Research into Concrete Blocks with Waste Glass

P. Turgut, E. S. Yahlizade

***Abstract*—In this paper, a parametric experimental study for producing paving blocks using fine and coarse waste glass is presented. Some of the physical and mechanical properties of paving blocks having various levels of fine glass (FG) and coarse glass (CG) replacements with fine aggregate (FA) are investigated. The test results show that the replacement of FG by FA at level of 20% by weight has a significant effect on the compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the paving blocks as compared with the control sample because of puzzolanic nature of FG. The compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the paving block samples in the FG replacement level of 20% are 69%, 90%, 47% and 15 % higher as compared with the control sample respectively. It is reported in the earlier works the replacement of FG by FA at level of 20% by weight suppress the alkali-silica reaction (ASR) in the concrete. The test results show that the FG at level of 20% has a potential to be used in the production of paving blocks. The beneficial effect on these properties of CG replacement with FA is little as compared with FG.

***Keywords*—Concrete paving , Properties, Waste glass.

I. INTRODUCTION

GLASS is a transparent material produced by melting a mixture of materials such as silica, soda ash, and $CaCO_3$ at high temperature followed by cooling during which solidification occurs without crystallization. Glass is widely used in our lives through manufactured products such as sheet glass, bottles, glassware, and vacuum tubing [1]. Glass is an ideal material for recycling. The use of recycled glass in new container helps save of energy. It helps in brick and ceramic manufacture, and it conserves raw materials, reduces energy consumption, and the volume of waste sent to landfill [2]. In the UK the container industry cannot consume all of the recycled container glass that will become available in the coming years, mainly due to the color imbalance between that which is manufactured and that which is consumed. The resulting surplus of green glass from imported bottles containing red wine may be exported to producer countries, or used locally in the growing diversity of secondary end uses for recycled glass [3].

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UK produces over three million tonnes of waste glass annually, of which 71% comes from waste containers [4]. UN estimates the volume of yearly disposed waste glass 14 million tons. For Turkey, this amounts to 120.000 tons [5]. The amount of waste glass is gradually increased over the recent years due to an ever-growing use of glass products. Most waste glasses have been dumped into landfill sites. The landfilling of waste glasses is undesirable because they are not biodegradable, which makes them environmentally less friendly. There is huge potential for using waste glass in the concrete construction sector. When waste glasses are reused in making concrete products, the production cost of concrete will go down [5]. Crushed glass or cullet, if properly sized and processed, can exhibit characteristics similar to that of gravel or sand. When used in construction applications, waste glass must be crushed and screened to produce an appropriate design gradation. Glass crushing equipment normally used to produce a cullet is similar to rock crushing equipment. Because glass crushing equipment in glass sector has been primarily designed to reduce the size or density the cullet for transportation purposes and for use as a glass production feedstock material, the crushing equipment used is typically smaller and uses less energy than conventional aggregate or rock crushing equipment [6].

Waste glasses are used as aggregates for concrete [7]–[9]. However, the applications are limited due to the damaging expansion in the concrete caused by ASR between high-alkali pore water in cement paste and reactive silica in the waste glasses. The chemical reaction between the alkali in Portland cement and the silica in aggregates forms silica gel that not only causes crack upon expansion, but also weakens the concrete and shortens its life [10]. Ground waste glass was used as aggregate for mortars and no reaction was detected with fine particle size, thus indicating the feasibility of the waste glass reuse as fine aggregate in mortars and concrete. In addition, waste glass seemed to positively contribute to the mortar micro-structural properties resulting in an evident improvement of its mechanical performance [11]. Recently, some studies are carried out to suppress the ASR expansion in concrete and find method to recycle waste glasses [12]–[14]. The concrete containing 20% waste glass reduced the expansion ratio by 40% [12]. Shayan and Xu [14] reported fine glass powder for incorporation into concrete up to 30% as a pozzolanic material suppressed the ASR. Topcu and Canbaz [5] reported the waste glass in size of 4-16 mm used as aggregate in the concrete reduced the compressive strength of concrete. Tuncan et. al. [15] showed the addition of waste glass powder (15%) into concrete increased the compressive strength of concrete as much as 13%. Kısacık[16] also reported the compressive strength of concrete with waste glass decreased 19%. In the study of Park et. al. [1], 30% of waste glass with size of 0-5 mm addition into concrete decreased the compressive strength of concrete as much as 4%. Park et. al. [1], Topcu and Canbaz [5], Tuncan et. al. [15] and Kısacık[16] reported in their studies the addition of waste glass into concrete in crushed forms decreased the flexural strength. Park et. al. [1], Topcu and Canbaz [5] and Kısacık [16] also reported in their studies the addition of waste glass into concrete in crushed forms decreased the splitting tensile strength, while Tuncan et. al. [15] reported an increase of 6%. Sangha et. al. [17] investigated the effect on concrete strength of green glass as an aggregate replacement. They observed that increases in the compressive strength values at the 10%, 40%, and 60% aggregate replacement by waste glass with 0-10 mm particle size were 3%, 8% and 5% as compared with control sample without waste glass but decrease in the compressive strength value was 2% at the 20% replacement.

In this study, different from earlier studies on concrete with waste glass it is produced paving blocks with FG and CG. In addition, it is compared the test results obtained from mix of FG and CG.

In this study, as difference from earlier studies on concrete with waste glass it is produced paving blocks with FG and CG and compared the test results obtained from FG and CG mixes. In this study, different from earlier studies on concrete with waste glass it is produced paving blocks with FG and CG. In addition, it is compared the test results obtained from mix of FG and CG.

This study shows that the replacement of FG by FA at level of 20% by weight has significant effect on the compressive strength, flexural strength, splitting tensile strength and abrasion resistance of the paving blocks with FG compared with the control sample while the beneficial effect on these properties of CG replacement with FA by weight is little.

II. Materials

The FA and coarse aggregate (CA) are obtained from the Goksu River in Adiyaman-Turkey. The white windows glass as waste is supplied from windows glass market as broken. Then, FG and CG are produced by using Los Angeles abrasion apparatus. The some properties of these materials are given in Table 1. The grading of the FA, CA, FG and CG is shown in Fig. 1. The cement used in this study is PÇ 42.5 Portland cement complied with TS EN 197-1 [18], produced at the cement mill in Adiyaman-Turkey. The chemical properties of cement and waste glass are given in Table 2. Tab water is used in the brick samples. The properties of the water used in this study are of pH 6.2, 5.6 mg/lt sulphate content and hardness of 3.7.

TABLE I
THE PROPERTIES WASTE GLASSES AND AGGREGATES

Materials	Specific Gravity (SSD)	Absorption (%)
FA (0-4.75 mm)	2.63	0.5
CA (4.75-12.5 mm)	2.67	1.5
FG (0-1.18 mm)	2.42	0.4
CG (0-4.75 mm)	2.42	0.3

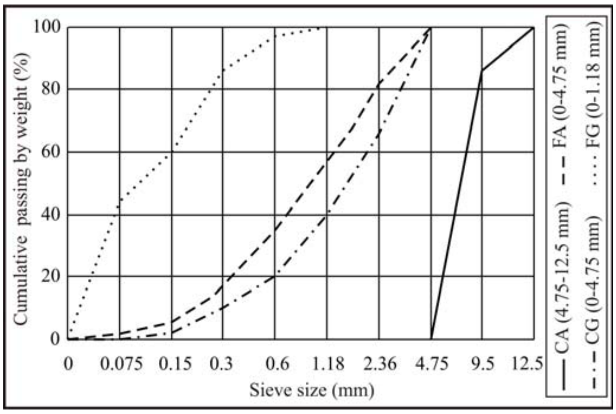

Fig.1 Gradation curves of the FA, CA, FG and CG

TABLE II
THE PROPERTIES WASTE GLASS AND CEMENT

Properties	Waste glass	Cement
SiO_2 (%)	70.22	23.71
CaO (%)	11.13	57.27
MgO (%)	-	3.85
Al_2O_3 (%)	1.64	4.51
Fe_2O_3 (%)	0.52	4.83
SO_3 (%)	-	2.73
Na_2O (%)	15.29	-
K_2O (%)	-	0.37
Cl (%)	-	0.0068
Loss on ignition (%)	0.80	7.24
Undetermined	-	0.94
Density	2.42	3.03
Specific surface area (m^2/kg)	133	437.6
Compr. str. for 28 days (MPa)	-	50.9

III. Experimental Procedures

A total of seven series of mixtures are prepared in the laboratory trials according to the requirements of BS 6717 [19] and TS 2824 EN 1338 [20]. The seven mixtures in series include a control mixture using only natural FA and CA. The details of mixes are given in Table 3. The cement and water proportions in the mixes are taken as constant to determine the effect of various FG and CG combinations. The replacements of FA with FG and CG are at levels from 10 to 30% by weight. For instance, the 20% replacement of FG means that the 20% of corresponding FA weight is replaced by FG in the FG-20 samples (see Table 3).

In the mixing process of samples, waste glass, FA, CA and cement contents are placed in a concrete mixer and mixed for 1 min as dry. Then, water is poured into concrete mixer for another 3 min. Afterward, the fresh mixes are fed into the steel moulds with internal dimensions of 105×75×225 mm^3.

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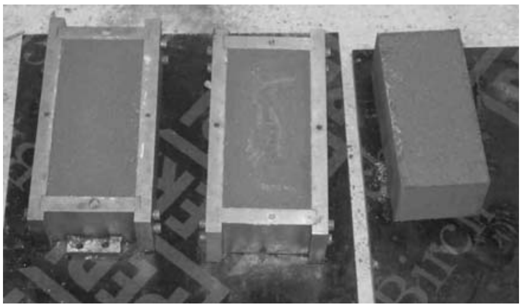
The steel moulds are filled over with material and the initial depth of materials covering the mould is approximately 85 mm. A pressure force of 17 MPa is applied for 1 min to compact the materials in the mould (see Fig.2). The formed paving blocks are then removed from the moulds (see Fig. 2) and cured under the water according to the rule [20] for 28 days (see Fig. 3).

(a) Before compaction



(b) After compaction

Fig.2 Fabrication of paving block samples

Fig.3 The curing of paving block samples

The total number of samples with dimensions of 105×75×225 mm prepared by this procedure is 84. The samples with dimensions of 105×94×75 mm^3 for the compressive strength, unit weight tests and 71×71×71 mm^3 for the abrasion test are obtained by cutting the samples with the dimensions of 105×75×225 mm with diamond saw. Table 4 shows the sample sizes and the number of samples is prepared for the corresponding the compressive strength, the flexural strength, the splitting tensile strength, the unit weight and abrasion resistance tests. Then, the paving block samples are dried for 24 hours by a ventilated oven at 105 ^oC. The water absorption is obtained from the samples prepared for the unit weight tests. The UPV (Ultrasonic Pulse Velocity) tests are also conducted on the samples made for the flexural strength tests.

TABLE III
THE MIXTURE PROPORTIONS

Mixture no	Cement (kg/m^3)	Water (kg/m^3)	Aggregates (kg/m^3)		Waste glasses (kg/m^3)	Pressure applied (MPa)
			Fine (0-4.75)	Coarse (4.75-12.5)		
Control	350	121	1100	900	0	17
FG-10	350	121	990	900	110	17
FG-20	350	121	880	900	220	17
FG-30	350	121	770	900	330	17
CG-10	350	121	990	900	110	17
CG-20	350	121	880	900	220	17
CG-30	350	121	770	900	330	17

TABLE IV
THE SIZES AND NUMBERS OF SAMPLES

Mixture no	Compr. Strength	Flexr. Strength	Split. Tens. Strength	Unit weight	Volume loss on wear
Sizes (mm)	105×94×7	105×75×22	105×75×22	105×90×7	71×71×71
Control	5	5	5	5	3
FG-10	3	3	3	3	3
FG-20	3	3	3	3	3
FG-30	3	3	3	3	3
CG-10	3	3	3	3	3
CG-20	3	3	3	3	3
CG-30	3	3	3	3	3
Total	3	3	3	3	21
	21	21	21	21	

The series of tests are carried out according to BS 6717 [19] and TS 2824 EN 1338 [20] to determine the water absorption, the unit weight, the compressive strength and the flexural strength, the splitting tensile strength and the abrasion values of the paving block samples.

After 28 days of curing, the paving block samples are tested for water absorption. They are taken out of the curing and allowed to drain the surface water by placing them on a metal wire mesh. The visible surface water is removed with a damp cloth and the samples are weighted immediately. After obtaining the saturated weight content, they are placed into an oven at 105 °C and dried to a constant mass for 28 hours, and then taken out from the oven and weighted at the room temperature. The water absorption of wet and dry weight of paving block samples is calculated. The paving block samples are cooled at room temperature and each unit weights is obtained by dividing the mass of the paving block samples by their overall volume.

The compressive strength of paving block samples is determined by using the servo controlled compression test machine with a maximum capacity of 800kN. The compression load is applied onto the face of sample having the dimensions of 105×94 mm.

The flexural strength of paving block samples is determined by the three-point bending test with a supporting span of 180 mm, a height of 75 mm and a width of 105 mm.

The splitting tensile strength of the paving block samples is obtained by applying load over the 225 mm length and 75 mm height of the paving block samples. The cube samples of 71 mm are used for the determination of abrasion resistance at 28 days according to TS 2824 EN 1338 [20]. In compliance with TS 2824 EN 1338 [20], the Bohme abrasion system has a steel disc, which has a diameter of 750 mm and rotating speed of 30 cycle/min, a counter and weight made of solid steel, which applies 0.3 kN on sample. In the test procedure, 20 g of abrasion dust is spread on the disc, the sample is then placed. The load is applied to the sample and the disc is rotated for a period that is equal to 22 cycles. After that, the surface of the disc and sample are cleaned. The mentioned procedure is repeated for 20 periods (totally 440 cycles) by rotating the sample 90^o in each period. The corundum (crystalline Al_2O_3) is used as abrasive dust in this abrasion test.

The UPV measurements are also taken for each paving block samples according to BS 1881 [21]. The UPV through a material is a function of the elastic modulus and density of the material. The pulse velocity can therefore be used to assess the quality and uniformity of the material. The UPV value of concrete paving block is determined by placing a pulse transmitter on one face of concrete paving block, and a receiver on the opposite face. A timing device measures the transit time of the ultrasonic pulse through the concrete paving block. Then the UPV can be calculated from the path length divided by the transit time. The path length for the UPV is through the concrete paving block length of 225 mm.

IV. Results and Discussions

Table 5 and 6 show the averaged mechanical and physical test results obtained from the tests, respectively. The test results showed that the unit weight and absorption values are approximately similar in the all paving block samples. The Fig. 6-9 illustrates the comparisons of the compressive strength, the flexural strength, the splitting tensile strength and the abrasion values in the replacements of FG and CG by FA.

TABLE V
MECHANICAL PROPERTIES

Mixture No	Compr. Strength (MPa)	Flexur. Strength (MPa)	Split. Tens. Strength (MPa)
Control	23.5±2.5	3.41±0.23	2.62±0.61
FG-10	34.7±3.2	4.17±0.72	3.35±0.23
FG-20	39.7±4.5	6.48±0.60	3.84±0.50
FG-30	30.9±1.0	5.09±0.12	2.72±0.13
CG-10	25.2±2.5	3.89±0.68	2.90±0.74
CG-20	28.8±1.7	3.77±0.18	2.55±0.20
CG-30	31.5±1.5	3.93±0.40	2.33±0.16

TABLE VI
PHYSICAL PROPERTIES

Mixture No	Volume loss on wear ($cm^3/50\ cm^2$)	Unit weight (g/cm^3)	Absorp. (as mass) (%)	UPV (km/h)
Control	11.95±1.42	2.18±0.01	6±0	3.43±0.45
FG-10	10.82±2.75	2.18±00.2	7±0	3.79±0.47
FG-20	10.18±0.44	2.16±0.06	7±1	3.88±0.09
FG-30	10.93±3.68	2.16±0.02	7±0	3.76±0.39
CG-10	10.93±0.94	2.20±0.02	6±0	4.05±0.07
CG-20	11.48±1.05	2.19±0.03	6±1	3.71±0.47
CG-30	14.11±1.02	2.17±0.03	6±1	4.04±0.09

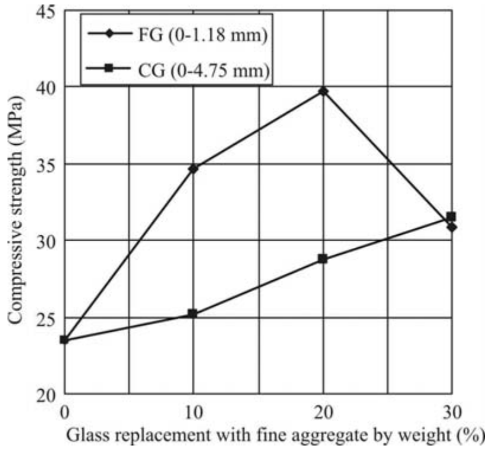


Fig.6 The variation of the compressive strength

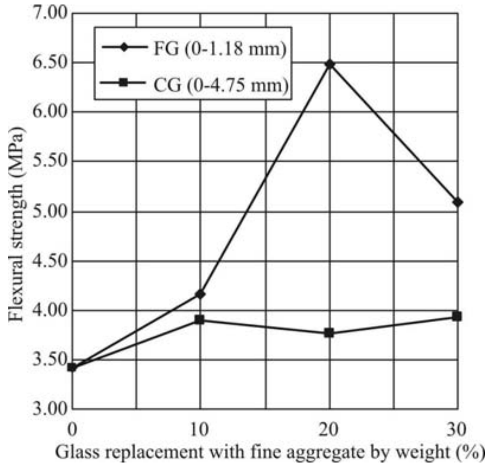


Fig.7 The variation of the flexural strength

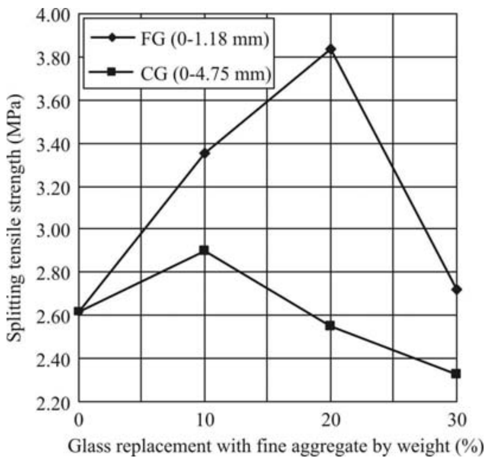


Fig.8 The variation of the splitting tensile strength

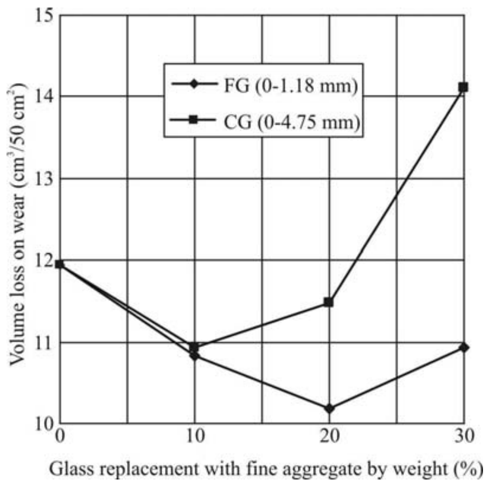


Fig.9 The variation of the abrasion value

The Fig.10 shows the variation % of test results in FG replacement with FA. As shown in Fig. 10, the compressive strength, the flexural strength, the splitting tensile strength and abrasion resistance increase in all of the paving block samples in the replacements of FG with FA by weight as compared with the control sample. The increases in the compressive strength of the paving blocks in the FG replacement levels of 10%, 20% and 30% are 48%, 69% and 31% as compared with the control sample, respectively. In the FG replacement levels of 10%, 20% and 30% the increases in the flexural strength of paving blocks are 22%, 90% and 49% as compared with the control sample, respectively. Park and Lee [13] showed there was an increase of 110% in the flexural strength of concrete in the case of using 20% FG, which is in agreement with the results in this study. Moreover, adding 20% FG into waste limestone sawdust increased compressive strength and flexural strength of masonry blocks about 7.3% and 86%, respectively [22].

In the case of using 10% FG, there is an increase of 28% in the splitting tensile strength of the paving block sample, while there is an increase of 47% in the splitting tensile strength of paving block sample with 20% FG as compared with the control sample. There is no significant increase in the splitting tensile strength of paving block sample in the FG replacement level of 30% as compared with the control sample.

The increases in the compressive strength and flexural strength of the paving blocks are explained by puzzolanic reaction of FG. Finely-ground glass has the appropriate chemical composition to react with alkalis in cement, forming cementitious products, which are known as pozzolanic reactions. A pozzolan is usually a siliceous (SiO_2) material of very fine particle size. It does not by itself act like cement, but with water it reacts with lime or slaked lime to form a hydrated gel called tobermorite. The gel and others like it, bonds the mass together. Glass has a high SiO_2 content making it suitable for use as a puzzolanic material. As the particles are amorphous silica (85% SiO_2) with an extremely high surface area, they react chemically with the calcium hydroxide from the cement to form calcium silicate hydrates (CSH). CSH is the hydration product found in hardened cement paste. Increase of CSH leads to higher strength and a pore-blocking effect with the use of recycled glass as a pozzolan [23]. Byars et. al. [24] also showed the puzzolanic effect of waste glass in concrete.

The FG replacement also reduces the loss of volume on wear of the paving block samples. There is a 15% improvement in the abrasion resistance of the paving block samples with 20% FG replacement. In the Fig.10, there is a strong relationship between the UPV and abrasion resistance in the case of using FG in this study and this relationship was showed by Haktanir [25] earlier. The higher pulse velocities using waste glass are indicative of better quality of paving blocks.

As shown in Fig. 10, the test results show that the replacement of FG by FA at replacement level of 20% has significant effect on the properties of paving block samples studied in this work because of puzzolanic nature of FG. The obtained test results satisfy the relevant standard for paving blocks [20].

In the case of using CG there is no significant improvement in the properties studied of paving block samples as compared to the paving block samples with FG. There are decreases in the splitting tensile strength and abrasion resistance of paving block samples in the replacement level of 30% CG as compared with the control sample.

The increases in the compressive strength of paving block samples in the CG replacement levels of 10%, 20% and 30% are 7%, 23% and 34% as compared with the control sample, respectively (see Fig. 11).

In the CG replacement levels of 10%, 20% and 30% the increases in the flexural strength of paving block samples are 14%, 11% and 15% as compared with the control sample, respectively (see Fig. 11).

In the case of using 10% CG, there is an increase of 11% in the splitting tensile strength of paving block sample, while there are decreases of 3% and 11% in the splitting tensile strength of paving block samples with 20% and 30% CG as compared with the control sample, respectively (see Fig. 11).

The abrasion resistance of the paving block samples is slightly improved in the 10% and 20% CG replacements. In the case of using 30% CG, there is an 18% reduction in the abrasion resistance of the CG-30 sample as compared with the control sample (see Fig. 11).In addition to the pozzolanic reactivity in paving stone with FG, the compaction of samples under 17 MPa pressure in the mould may increase strength of paving blocks.

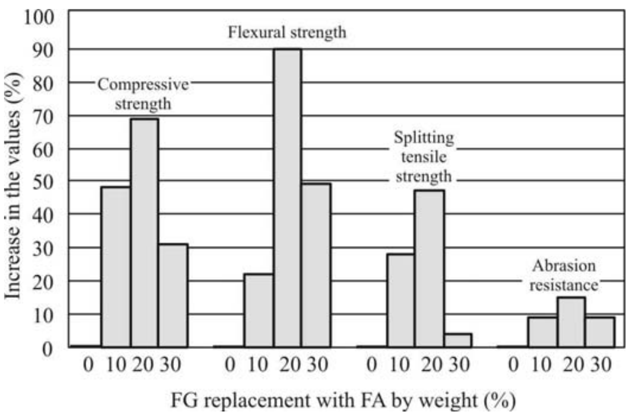


Fig.10 The variation (%) of test results in FG replacement with FA

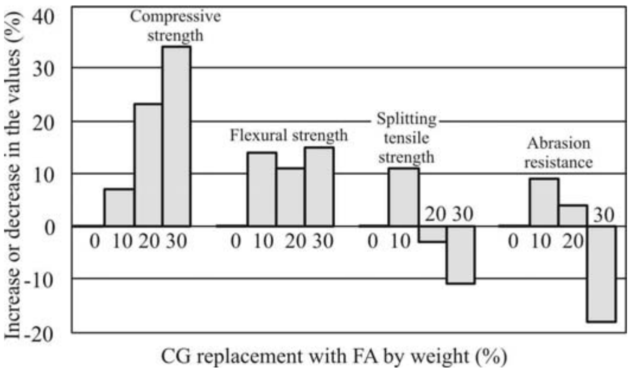


Fig.11 The variation % of test results in CG replacement with FA

V. Conclusion

The feasibility of paving blocks with the FG and CG was showed technically in the present study. Based on the experimental investigation reported in this paper, the following conclusions were drawn:

1) The replacement of FG by fine aggregate (FA) at level of 20% by weight had a significant effect on the some properties of concrete paving block samples as compared with the control sample. The compressive strength, the flexural strength, the splitting tensile strength and abrasion resistance of the paving block samples in the FG replacement level of 20% are 69%, 90%, 47% and 15 % higher as compared with the control sample, respectively.
2) It had been reported in the earlier studies the replacement of FG by fine aggregate (FA) at level of 20% by weight suppressed the ASR in the concrete [12]–[14].
3) The test results showed that the FG at level of 20% had a potential to be used in the production of paving blocks.

It would be valuable to investigate the durability properties of these paving blocks in the future work.

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