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Properties of Concrete with Crumb Rubber Replacing Fine Aggregates (Sand)

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ABSTRACT:
In this paper, crumb rubber is proposed as a possible lightweight replacement for fine aggre- gate in concrete. The performance of concrete with crumb rubber is analyzed through comparison to conven- tional concrete in terms of compressive strength (ASTM C39), tensile strength (ASTM C78 and ASTM C496), failure patterns, energy absorption during loading, and workability. The results show that up to 15 % of fine aggregates can be replaced with an equal volume of crumb rubber with a slight improvement of the concrete workability. The crumb rubber improves the compressive strength by over 5 %. The splitting tensile strength decreases with an increase in the quantity of crumb rubber, and the modulus of rupture is decreased by an average of 12 %. However, increased strain at failure, good energy absorption, improved modulus of toughness, and ductility are observed in rubberized concrete. Typical concrete brittle failure is not observed in rubberized concrete.

KEYWORDS: sustainable concrete, crumb rubber, strength of concrete, toughness of concrete, ductility of concrete

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I. INTRODUCTION

A significant number of used tires are discarded each year after their natural lifetime of use [1–3]. A number of approaches have been explored to recycle used tires [1–3]. In several instances, tire-derived aggregates, which are typically large aggregates, have been used as raw materials for civil engineering projects [3]. However, a significant fraction of used tires still find their way into land-fills, resulting in a public health and environmental hazard [2]. Landfill facilities require tires to be shredded in order to minimize the extent of floating tires; the cost of shredding is dependent on the final particle size of the rubber, with finer particles being more expensive [4].

A number of studies have been conducted exploring the use of tire-derived particles as a substi- tute for either coarse or fine aggregates, with varying degrees of success [5–15]. In this study, crumb rubber was used as a replacement for part of the fine aggregate (sand) in a concrete mix. The performance of the concrete with crumb rubber is compared to that of conventional concrete in terms of the compressive strength, tensile strength, failure patterns, energy absorption during loading to failure, and workability.

Research Significance

In this study, crumb rubber has been used to partially replace fine aggregate in concrete. This was a comprehensive study in which additives such as silica fume, crumb rubber, and tire-derived aggre- gates were added to concrete and properties such as the compressive strength, flexure strength, workability, and splitting tensile strength were examined. This study has shown that it is possible to develop concrete with compressive strength that is nearly the same as or better than that of tra- ditional concrete and at the same time increase the ductility of the concrete while using crumb rub- ber in place of fine aggregates. The mechanical properties and fracture characteristics of the crumb rubber concrete are compared with those of traditional concrete. More studies on the performance of this rubberized concrete at high and freezing temperatures and in high alkaline and acidic condi- tions needs to be done. For now, its use should be limited to structures exposed to normal ambient conditions.

Experimental Procedures

The particle size distribution of crumb rubber is compared to that of fine aggregate in Fig. 1.

The curve shows the percentage of crumb rubber retained on each individual sieve. The crumb rubber was sourced from TBJ, where used tires are ground utilizing ambient systems. No surface treatment was applied to the crumb rubber before it was incorporated into the concrete. The concrete proportioning was done following the absolute volume method as described by the Portland Cement Association [16]. A 28-day compressive strength of over 4500 psi (31 MPa) was targeted, and the Portland cement content was based upon a water/cement (w/c) ratio of between 0.55 and 0.60. Once an optimum mix was found, this became the control concrete (0 % crumb).

In order to incorporate crumb rubber into the mix, a specific amount by weight of fine aggregate was removed and replaced with an equal volume of crumb rubber, keeping all other factors con- stant. Two different quantities of fine aggregate were replaced (i.e., 7.5 % and 15 %). For example, if the total weight of fine aggregates required was *X* lb in the control batch, 7.5 % of *X* lb was taken

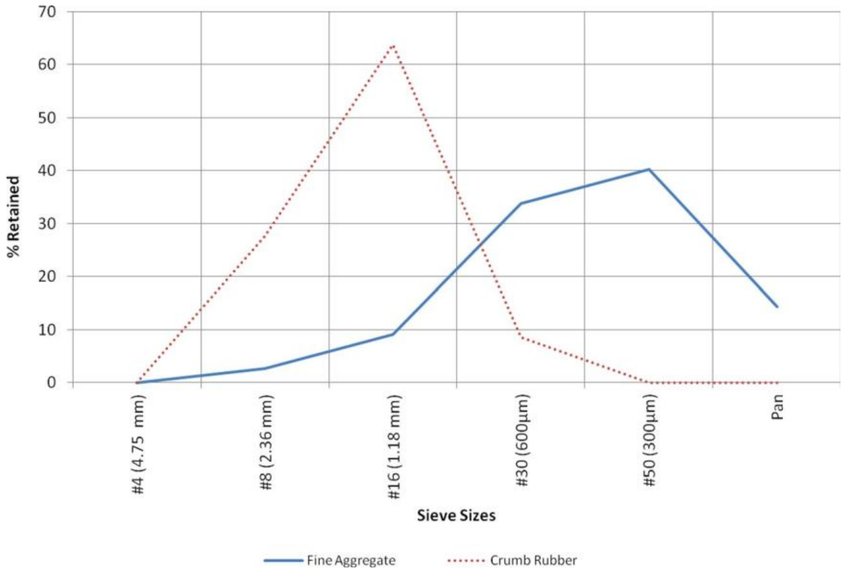

FIG. 1—*Particle size distribution for fine aggregate and crumb rubber.*

TABLE 1—*Mix compositions for various batches per cubic yard.*

Description of Type of Concrete	Control	7.5%Fine Aggregate Replaced With Crumb Rubber	15%Fine Aggregate Replaced With Crumb Rubber	Control With Addition of Silica Fume	7.5% Fine Aggregate Replaced With Crumb Rubber With Addition of Silica Fume	7.5% Fine Aggregate Replaced With Crumb Rubber and 7.5% Coarse Aggregate Replaced With Tire-Derived Aggregate
Designation	0% Crumb	7.5% Crumb	15% Crumb	0% Crumb-SF	7.5% Crumb-SF	7.5% Crumb þ 7.5%TDA
Cement, lb	470	470	470	470	470	470
Silica fume, lb				59	57	
Coarse aggregate, lb	2000	2000	2000	2000	2000	1850
Fine aggregate, lb	1317	1218	1119	1317	1218	1218
Water, lb	260	260	260	315	314	260
Crumb rubber, lb		41	70		42	36
TDA, lb						55
Total, lb	4047	3989	3919	4138	4079	3802
Water/cementitious material ratio	0.55	0.55	0.55	0.60	0.60	0.55
Slump, in. (mm)	1 (25.4)	1.5 (38.1)	1.25 (31.2)	2 (50.4)	3 (76.2)	1.5 (38.1)

out and replaced by crumb rubber equal in volume to the fine aggregate replaced (0.075*X* lb). This crumb rubber (equal in volume to the fine aggregates replaced) was then weighed and put back into the batch to replace the fine aggregate to make the 7.5 % crumb. This method was preferred because of variations in the crumb rubber's specific gravity depending on how compacted it was. In order to further improve concrete properties, silica fume was added to some batches. The actual batch compositions in terms of weight and batch designations are shown in Table 1. The batches were prepared and cured as per ASTM C192 [17].

Before the rotation of the drum was started, the mixer was charged with the coarse aggregates and about one quarter of the mixing water. Then the mixer was started and fine aggregate, crumb rubber, cement, and required mixing water were added in that order. The mixer was then operated for 5 min after all of the ingredients had been added, followed by a brief rest period to confirm that the mixture was workable, and then additional mixing for another 2 min. At the completion of the mixing, the concrete was deposited in a wheel barrow and a slump test was carried out following ASTM C143 [18].

We used 6 in. by 12 in. (150 mm by 300 mm) cylinders and 20 in. by 6 in. by 6 in. (510 mm by 150 mm by 150 mm) rigid steel forms. The cylinders were filled with three lifts of freshly mixed concrete, with each lift tamped 25 times with a tamping rod and tapped lightly with a mallet 10 to 15 times. The excess concrete was struck off, and the remainder was finished to a smooth surface with a trowel. The cylinders were used to test for compressive strength based on ASTM C39 [19] and splitting tensile strength following ASTM C496 [20]. The 20 in. by 6 in. by 6 in. (510 mm by 150 mm by 150 mm) concrete beams were used to test for flexural strength following ASTM C78 [21].

The molded cylinders were cured at 80°F (26°C) and 95 % to 100 % relative humidity. One set of three cylinders or beams was tested after 7 days, and another set of three after 28 days. During the ASTM C39 test, the applied load was measured using a load cell and the displacement was measured using two linear variable differential transducers (LVDTs), all of which were connected to a computer system. The computer system included a Vishay Scanner, Model 5100B, and a lap- top computer with Strainsmart5000 software. The two LVDTs were attached on a tailored cylinder that was screwed to the body of the concrete cylinder to measure the displacement of the concrete directly as shown in Fig. 2. The LVDTs used were Omega LD621-5 models with a range of 0 to 10 mm (0 to 0.4 in.). The data collected were the load (in pounds) from the load cell and the dis- placement (in inches) from each LVDT. In all the calculations, the average displacement from the two LVDTs was used. The compressive test was done using either a 500 kip (2.2 MN) compression machine or 400 kip (1.8 MN) tensile/compression machine.

The splitting tensile test followed ASTM C496, and flexural strength testing followed ASTM C78. Both the applied load and the displacement of the testing machine head were recorded directly by the testing machine software. A 60 kip (0.27 MN) tensile/compression machine was used for both the splitting tensile test (ASTM C496) and the flexural strength test (ASTM C78).

II. RESULTS AND DISCUSSION

Workability

The workability of freshly mixed concrete was evaluated through slump measurements as outlined in ASTM C143 [18]. Table 1 shows the results of slump measurements for the different batches that were prepared at the same w/c ratio. For the batches that contained silica fume, the silica fume was considered a cementitious material and was included in calculations of the total water requirement.

The results show that the crumb rubber improved concrete workability slightly; the slump recorded was higher by between 0.25 in. and 0.5 in. than that of the control concrete (0 % crumb). Khaloo et al. [5] also report that fresh rubberized concrete exhibits a lower unit weight and accepta- ble workability relative to plain concrete when rubber particles that leave a sieve residue on mesh 60 (0.25 mm) of 80 % are used to replace 12.5 %, 25 %, 37.5 %, and 50 % of the total mineral aggre- gate volume in concrete.

The slump test is considered to be a measure of the shear resistance of concrete to flowing under its own weight. Therefore, the amount of mechanical work or energy required to produce full

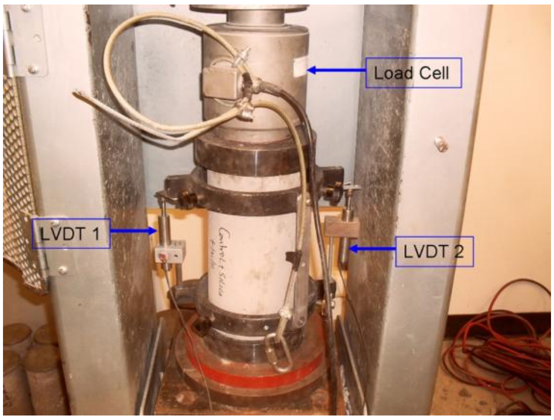

FIG. 2—*ASTM C39 compressive strength test setup.*

TABLE 2—*Compression test results for the various concretes at 7 and 28 days.*

	0% Crumb, psi (MPa)	7.5% Crumb, psi (MPa)	15% Crumb, psi (MPa)	0% Crumb-SF, psi (MPa)	7.5% Crumb-SF, psi (MPa)	7.5% Crumb þ 7.5% TDA, psi (MPa)
7-day average strength	4018 (27.7)	4184 (28.8)	4129 (28.5)	4672 (32.2)	4883 (33.7)	3200
28-day average strength	4613 (31.8)	4890 (33.7)	4615 (31.8)	5096 (35.1)	5530 (38.1)	4108

Note: SF, silica fume; TDA, tire-derived aggregate.

compaction of concrete containing crumb rubber without segregation would be less than that required for the control concrete. It also implies that concrete with crumb rubber would be more consistent and easier to flow, pump, and compact when shaping the fresh concrete into desired shapes during construction.

CompressiveStrength

Average compressive strength test results for the 6 in. by 12 in. (150 mm by 300 mm) concrete cyl- inders based on ASTM C39 are shown in Table 2. Figure 3 shows the variability of the compressive strength within specimens of the same batch and comparisons between different batches.

The results in Table 2 indicate that up to 15 % of fine aggregates can be replaced with an equal volume of crumb rubber in a concrete mix without affecting the compressive strength of the con- crete. The addition of silica fume to the control concrete improved the compressive strength by 16

% at 7 days and 10 % at 28 days. However, the addition of both silica fume and crumb rubber improved the concrete strength by 22 % at 7 days and 20 % at 28 days. When the amount of silica fume was kept constant, the crumb rubber improved the strength by 5 % at 7 days and 9 % at 28 days.

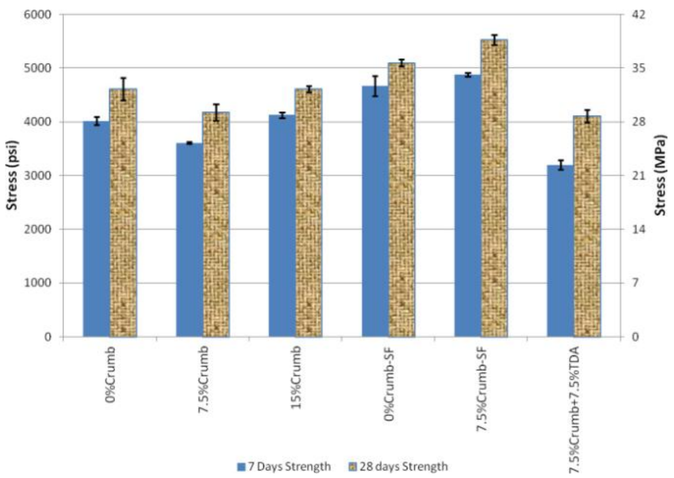

FIG. 3—*Compressive strengths of different concretes based on the batch. SF, silica fume; TDA, tire-derived aggregate; crumb, crumb rubber.*

FIG. 4—*Fracture of control concrete and concrete with 7.5% fine aggregate replaced with crumb rubber. From the figure, it can be seen that the concrete with crumb rubber did not have cracks running through it.*

The increase in compressive strength in concrete with crumb rubber is thought to be due to bet- ter stress dissipation within the concrete leading to better damage tolerance, as seen in Fig. 4. The concrete containing crumb rubber did not have excessive cracks running through it. Figure 5 shows the distribution of crumb rubber in the concrete.

In conclusion, crumb rubber can be used as a light aggregate substitute for the fine aggregates in concrete. Up to 15 % of the fine aggregate can be replaced by crumb rubber without any loss in strength, and the resulting concrete will have better damage tolerance properties, as shown in Figs. 6 and 7. Topçu and Demir [6], in their study of concrete specimens with 0 %, 10 %, 20 %, and 30 % rubber aggregate by volume and a grain size of 1 to 4 mm, concluded that in regions where the environmental conditions are not harsh, the use of concrete produced with 10 % rubber aggre- gate is appropriate, as it is economical and an effective way of recycling discarded tires.

However, Khaloo et al. [5] reported reductions in the strength and tangential modulus of elastic- ity when they used rubber particles with a sieve residue on mesh 60 (0.25 mm) of 80 % to replace

12.5 %, 25 %, 37.5 %, and 50 % of the total mineral aggregate volume in concrete in a uniaxial com- pressive strain control test conducted on hardened concrete specimens. Ghaly and Cahill [7] also reported that the addition of crumb rubber to concrete results in reduced strength relative to that of conventional concrete, and that the compressive stress of the concrete decreased with increasing

FIG. 5—*Distribution of crumb rubber in the concrete. The black spots represent crumb rubber.*

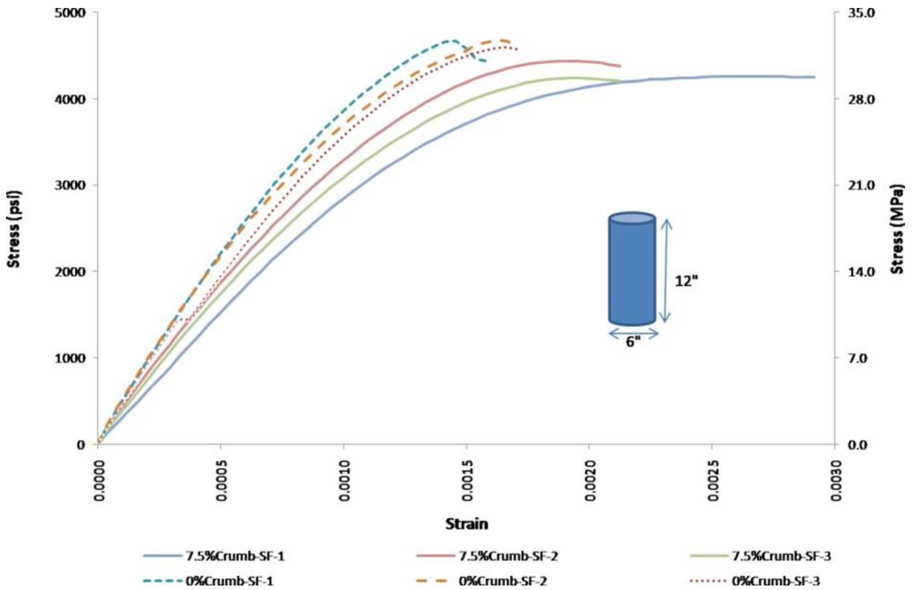

FIG. 6—*Stress versus strain comparison for concrete with 7.5% crumb with silica fume (SF) and control with SF.*

rubber content in the mix. In their study, Ghaly and Cahill tested small cubes of concrete (50.8 mm [2 in.] in dimension) in which the coarse aggregate size did not exceed 9.5 mm (0.3 in.), and they added crumb rubber with a size between 1 mm (0.04 in.) and 2 mm (0.08 in.) in quantities of 5 %, 10 %, and 15 % by volume of the mixture as a replacement for a portion of fine aggregate (sand). Finally, Güneyisi et al. [8] also reported test results indicating that there is a large reduction in the strength and modulus values with increasing rubber content, and that the addition of silica fume

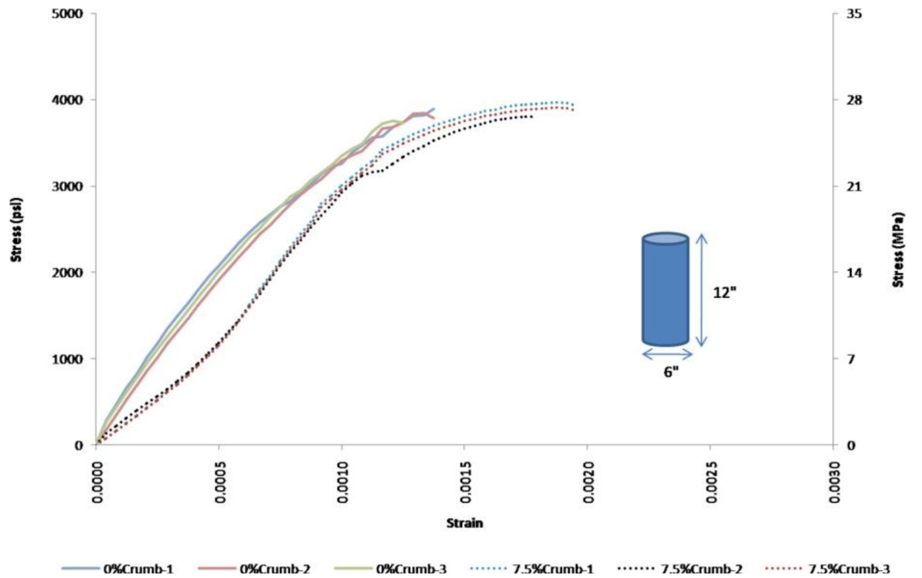

FIG. 7—*Stress versus strain comparison for control concrete (0%Crumb) and concrete with 7.5% of the fine aggregate replaced by crumb rubber (7.5%Crumb).*

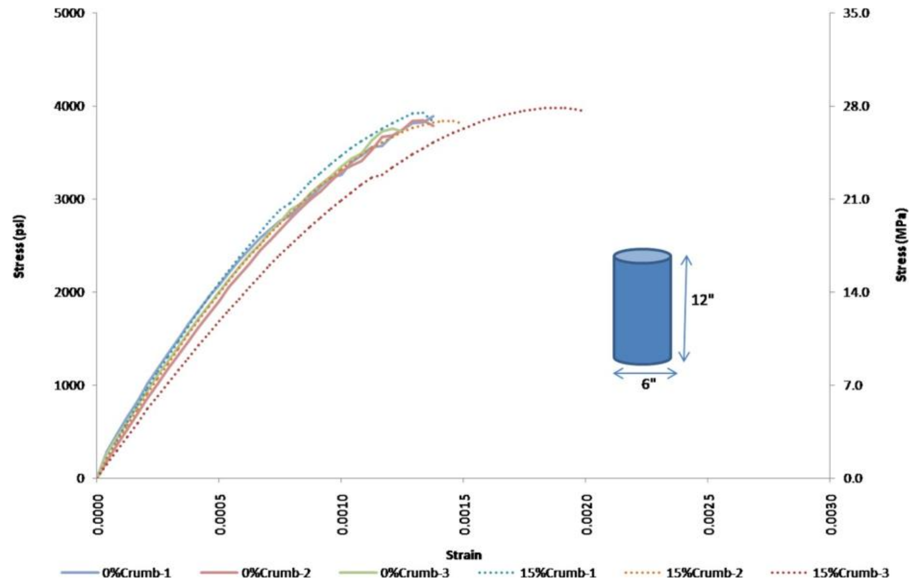

FIG. 8—*Stress versus strain comparison for control concrete (0%Crumb) and concrete with 15% of the fine aggregate replaced by crumb rubber (15%Crumb).*

into the matrix improves the mechanical properties of rubberized concretes and diminishes the rate of strength loss.

Concrete Ductility

Ductility is a measure of the amount of inelastic strain that can occur before the failure of a mate- rial. Ductility can be quantified by the fracture strain, which is the engineering strain at which a test specimen fractures. Typically, under compression, concrete appears to show an inelastic strain at fracture on the order of 2×10^{-3} [22]. Figure 6 is a comparison of the stress–strain curves for control concrete (0 % crumb-silica fume [SF]) and concrete with 7.5 % of the fine aggregate replaced with crumb rubber (7.5 % crumb-SF). Figure 7 compares control concrete (0 % crumb) and concrete with 7.5 % of the fine aggregate replaced with crumb rubber (15 % crumb), and Fig. 8 compares control concrete (0 % crumb) and concrete with 15 % of the fine aggregate replaced with crumb rubber (15 % crumb).

The control concrete had an average strain of 0.0015 at failure, whereas the concrete with 7.5 % replacement of fine aggregate by crumb rubber had an average strain of 0.0020 at failure. The ulti- mate failure stress for both concretes (control concrete and concrete with crumb rubber) did not vary by more than 5 %. Adding crumb rubber to the concrete mixture would increase the strain at failure by about 33 %, with a negligible loss of compressive strength. As strain is a measure of mate- rial deformation, this shows that the concrete with crumb rubber would experience more deforma- tion before the concrete failed. However, the deformation decreased with an increasing quantity of crumb rubber used. At 15 % replacement, the control concrete and crumb rubber concrete strains were approximately equal.

The plots for crumb rubber concrete in Figs. 6 and 7 exhibit good energy absorption and ductil- ity, as the concrete does not experience the typical brittle failure and instead undergoes a ductile, plastic failure mode. As seen in Fig. 4, the concrete containing crumb rubber did not have excessive cracks running through it. The absence of cracks running through the concrete explains the increased damage tolerance observed in the stress–strain curves for concrete with crumb rubber in Figs. 6 and 7. Khaloo et al. [5] also reported a significant decrease in the brittle behavior of concrete with increasing rubber content (rubber particles with a sieve residue on mesh 60 [0.25 mm] of 80%), and unlike in plain concrete, the failure state in rubberized concrete occurs gently and uni- formly and does not cause any separation in the specimen. Yang et al. [9], who added crumb rub- ber into reinforced concrete (RC), also found out that the stress–strain relationship of the concrete was changed. They found improved sectional ductility of the RC beam, and the ductility of the crumb rubber concrete beam was significantly improved.

Concrete Toughness

Toughness is a measure of the amount of strain energy required in order to break a material, and it is represented by the area under the curve of the stress–strain plot. The area under the stress–strain curve up to a given value of strain is the total mechanical energy per unit volume consumed by the material in straining it to that value. The calculated average of the area under the curves up to frac- ture in Figs. 6, 7, and 8 is summarized in Table 3, and this is termed the modulus of toughness, with units of pressure (psi or N/m^2) or strain energy per unit volume (Nm/m^3).

At 7.5 % replacement, crumb rubber improved the modulus of toughness by 54 %, whereas at 15 % the modulus of toughness for crumb rubber concrete was 15 % greater than that of the con- trol concrete. Therefore, the addition of crumb rubber into concrete can improve concrete tough- ness. The high moduli of toughness exhibited by crumb rubber concrete signifies that the concrete would show good impact resistance.

Modulus of Elasticity

The modulus of elasticity is the ratio between the stress and the reversible strain. It is a measure of $_3$the stiffness$_6$ of a component. The elastic modulus of concrete in compression varies from 14 × 10^3 to 40 × 10 MPa (2 × 10 to 6 × 10 psi) [22]. The significance of the elastic limit in structural design lies in the fact that it represents the maximum allowable stress before the material undergoes permanent deformation. The elastic modulus of the material influences the rigidity of the design.

In this study, the slope of a line drawn between two points on the stress–strain (*r*-*e*) curve was calculated. The slope is Young's modulus (modulus of elasticity). The modulus obtained via this method is also referred to as the chord modulus. The base was shifted from the origin to correct the slight concavity observed at the beginning of the *r*-*e* curve up to about 40 % of the stress at failure.

Table 3 summarizes the computed results for the elastic modulus. It is shown that at 15 % crumb rubber replacement, the concrete with crumb rubber had a modulus of elasticity that was 11

% higher than that of the control. However, when we compare the two concretes with SF, we see that the crumb-rubber-modified concrete had an elastic modulus that was 34 % less than that of

TABLE 3—*Modulus of toughness and modulus of elasticity for different types of concrete.*

	0% Crumb-SF, psi (MPa)	7.5% Crumb-SF, psi (MPa)	0% Crumb, psi (MPa)	7.5% Crumb, psi (MPa)	15% Crumb, psi (MPa)
Modulus of toughness	210 (1.45)	323 (2.23)	110 (0.76)	173 (1.19)	126 (0.87)
Modulus of elasticity	3 665 000 (25 269)	2 410 000 (16 616)	3 245 000 (22 373)	2 897 000 (19 975)	3 610 000 (24 890)

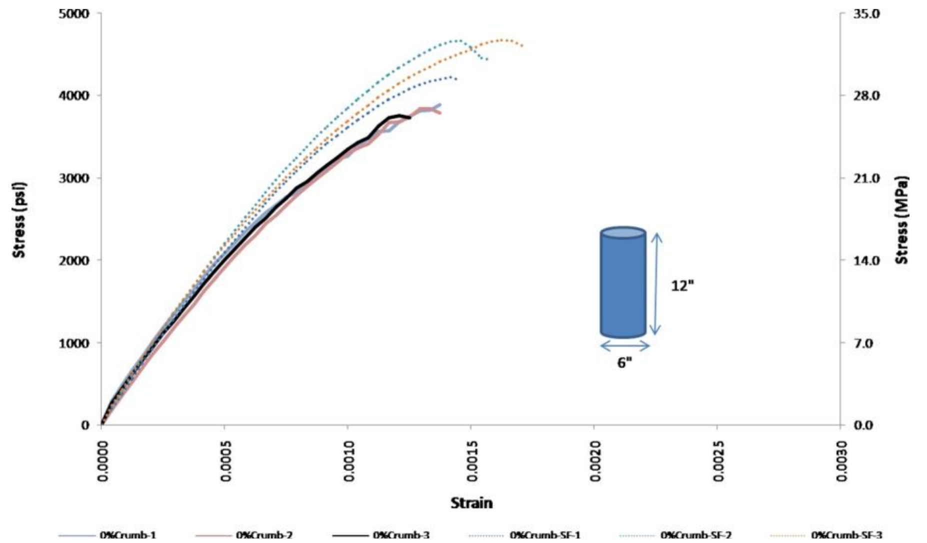

FIG. 9—*Stress–strain curves showing the effect of silica fume in concrete. Note the increase in compressive strength and the shift in the slope (modulus of elasticity).*

the control that also contained SF. SF has been shown to increase compressive strength (Table 2), and as seen in Fig. 9, it also increased the modulus of elasticity.

Splitting Tensile Strength of Cylindrical Concrete

The splitting tensile test is an indirect evaluation of the direct tensile strength of concrete. Table 4 is a summary of the splitting tensile strength results for concrete with different quantities of crumb rubber. It can be seen that the splitting tensile strength decreased with an increase in the quantity of crumb rubber used. However, the standard by which all concrete strengths are compared is the 28-day design compressive strength f'_c for the identical mix, cured under the identical conditions and at the same age; therefore, the percent splitting strength is compared to the 28-day f'_c. The con- trol batch developed an average of 8.1 % of f'_c, whereas both batches with crumb rubber developed splitting strength equivalent to 6.7 % of f'_c. The values of f'_c are shown in Table 2.

Figure 10 shows the stress-displacement plot for the control concrete (without crumb rubber) and one that had 7.5 % of fine aggregate replaced with crumb rubber. Both batches contained SF. It can be seen that the maximum displacements for the two concretes were almost equal. However, the concrete with crumb rubber showed more uniformity during loading, as can be seen from the plot of stress-displacement.

Flexural Strength (Modulus of Rupture) of a Concrete Beam

Table 5 summarizes the results for four-point loading of a concrete beam (ASTM C78) at 7 and 28 days after casting. Flexural strength is expressed in terms of the modulus of rupture, which is the

TABLE 4—*Splitting tensile strength of different types of concrete with varying amounts of crumb rubber.*

	Peak Splitting Tensile Strength		
	0% Crumb, psi (MPa)	7.5% Crumb, psi (MPa)	15% Crumb, psi (MPa)
Average tensile strength at 28 days	415 (3.1)	370 (2.5)	309 (2.1)

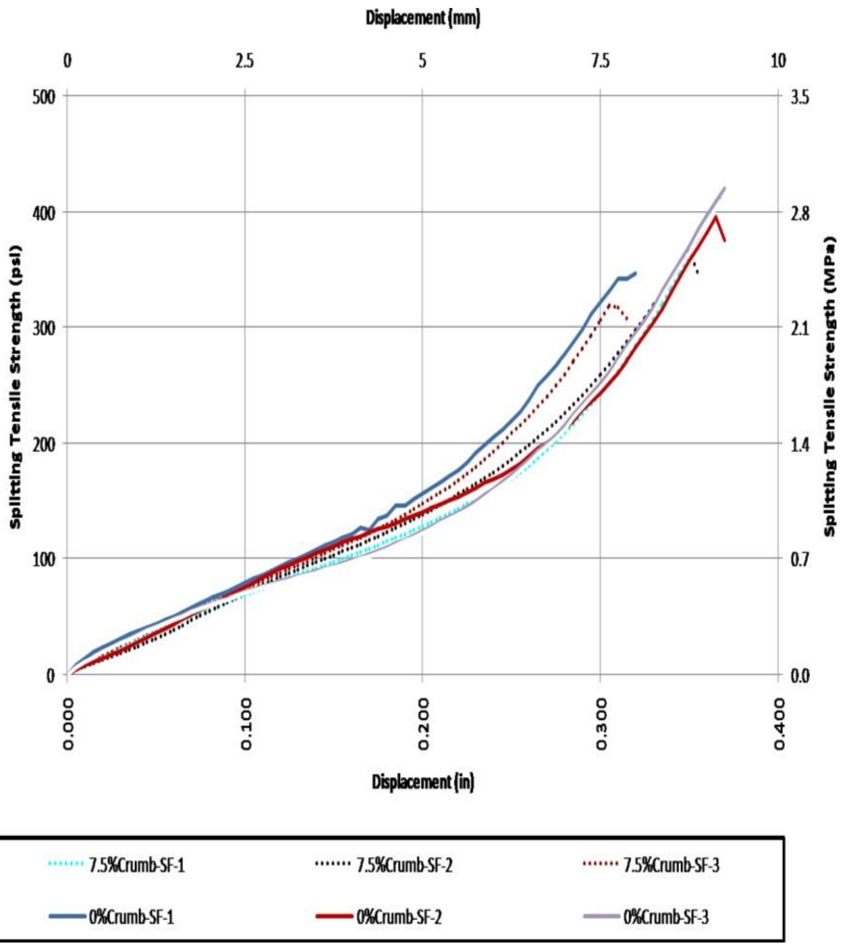

FIG. 10—*Splitting tensile strength versus displacement comparison between control concrete and concrete with 7.5% of the fine aggregate replaced by crumb rubber.*

maximum stress at rupture. The addition of SF was found to increase the compressive strength by 16 % at 7 days and 10 % at 28 days. However, it was found, as shown in Table 5, that it had a nega- tive effect on the flexural strength. A drop in flexural strength by 12 % and 17 % at 7 days and 28 days, respectively, was noticed with the addition of SF. The addition of crumb rubber to the con- crete also lowered the modulus of rupture by an average of 12 %.

One relationship that has been developed by the American Concrete Institute (ACI) to relate flexural and compressive strength is

$$f_r' \text{ ¼ } a\sqrt{f_c'}$$

where:
a ¼ 7.5 for a typical concrete,
f_r' ¼ flexural strength, and
f_c' ¼ compressive strength.

From experimental data, the flexural strength and compressive strength information has been
collected and used to calculate the proportionality factor a in the ACI equation above for various types of concrete. The results for the factor a are shown in Fig. 11. It can be concluded that for dif- ferent concretes, if the flexural strength is between 500 and 650 psi, the factor a will range from 7 to 10.

TABLE 5—*Flexural strength (modulus of rupture) for various types of concretes.*

	Modulus of Rupture, psi (MPa)				
	0% Crumb	0% Crumb-SF	7.5% Crumb	7.5% Crumb-SF	15% Crumb
7 Days	624 (4.31)	549 (3.79)	557 (3.84)	517 (3.57)	545 (3.76)
28 Days	717 (4.94)	595 (4.10)	640 (4.41)	610 (4.21)	614 (4.24)

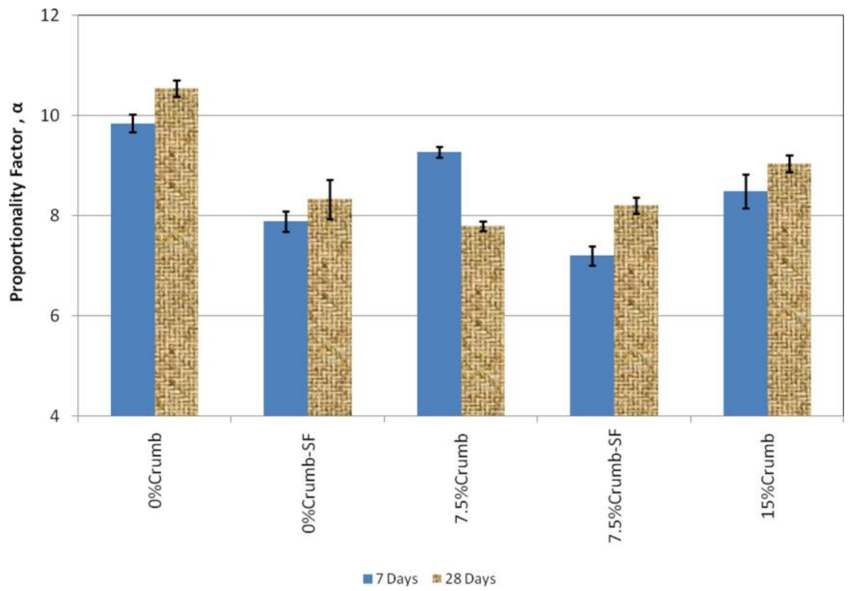

FIG. 11—*Proportionality factor relating flexural strength to compressive strength for various concretes.*

A plot of the modulus of rupture (pound-force per square inch) against the displacement (inches) is shown in Fig. 12 comparing the control concrete and concretes with 7.5 % and 15 % of fine aggregate replaced with crumb rubber. It is observed that the addition of crumb rubber did not have an effect on the displacement or deformation of the concrete beam, as the maximum displace- ment for all the concretes was approximately the same. Generally, as seen from Fig. 13, the concrete beam failure for concrete both with and without crumb rubber was similar; for both, there was a straight fracture line and the beam divided into two almost equal halves.

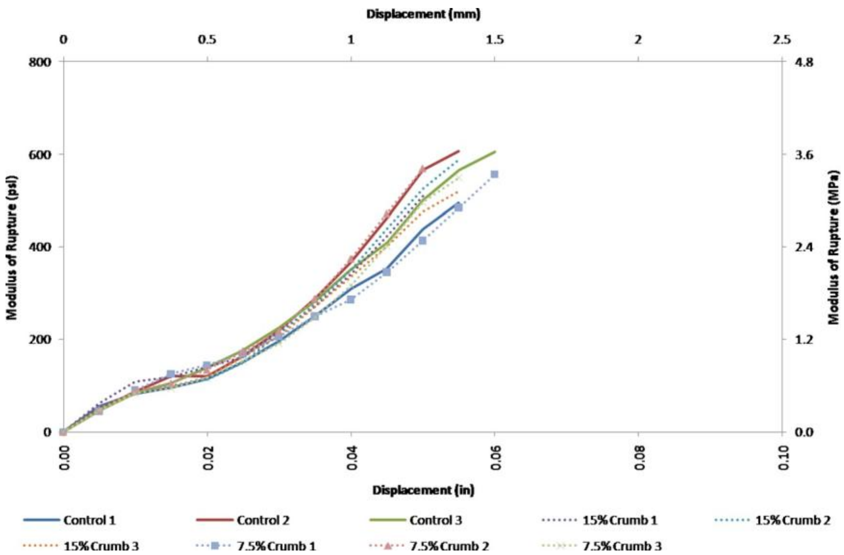

FIG. 12—*Modulus of rupture of control concrete and concrete with 7.5% and 15% of fine aggregates replaced with crumb rubber.*

FIG. 13—*Fracture pattern for control concrete and concrete with crumb rubber.*

From the flexural results, it is observed that crumb rubber was able to lower the modulus of rupture (maximum flexural strength) but had no effect on the maximum deformation sustained by the concrete beam and did not affect the way the concrete failed (fracture). The negative effect on flexural strength might be due to inferior bonding between the crumb rubber and the concrete. Poor bonding would have a more pronounced effect in tension than in compression.

III. CONCLUSION

It has been shown that up to 15 % of fine aggregates can be replaced with an equal volume of crumb rubber in a concrete mix without affecting the compressive strength of the concrete. When the amount of SF was kept constant, the crumb rubber improved the compressive strength by 5 % at 7 days and 9 % at 28 days.

Crumb rubber improved concrete workability slightly—the slump was higher by between 0.25 in. and 0.5 in. (6.4 mm and 12.7 mm). Adding crumb rubber to the concrete mixture could increase the strain at failure by about 33 % with a negligible loss of compressive strength. Given that strain is a measure of material deformation, this shows that the concrete with crumb rubber would expe- rience more deformation before the concrete failed during compressive loading. However, the deformation decreased with an increase in the quantity of crumb rubber used. At 15 % replacement, the control concrete and crumb rubber concrete strains were equal on average.

Crumb rubber concrete exhibits good energy absorption and ductility; the concrete does not ex- perience the typical brittle failure and instead experiences a ductile, plastic failure mode. At 7.5 % replacement, crumb rubber improved the modulus of toughness by 54 %, whereas at 15 % the modulus of toughness for crumb rubber concrete was 15 % higher than that of the control con- crete. Therefore, the addition of crumb rubber to concrete can improve the concrete's toughness and impact resistance.

It has been shown that at 15 % crumb rubber replacement, the concrete with crumb rubber had a modulus of elasticity that was 11 % higher than that of the control. When we compare the two concretes with SF, we find that the crumb-rubber-modified concrete had an elastic modulus that was 34 % less than that of the control that also contained SF. However, crumb rubber lowered the splitting tensile strength with an increase in the quantity of crumb rubber used. The addition of crumb rubber to the concrete also lowered the modulus of rupture by an average of 12 %.

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