFCON.

ACKNOWLEDGMENTS

This work was supported by Sakarya University Scientific Research Foundation (Project number: 2012-05-08-008, 2010-05-08-005). The author would like to thank Sakarya University.

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