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Properties of concrete containing waste glass

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Abstract

In our study, in which waste glass (WG) is considered as coarse aggregates in the concrete, WG was used reduced to 4–16 mm in proportions of 0–60% in the production of PKÇ/B 32.5/R type cement. The effects of WG on workability and strength of the concrete with fresh and hardened concrete tests were analyzed. As a result of the study conducted, WG was determined not to have a significant effect upon the workability of the concrete and only slightly in the reduction of its strength. Waste glass cannot be used as aggregate without taking into account its ASR properties. As for cost analysis, it was determined to lower the cost of concrete productions. Our study was an environmental one in consideration to the fact that WG could be used in the concrete as coarse aggregates without the need for a high cost or rigorous energy.
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Keywords: Concrete; Waste glass; Workability; Strength; Cost

1. Introduction

Glass has been indispensable to man's life due to such properties as pliability to take any shape with ease, bright surface, resistance to abrasion, safety and durability. As utility ranges of the glass increase, so does the amount of the waste glass (WG). United Nations estimates the volume of yearly disposed solid waste to be 200 million tons, 7% of which is made up of glass the world over. For Turkey, this amounts to 120,000 tons, 80,000 tons of which are recycled, with Germany reporting 3 million tons of WG being recycled. Furthermore, unlike other waste products, glass is imperishable and thus detrimental to the environment. Using WG in the concrete has gained far more importance in parallel to environmental consciousness. While using WG in the concrete as aggregate improves some of the concrete properties, it also negatively affects some others. A high amount of WG as aggregate is known to decrease the concrete unit weight. As the amount of the WG added into the concrete increases, compressive strength decreases on the grounds that adherence cannot be achieved fully between the WG and cement paste. Additionally, the toughness of the concrete weakens as the amount of WG increases, while shrinkage decreases as the amount of WG increases due to the fact that it fails to absorb water and therefore prevents a lot of the release of energy during the hydration reaction [1]. Studies into WG have reported an undesirable reaction between WG, in which active silica is present, and Portland cement, which has a high amount of alkali oxide, called alkali–silica reaction (ASR), as a result of which expansion increases to the detriment of the sustainability of the concrete [2,3]. Another related study emphasizes that as the amount of WG increases, so does the air content due to the awkward shape of the WG and poor compactness. Compressive, tensile and flexural strengths all decrease when adhesion is not fully achieved in the concrete containing WG [4]. A study into the application of WG with fly ashes in the concrete pointed out that compressive strength and indirect (Brazilian) tensile strength increase as a result of the combination of both together in the concrete. This combination showed that only a slight change occurred with regards to the dynamic modulus of elasticity, with the modulus remaining largely unaffected. In fact, according to freezing and thawing results, the incorporation of WG and fly ashes into the concrete increases durability of concrete specimens [5]. WG, finer than 38 μm, exhibited a pozzolanic behavior and if the WG can be even finer,

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WG pozzolanic activity can be remarkably improved. The use of ground WG as a high-volume cement replacement in concrete seems feasible [6].

The expansion, which occurred at the end of the alkali silica reaction, of mortar bars are dependent on the color of the glass. For instance, clear soda-lime glass was most reactive, followed by amber glass. Green glass caused more expansion [7]. Coarse WG particles, used as aggregate, produced poor concrete strength, due to WG aggregates extremely poor shape, poor surface characteristics, and high friability [8]. The volume expansion and strength of concretes containing WG particles, caused by ASR, are modeled by Bazant et al. [9].

The purpose of this study is to investigate whether domestic WG could be evaluated in concrete through the recycling process. Fresh and hardened concrete tests were carried out and the results obtained were assessed. Considering the fact that the specific gravity of WG is lower than that of natural aggregates, it would be conceivable to expect WG to lessen concrete unit weight and lower concrete unit cost by evaluating a waste material in concrete. Using WG in concrete is an environmentally friendly process as it is too tough a material for nature to eliminate in an acceptable period of time.

2. Experimental studies

2.1. Materials

2.1.1. Aggregate

The sand used is from the Sakarya River from Osmaneli, Eskişehir and the crushed stone from Sögüt-Zemzemiye, the largest being 32 mm in size. Unit weights of aggregates were sand (S) (0–4 mm) 1713 kg/m^3; crushed stone (CS I) (4–16 mm) 1545 kg/m^3; crushed stone (CS II) (16–32 mm) 1524 kg/m^3 graded according to the ISO 6782:1982. The specific gravity of aggregates was sand (0–4 mm) 2584 kg/m^3; crushed stone (CS I) (4–16 mm) 2714 kg/m^3; crushed stone (CS II) (16–32 mm) 2715 kg/m^3 according to ISO 6783:1982. The grading of aggregate mixtures is presented according to references issued by EN 932-2; DIN 4226.

Table 1
Properties of cement

Chemical analysis (%)		Physical properties	
CaO	47.78	Initial Setting, h-min	3^{50}
SiO_2	30.88	Final Setting, h-min	5^{20}
Al_2O_3	6.75	Spec. Gravity (g/cm^3)	2850
Fe_2O_3	3.57	Fineness (cm^2/g)	3574
MgO	1.30	Compressive strength MPa	
SO_3	1.67	2 days	12.8
Loss on Ignition	6.20	7 days	26.9
Cl	0.011	28 days	42.5

Table 2
Mixture proportions of concrete containing waste glass aggregate

Materials	Waste glass content (%)									
	0		15		30		45		60	
	dm^3	kg	dm^3	kg	dm^3	kg	dm^3	kg	dm^3	kg
C	112	350	112	350	112	350	112	350	112	350
W	190	190	190	190	190	190	190	190	190	190
S (0–4)	255	647	255	647	255	647	255	647	255	647
WG (4–16)	–	–	38	82	76	164	114	246	152	328
CS I (4–16)	208	561	177	478	146	394	115	310	84	225
CS II (16–32)	207	559	207	559	207	559	207	559	207	559

2.1.2. Cement

Cement (C) used here is compose PKÇ/B 32.5R produced at the Cement Mill in Eskişehir. Analysis of the cement used in the study is given in Table 1.

2.1.3. Water

Water used in the concrete was taken from the city of Eskişehir. The properties of the water used in the study were pH 6.3; sulfate content 5.8 mg/lit, hardness 3.9.

2.1.4. Waste glass

Glass forms as a result of solutions containing alkali and soil alkali metal oxides in addition to some other metal oxides. Its essential material is (SiO_2) silica. WG used in the experiments was that of colored soda bottles, which is a type of print silk WG. Following the gathering process, these bottles were kept in water so that the labels on them would be removed, and were then reduced to as fine as 4–16 mm. Unit weight and specific gravity of the WG used in place of natural aggregates as fine as 4–16 mm were 1493 kg/m^3 and 2400 kg/m^3 according to ISO 6782:1982 and ISO 6783:1982, respectively. The chemical combination of the glass was as follows: SiO_2 70–75%; Na_2O 12–18%; K_2O 0–1%; CaO 5–14%; Al_2O_3 0.5–2.5%; and MgO 0–4%.

2.2. Method

Crushed green soda glass was used as a coarse aggregate in concrete. Because of soda glass were used very common and not recycled. WG was used as 0, 15, 30, 45, 60% of the aggregate mixture in place of calcareous crushed stone aggregates, to a fineness of 4–16 mm. Five types of concrete with a 0.54 w–c ratio were produced in such a way that it would have the consistency of plastic with constant dosage 350 kg/m^3. For each type of concrete, 3, and for each tests, 15, cylindrical concrete specimen, sizes $\phi 15 \times 30$ mm, were reserved. The mix proportions of the concrete produced are presented in Table 2. Concrete specimens were cured in lime-saturated water at 22 °C in cure tanks for 28 days. ASR test was done on mortar bar specimens according to ASTM C1260. WG was used as 0–25–50–75–100% of sand and three mortar bar specimens were produced for each mixture proportions. During the test period, every day the expansion of mortar bar specimens was measured with comparator [10].

3. Tests results and discussions

3.1. Discussion of results of fresh concrete tests

The results of the tests, such as unit weight, slump, air content, VeBe and flow table test, performed with fresh concrete produced by using PKÇ/B 32.5R cement and WG of various proportions, are all given in Figs. 1–3. While the unit weight of concrete without WG was 2340 kg/m^3, in consideration to the linear relation between WG addition and unit weight, we observed a decline as much as 0.3% in unit weights. Such a difference was attributed to the fact that the specific gravity of WG is much lower than that of calcareous crushed aggregate produced with general rock. The fact that the test results of Kısacık are in agreement with our results seems to verify the conclusion that the unit weight of concrete without WG is higher than that with WG [1]. As a result of the slump test on the workability of the fresh concrete, the slump value was determined to be 8–10 cm. Using a high proportion of WG was observed to decrease slump value as much as 0.2% due to the fact that WG has a poor geometry, which is also supported by the Kısacık study which found this amount to be 2% [1]. The air content of the concretes produced was 0.4–0.7%, while a high proportion of WG addition unevenly decreased air content as much as 27%. The reason for such a discrepancy was thought to result from the poor geometry of WG, as a result of which water and air voids occur in particularly lower parts. Furthermore, low air content in concrete containing a high proportion of WG was thought to be connected to the smooth surface of WG, which helps decrease porosity between WG and cement paste. Flow table test results revealed that the flow table values of concrete produced was 35–37 cm. WG addition increased workability and flow table values as much as 4% due to fact that WG does not absorb water and that the water layer over the surface of WG is thinner. According to VeBe test results, VeBe values range from 4.5 to 7 s and 60% addition of WG increased VeBe values at a rate of 19%. The poor geometry of WG retards the placing period of fresh concrete when there is a high proportion of WG addition.

3.2. Test results of hardened concrete

Using PKÇ/B 32.5R cement and WG of various proportions after curing for 28 days, produced concrete specimens. The test results for compressive strength, flexural strength and tensile strength after cracking, as well as resonance frequency, ultrasonic velocity and Schmidt hardness are all presented in Figs. 4–7. The compressive strength of concrete specimen with out WG, after being cured for 28 days, was 2.04–23.50 MPa. Compressive strength was observed to decrease, as the proportion of WG in concrete produced increased. In the case of using 15% addition of WG, there was a decrease of 8% in compressive strength, while there was a decrease of 15% in the compressive strength of concrete with 30% of WG. When the proportion of WG was 45%, a decrease of 31% was determined. However, when this proportion increased to 60%, 49% of decrease in compressive strength was determined. The high brittleness of WG leading to cracks was determined to lead to incomplete adhesion between the WG and cement paste interphase. Due to the poor geometry of WG, a homogenous distribution of aggregates could not be achieved. Accordingly, an increase in the amount of WG used in concrete decreased compressive strength. A study by Tuncan et al. [5] reported that the addition of WG (15%) into concrete in crushed forms increased the compressive strength of concrete as much as 13%. In this study, the WG are finely divided and have a pozzolanic activity. So, addition of WG increased the compressive strength of concrete. As for a study by Park et al. [4], 30% of WG addition into concrete

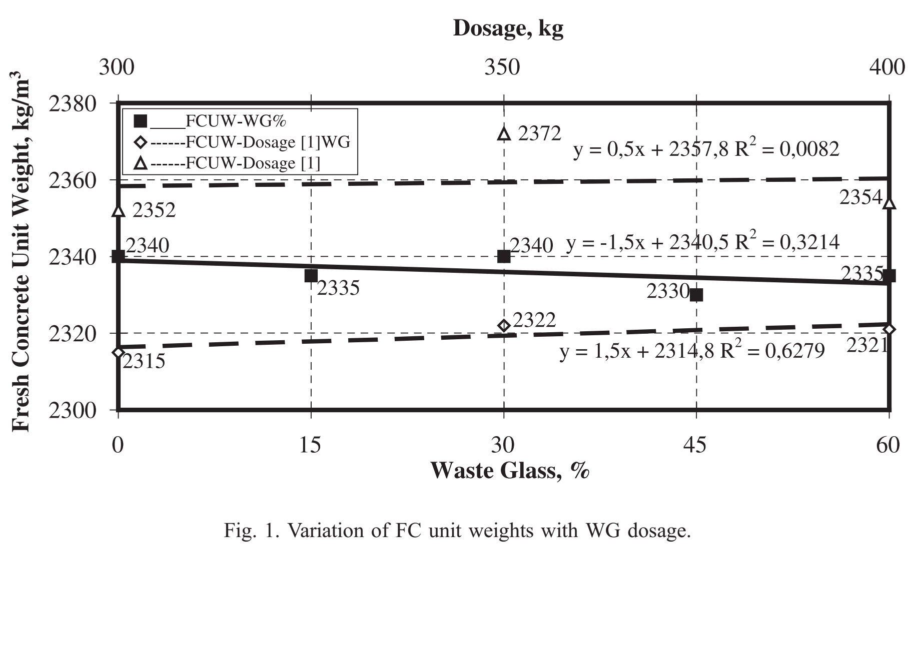

Fig. 1. Variation of FC unit weights with WG dosage.

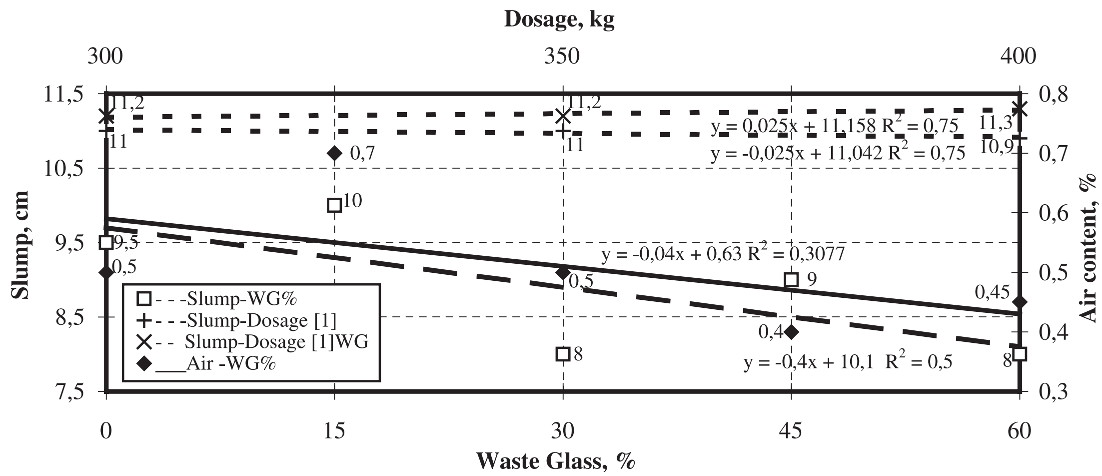

Fig. 2. Variation of slump and air content with WG dosage.

caused a decrease of 4% in compressive strength, which is in agreement with our result. The study by Kısacık [1] reported compressive strength in concrete with out WG increased in accordance with dosage, but when WG was used, compressive strength decreased as much as 19%.

Flexural strength was observed to change inconsistently between 3.00 and 5.27 MPa, and also as the proportion of WG increased this level decreased as much as 2%. Flexural strength was observed to decrease as much as 3% in the case of 15% addition in the study by Park et al. [4], Kısacık's [1] research showed that when WG was used, flexural strength decreased as much as 8%. Tensile (Brazilian) strength test results produced an indirect tensile strength of 1.63–2.59 MPa. WG addition decreased indirect tensile strength as much as 10%. Indirect tensile strength showed a decrease of 37% as a result of 60% of WG addition. Park et al. [4] reported a decrease of 5% in the indirect tensile strength of concrete in the case of 30% addition of WG, while Tuncan et al. [5] reported an increase of 6% in the case of 15% addition of ground WG due to amorphous structure, as fine as cement and easily reacted with hydration product. Kısacık observed a decrease of 2% in the indirect tensile strength of concrete with WG, in comparison with that of normal concrete [1]. Nondestructive tests of concrete containing WG showed that ultrasonic velocity was 3.08–5.02 km/s. The homogenous placing of the concrete failed due to the poor geometry of WG, and as the proportion of WG increased, ultrasonic velocity decreased only inconsistently. When compared with normal concrete specimens, ultrasonic velocity decreased as much as 20% in the case of 60% addition of WG. The resonance frequency test measured resonance frequency of the concrete series produced as 2.83–3.03 kHz. Using WG was observed not to have much effect on concrete resonance frequency and to cause only a slight and inconsistent decrease. The Schmidt hardness of concrete produced was 28–36. As with the compressive strength values of produced concrete specimens, as the proportion of WG increases, the Schmidt hardness values of concrete decrease. Such a

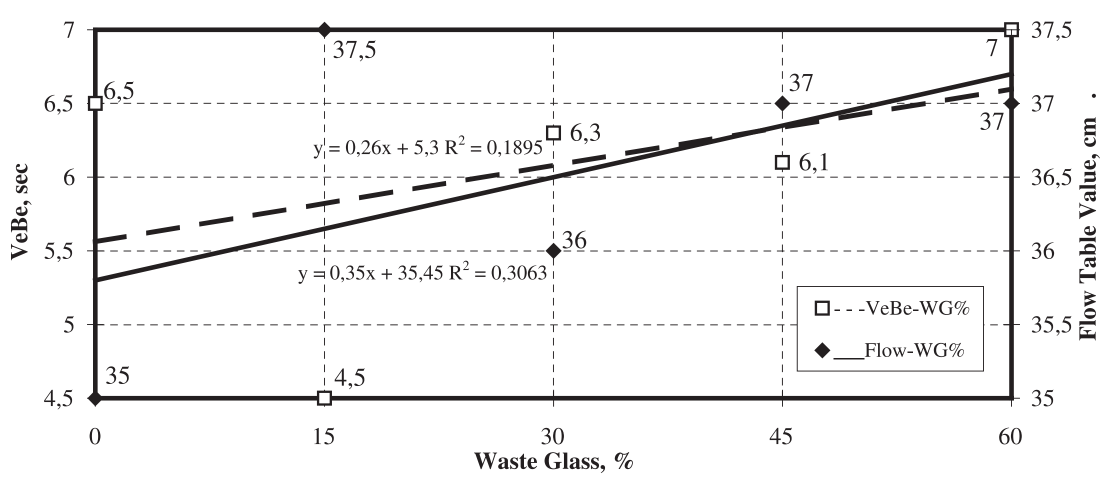

Fig. 3. Variation of VeBe and flow-table tests with WG content.

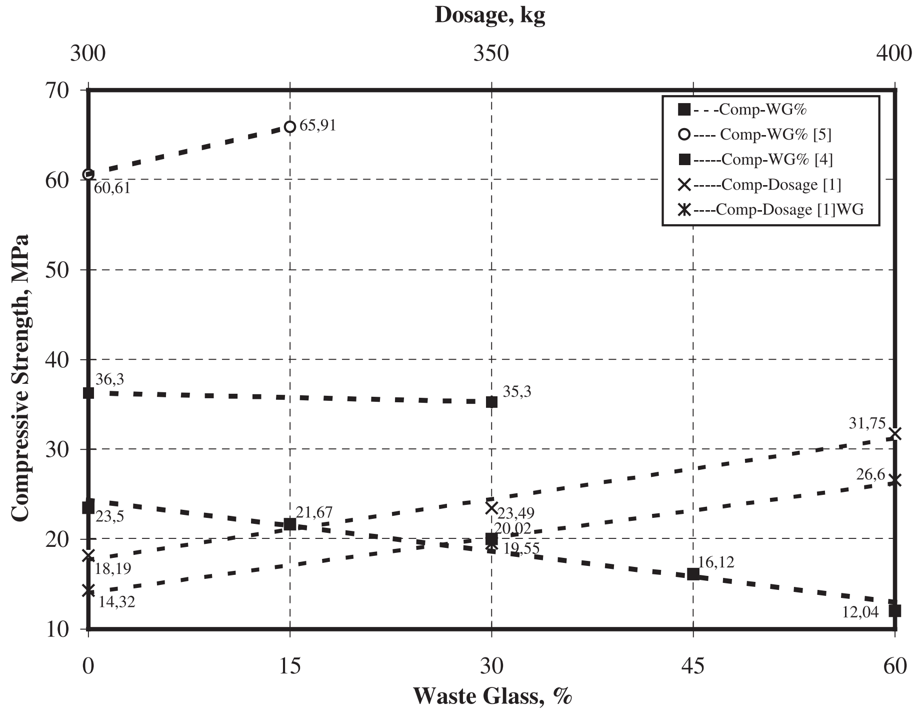

Fig. 4. Variation of compressive strength with WG dosage.

decrease approximates to 20% with 60% of WG addition. In the study by Kısacık [1], in the case of WG addition, there was a decline of 8% of Schmidt hardness in comparison with normal concrete.

The dynamic modulus of elasticity of concrete produced varied between 59.98 and 22.58 GPa. With WG addition into concrete, the dynamic modulus of elasticity was observed to decrease. When the amount of WG addition was 60%, the dynamic modulus of elasticity of normal concrete decreased as much as 39%. Tuncan et al.'s [5] dynamic modulus of elasticity increased as much as 10% with 15% of ground WG addition, because of finely divided WG effect to

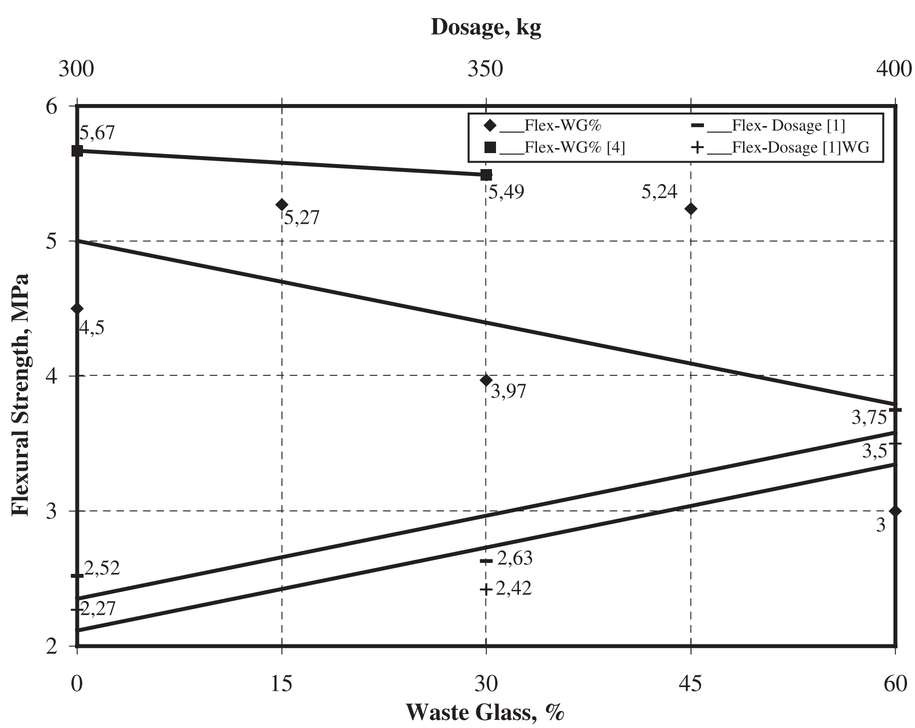

Fig. 5. Variation of flexural strength with WG dosage.

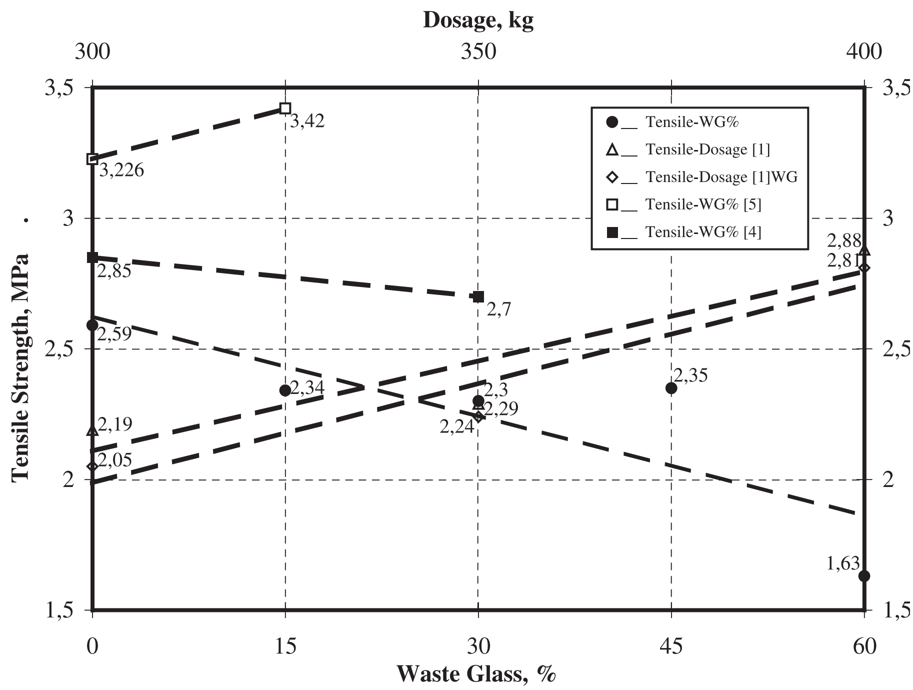

Fig. 6. Variation of tensile strength with WG dosage.

bond properties positively. In the study by Kısacık [1], the dynamic modulus of elasticity increased as much as 36% as the dosage increased, and the dynamic modulus of elasticity of concrete with WG increased as much as 6% with dosages of 300–400 in comparison with normal concrete.

ASR test results were shown in Fig. 8. Expansion of the mortar bar specimen, included 100% WG, more than 0.2% before 3 days. When the WG content was 0%, expansions were more than 0.2% after 4 days. For this reason, alkali–silica reactions slow down with decreasing WG content. ASR occurred on mortar bars with 0% WG due to very effective curing conditions [10]. The color of the waste glass fine aggregate did not have any significant affect on the compressive, tensile and flexural strength [4]. After 9 days

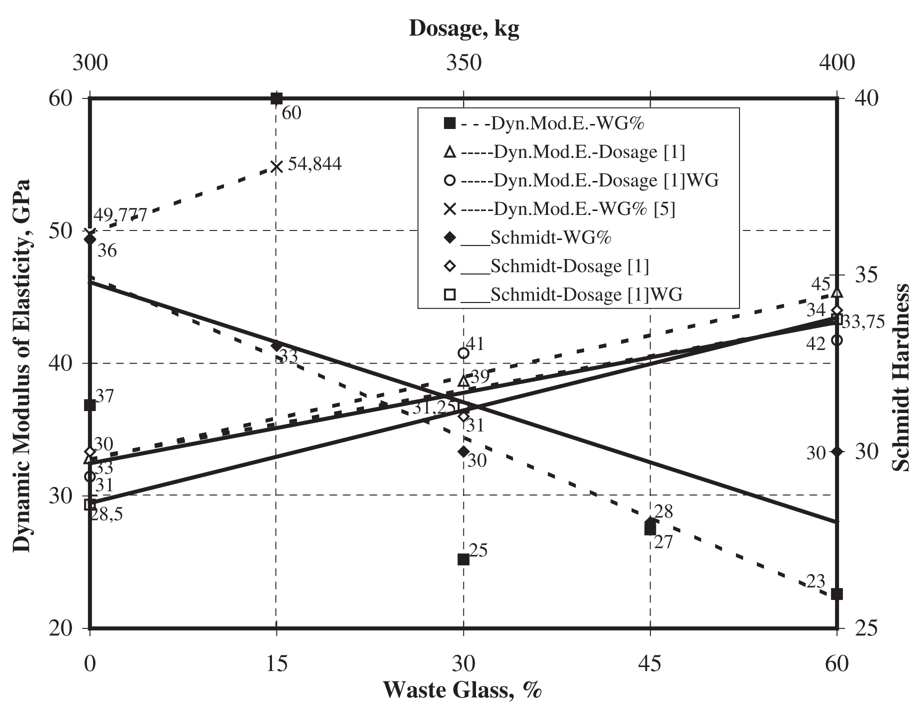

Fig. 7. Variation of tests results with WG dosage.

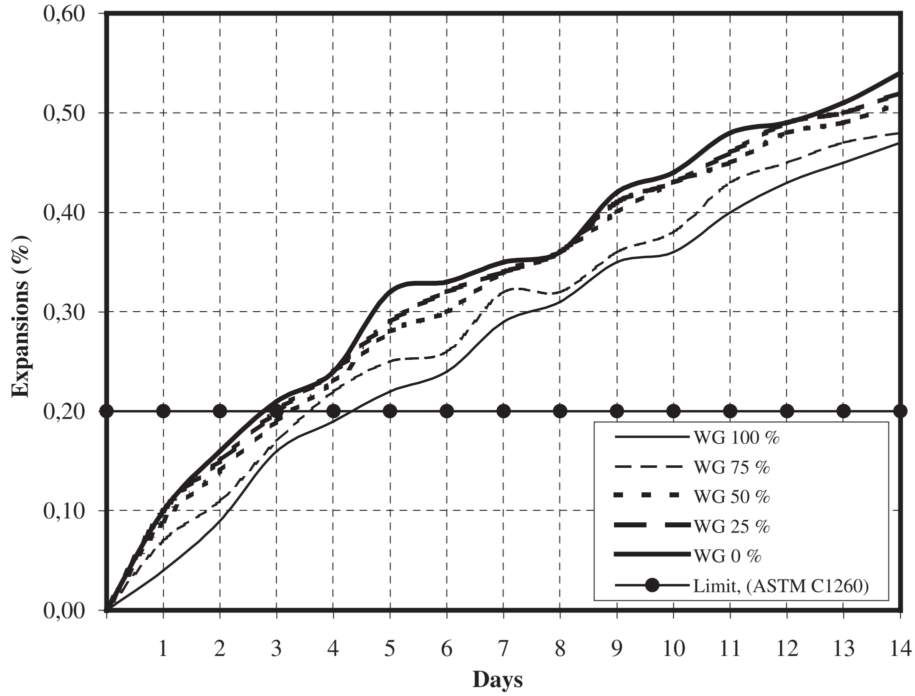

Fig. 8. Effect of ASR on WG mortar bars [10].

of experiment, it is seen that white glass causes more dilatation than green and brown glass and ASR limit value exceed [11,12].

3.3. Cost analysis

For the purpose of analysis of concrete produced, in consideration of unit weight cost issued by Ministry of Public Works in 2002, we calculated the cost of materials used in concrete as follows: compose cement 32.5 \$/ton; sand 3.8 \$/m^3; crushed stone 3.9 \$/m^3; water 0.5 \$/m^3; and WG 1.9 \$/m^3. The total cost was determined to change between 18.1 and 17.6 \$/m^3. The cost of concrete with 60% of WG addition was determined to be lower than that of normal concrete (2.8%).

4. Conclusions

As was already anticipated, using WG as aggregate did not have a marked effect on the workability of concrete. While WG addition decreased the slump, air content and fresh unit weight, it increased flowing and VeBe values. When hardened concrete specimen properties were analyzed, compressive, flexural and indirect tensile strengths as well as Schmidt hardness values were determined to decrease in proportion to an increase in WG. In particular, the compressive strength decreased as much as 49% with a 60% of WG addition. We conclude that using WG in preference to fine aggregate would produce better results assuming that its geometry be more proper and almost spherical. Besides this, provided that WG is ground finely due to the fact that WG contains a high amount of silica (SiO_2) and is amorphous, it will show a pozzolanic activity, in which case alkali silica reactivity should be taken into account. Waste glass cannot be used as aggregate without taking into account its ASR properties. In conclusion, if C20 quality concrete containing WG is sought, 23% of WG addition is necessary. This would be possible if slump was 9.1 cm, with the flow-table value 36.35 cm, VeBe value 5.96 s. and air content 0.53%. The predicted unit weight would be 2336 kg/m^3. Other strength properties of C20 quality concrete would be as follows: indirect tensile strength 2.4 MPa, flexural strength 4.5 MPa, Schmidt hardness 32.2, resonance frequency 2.96 kHz, ultrasonic velocity 5.96 km/s and dynamic modulus of elasticity 37.2 GPa. The cost of such concrete would accrue to 17.9 \$/m^3, in which case it would be 1% more economical than normal concrete.

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