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Impact Resistance of Waste Rubber Fiber Silica Fume Concrete

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Abstract—*Higher impact resistance and better energy absorption capacity are one of the desirable and important properties for concrete. Innovative and sustainable materials may be used to improve these properties of concrete. Ongoing research revealed the impact resistance of concrete by replacement of fine aggregates by waste tire rubber fibers and Silica fume as cementitious material. Three replacement levels of rubber fiber (0%, 25%, and 30%) and three replacement levels of silica fume (0%, 10% and 15%) have been considered for two different water cement ratios(0.40 & 0.50). Impact tests on concrete have been conducted by three different type of techniques; drop weight test, flexural loading test and rebound test (as per ACI). Also, relationship between impact test results has been derived. The study demonstrates that, waste rubber fiber can be used as a sustainable material to improve the impact resistance and ductility of concrete. The study also demonstrates that the silica fume improves the impact resistance and reduces the ductility of rubber fiber concrete.*

1. INTRODUCTION

Concrete is a brittle material with high rigidity. High impact resistance and more energy absorption capacity are very important and required in many applications such as shock absorbers, railway buffers and foundation pads of machinery etc. Additional ingredients are required to improve the properties of concrete in some situations where these requirements are not fulfilled. Many studies have been carried out for evaluating the impact resistance and energy absorption capacity on fibrous concrete. Rubcrete (rubberized concrete) which possesses good mechanical properties and is considered to be one of the best and economical ways of recycling the used tyres[1]. In the rubberized concrete Panda et al.[2] concluded that the loss of strength was 45% with 15% replacement of coarse Aggregate by rubber particles. Torgal et al.[3] Investigated that tyre waste concrete is specially recommended for concrete structures located in areas of severe earthquake risk and also for applications submitted to severe dynamic actions like railway sleepers. Mavroulidou et al.[4] investigated on Discarded tyre rubber as concrete Aggregate (a possible outlet for used tyres) and shows that discarded tyre lower the value of mechanical properties of concrete. Gupta et al.[5] Focused on impact resistance of concrete and showed that the impact resistance of concrete improves on replacement of fine Aggregate by rubber Fibers and Compressive strength increased on replacement of cement by Silica Fume. The reduced compressive strength(upto 30%) of rubberized concrete in comparison to conventional concrete[6]. Iman et al.[7] reported that introduction of rubber into concrete mixes results in the control of shrinkage cracks if the optimised content of rubber(20% to 25%) is selected. Chaudhary et al.[8] reported Workability of concrete is not affected significantly by adding rubber Fibers but compressive strength of waste rubber tyre fiber concrete decreases with increase in the replacement level of fine Aggregate by rubber Fibers. The impact resistance of concrete has been found to increase up to fifteen times on using steel fibers [9-10] and up to ten times on using polypropylene fibers [11,12]. Khaloo et al.[13] carried out a study on concrete containing high volume chip rubber as partial replacement of coarse aggregate and crumb rubber as partial replacement of fine aggregate. The toughness was reported to be highest for 25% concentration of both the types of rubber particles as a part of the total aggregate volume. Aiello and Leuzzi [14] carried out flexural tests and reported a significant increase in the energy absorption for up to 75% replacements of coarse/fine aggregate by rubber shreds. Ozbay et al.[15] carried out rebound tests and reported about 25% increase in energy absorption capacity of concrete on 25% replacement of fine aggregate by crumb rubber. Accumulation of discarded rubber tyres is a major problem as its degradation is very difficult because of the highly complex configuration of ingredient materials. The available studies regarding utilization of waste rubber tyres in concrete provide a strong

Table 1: Chemical compositions of cement and silica fume

Component	CaO	SiO2	Al2O3	Fe2O3	SO3	MgO	K2O	LOI
Cement	62.34	20.14	4.65	3.29	2.42	2.23	0.72	1.96
Silica Fume	0.87	90.12	0.94	1.62	0.29	-	1.21	2.87

recommendation for the use of this waste as a partial replacement of fine aggregate in concrete production.

It is evident from the work reported above that although a number of studies have been undertaken for the impact resistance of rubberised concrete; none of the studies has considered waste rubber in the form of fibers. Therefore, there is a need to carry out systematic experimental studies to evaluate the impact resistance of concrete incorporating rubber fibers with silica fume, as partial replacement of fine aggregate, for varying w/c ratios. In the present work, detailed experimental studies have been carried out to determine the impact resistance of concrete containing waste tire rubber fibers. The studies have been undertaken for varying percentage of waste tire rubber fibers (0%,25%, and 30%)as partial replacement of fine aggregate at two different w/c ratio (0.4 and 0.5).Three replacement levels of silica fume (0%, 10% and 15%) have been considered for partial replacement of cement in the rubber fiber concrete. Impact resistance has been evaluated by carrying out drop weight test (concrete cylinder subjected to impact), flexural loading test(concrete beam subjected to impact) and rebound test (concrete cube subjected to impact).

2. EXPERIMENTAL STUDIES

2.1 Material

Ordinary Portland cement of specific gravity 3.12 and silica fume of specific gravity 2.18 were used for the concrete mixes in this study. The chemical compositions of cement and silica fume are shown in Table 1. Fine aggregate (natural sand) of specific gravity 2.56 and coarse aggregate (crushed gravel) of maximum size of 20 mm and of specific gravity 2.59 were used in the concrete mixes. Super plasticizer (SP) "Viscocrete 4031 NS" from sika was used as an admixture to obtain the desired workability. Rubber fibers, obtained from mechanical grinding of waste rubber tyres, were used as partial replacement of fine aggregates. Chemical composition of rubber fibers shown in table 2. These rubber fibers were of 2 to 5 mm in width and up to 20 mm in length (aspect ratio 4 to10) with a specific gravity of 1.07.

Table 2: Chemical composition of rubber fibers

Element	Rubber fiber
Carbon (C)	87.51
Oxygen (O)	9.23
Zinc (Z)	1.76
Sulfur (S)	1.08
Silicon (Si)	0.20
Magnesium (Mg)	0.14
Aluminium (Al)	0.08

2.2 Mix proportions

Concrete mixes were prepared using water/cement ratios of 0.40 and 0.50 with partial replacement of fine aggregate by rubber fiber by 0%, 25% and 30%. Concrete mixes were also cast by replacing cement with silica fume by 0%,10% and 15% in the control concrete as well as rubber fiber concrete. Concrete mixes were first dry-mixed for 2 to 3 min in the mixer. To maintain the workability and the uniformity of the mixes, the proportion of super-plasticizer (SP) with that of cement by weight was varied. When the concrete mix showed the desired workability and uniform rubber fiber distribution, it was placed in a mould and vibrated.

3. TESTING PROGRAM

In this experimental study, following properties of hardened concrete were evaluated as per the relevant standards.

3.1 Compressive strength

The mechanical strength of waste rubber fiber silica fume concrete was measured by conducting compression strength test. This test was performed on 150 mm concrete cubes (three for each mix) at 28 days. Load was applied gradually with the rate of travel of machine equivalent to 5.2 kN/s.

3.2 Impact resistance under drop weight test

Drop weight test was performed on cylindrical specimens (100 mm in diameter and 200 mm in height, three specimens for each mix) as per ACI Committee 544 [17] to estimate the energy absorption capacity of concrete specimens. In this test, repeated loading was applied on the specimen from a specific height. The number of blows was obtained for the prescribed level of distress (occurrence of first crack and failure cracks).

Specimens of 28 days age were tested by the drop weight impact testing machine as per guidelines of ACI committee 544. The machine consists of a 4.5 kg hammer ball dropping from 450 mm height (shown in Fig. 1-A). The hammer ball was dropped repeatedly and the number of blows(N1) required to cause the first visible crack on the top was recorded. Number of blows (N2) which caused opening of cracks was also recorded. The values of N1 and N2 were designated as initial crack resistance factor and ultimate crack resistance factor respectively. The impact energy at initial crack, Ep,dwi (where first subscript p denotes the type of energy absorbed i.e. potential energy and second subscript dw denotes the type of test i.e. drop weight) was calculated by the equation given below:

Ep,dwi =N1mgh

Similarly, the impact energy at ultimate crack, Ep,dwu was calculated by the equation given below:

Ep,dwu =N2mgh

where, N1 and N2 are the number of blows at initial and ultimate crack level, m is the mass of drop hammer (4.5 kg), g is acceleration due to gravity (9.81 m/s^2) and h is the releasing height of drop hammer (450 mm).

3.3 Impact resistance under flexural loading

Impact test on the beams was performed to determine the potential energy of rubber fiber concrete. In this test, beams of 150 mm X 150 mm X 700 mm size (three specimens for each mix) were tested. A ball of 1.0 kg weight was dropped on the mid span of the beam from a height of 450 mm (shown in Fig. 1-B). Number of drops up to failure, Nf was measured and energy absorbed by the specimen, Ep,fl (subscript fl denotes flexural loading)was calculated by the following equation:

Ep,fl = Nf mighi
where, mi is the mass of drop hammer (1.0 kg) and hi is the drop height (450 mm).

3.4 Impact resistance under rebound test

Rebound test was performed on cubes of 150 mm size to determine the impact resistance of waste rubber fiber concrete. A steel ball of 0.5 kg weight was dropped on to the specimens (three for each mix) from a standard height of 1.0 m (shown in Fig. 1-C). The rebound height of steel ball was recorded. Initial potential energy before rebound, Ep,ri and final potential energy after rebound, Ep,rf were calculated using following equations:

Ep,ri =mghi

Ep,rf =mghf

where m is mass of steel ball (0.5 kg), hi is the initial height of steel ball (1.0 m) and hf is height recorded after rebound (varies for different mixes).

The energy absorption capacity of concrete specimen, Ep,r was calculated as the difference of the final and initial potential energy (Ep,r=Ep,ri-Ep,rf). Loss due to air resistance was ignored.

Fig. 1: A. Impact Resistance Under Drop Weight Test , B. Impact Resistance Under Flexural Loading and C. Impact Resistance Under Rebound Test

3.5 Testing machine

As per ACI Committee 544 [17] to estimate the energy absorption capacity of concrete specimens one machine was developed. Height of free fall and other required dimensions shows in Fig. 2. Three different steel ball shows in Fig.2. Weight of given steel ball is 4.5 kg (for drop weight test), 1 kg (flexural loading test) and 0.5 kg (for rebound test).

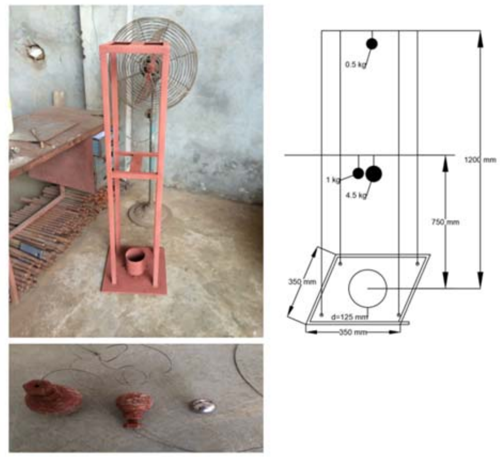

Fig. 2: Testing Machine

4. RESULTS AND DISCUSSION

4.1 Compressive strength

Three specimens were tested for compressive strength for each type of mix. The compressive strength of the waste rubber fiber silica fume concrete for w/c ratios of 0.4 and 0.5 at 28 days, is shown in Fig.3. It can be seen that the compressive strength decreases with an increase in the replacement level of rubber fibers for both w/c ratios. The compressive strength of control concrete (without rubber fiber and silica fume) decreases from 40.79 N/mm^2 to 21.58 N/mm^2 and 31.16 N/mm^2 to 19.90 N/mm^2 for w/c ratios of 0.4 and 0.5 respectively, on 30% replacement of sand by rubber fiber. It is also observed from Fig.3 that on replacement of cement by silica fume (SF), the compressive strength increases for control concrete as well as for the rubber fiber (RF) concrete. Compressive strength of control concrete increases from 40.79 N/mm^2 to 47.01 N/mm^2, and 31.16 N/mm^2 to 34.21 N/mm^2 for w/c ratios of 0.4 and 0.5 respectively on 10% replacement of cement by silica fume. Compressive strength is reduced for 15% replacement of cement by silica fume with compare to 10% replacement of cement by silica fume. Compressive strength of rubber fiber concrete (25% rubber fiber) increases from 22.90 N/mm^2 to 27.58 N/ mm^2, and 21.56 N/mm^2 to 25.33 N/ mm^2 for w/c ratios of 0.4 and 0.5 respectively, on 10% replacement of cement by silica fume. Compressive strength of rubber fiber concrete (30% rubber fiber) increases from 21.58 N/mm^2 to 27.22 N/ mm^2, and 19.90 N/mm^2 to

21.90 N/ mm^2 for w/c ratios of 0.4 and 0.5 respectively, on 10% replacement of cement by silica fume.

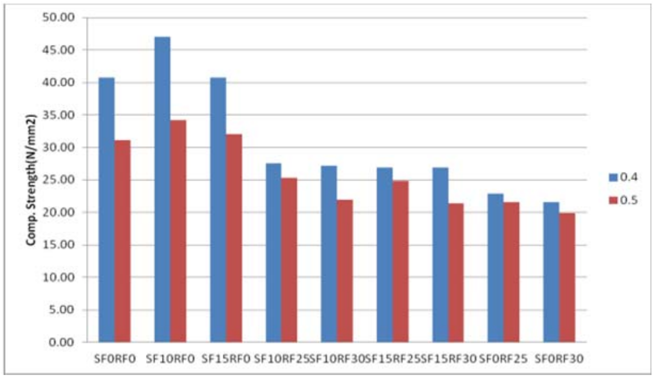

Fig. 3 Compressive Strength

4.2 Impact resistance under drop weight test

The impact resistance of waste rubber fiber silica fume concrete for two different w/c ratios (0.4 and 0.5) was recorded in terms of numbers of blows required for producing first visible crack (N1) and ultimate failure (N2) of the specimen. The average numbers of blows for different mixes at two selected w/c ratios are shown in Fig.5. It can be seen from the Fig. that the number of blows, required for causing the first crack and ultimate failure, increase significantly with the increase in replacement level of rubber content for both the w/c ratios. The difference between number of blows for ultimate failure and first crack (N2-N1) is also found to increase significantly with the increase of replacement level of rubber fibers for both w/c ratios. The difference is almost double with compare to control concrete on 30% replacement of fine aggregate by rubber fibers for both w/c ratios. An increase in number of blows is observed with the increase in replacement level of rubber fiber as observed earlier in Fig. The values of N1 and N2 for both water cement ratios, increase by about three times on incorporation of 30% rubber fiber for both 10% silica fume concrete and 15% silica fume concrete. As shown in Fig.4 Impact energy increased from 43.70 J to 125.15 J and 35.10 J to 121.84 J for w/c ratios of 0.4 and 0.5 respectively, on 30% replacement of fine aggregate by rubber fiber. Potential energy increased from 55.62 J to 150.31 J and 39.73 J to 139.72 J for w/c ratios of 0.4 and 0.5 respectively, on 30% replacement of fine aggregate by rubber fiber. In general, it can be concluded that the impact resistance, for first crack as well as for ultimate failure, increases with the increase in rubber fiber content. The number of blows required for the first crack in concrete, for both w/c ratios, is shown in Fig.5. It can be observed that the number of blows is more for the rubberized concrete as compared to the corresponding case of non rubberized concrete.

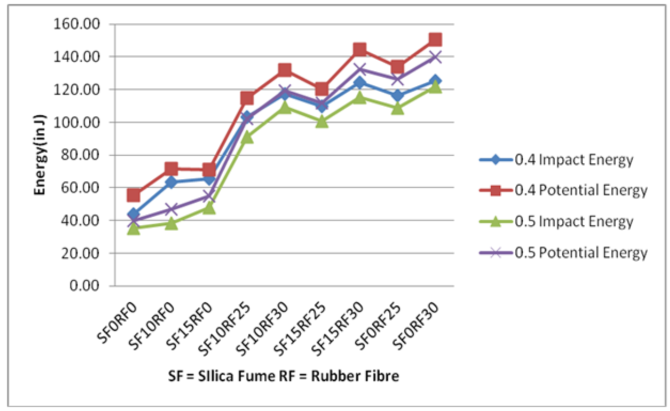

Fig. 4 Impact & Potential Energy

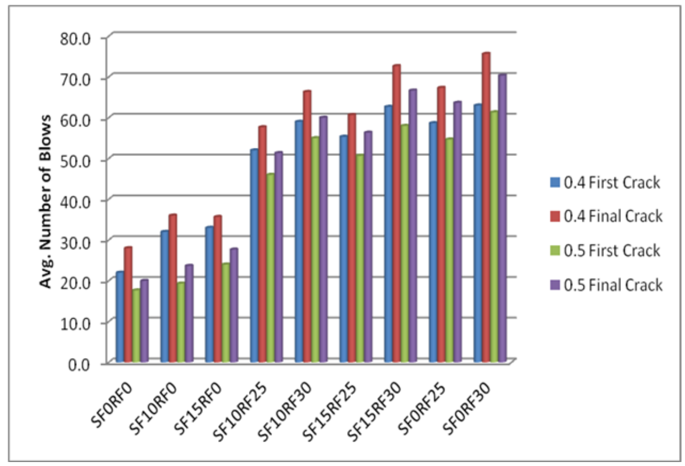

Fig. 5 Number of blows for Initial & Final crack

4.3 Impact resistance under flexural loading

Fig.7 shows the impact energy at failure, under flexural loading, for rubber fiber silica fume concrete. It can be seen that increase in the replacement level of rubber fibers significantly improves the impact energy for both w/c ratios. It is observed that on 30% replacement with rubber fibers in fine aggregates, the impact energy of control concrete increases from 21.93 J to 40.76 J, and 18.69 to 38.11 J for w/c ratios 0.4 and 0.5 respectively. Fig. 7 show the impact energy at failure under flexural loading for different mixes. It is again observed that the impact energy increases with the increase of replacement level of fine aggregate by rubber fiber. It can be observed from Fig. 6 and Fig. 7 that the impact energy increases with the increase of silica fume in concrete. It is observed from Fig. 6 that number of blows upto failure of beam on 30% replacement with rubber fibers in fine aggregates, increases from 50 to 92 and 42 to 86 for w/c ratios 0.4 and 0.5 respectively. It is also observed that adding silica fume in place of cement very minor effect on number of drops upto failure of beam.

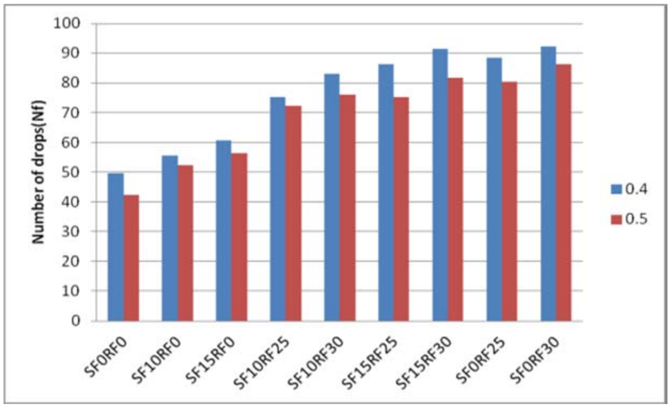

Fig. 6 Number of Drops up to Failure

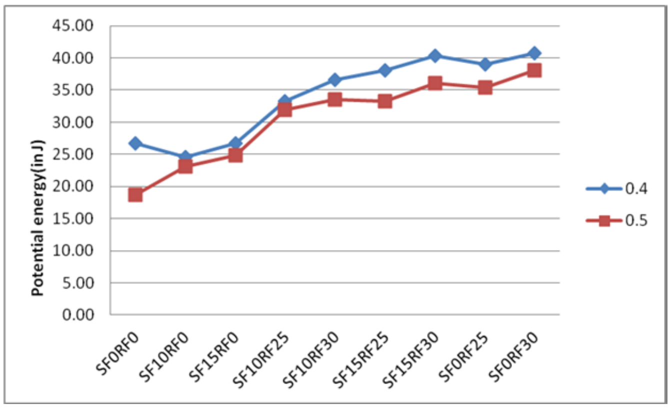

Fig. 7 Potential Energy Under Flexural Loading

4.4 Impact resistance under rebound test

Fig. 8 shows the impact energy absorbed in rebound test for waste rubber fiber silica fume concrete. It can be seen that the increase in the replacement level of rubber fibers significantly improves the impact energy absorbed for both w/c ratios of 0.4 and 0.5. It is also observed that on 30% replacement of fine aggregates by rubber fibers, the impact energy absorbed by concrete increases from 4.06 J to 4.72 J and 3.73 J to 4.64 J for w/c ratios 0.4 and 0.5 respectively. It is observed that the rebound height is decreased and impact energy absorbed increases with the increase of replacement level of rubber fiber. Similar observations were made by Obzay et al. [15] for the crumb rubber concrete. It is also observed that 15% to 20% energy absorption capacity is increased with 30% replacement of fine aggregates by rubber fibers under rebound test.

It can be observed from Fig. 8 , that there is a minor effect of replacement of cement by silica fume on the impact energy absorbed. on 10% replacement of cement by silica fume, the impact energy absorbed by control concrete increases marginally from 4.06 J to 4.12 J and 3.73 J to 3.82 J for w/c ratios 0.4 and 0.5 respectively. on 15% replacement of cement by silica fume, the impact energy absorbed by control concrete is almost same. Similarly, impact energy absorbed by rubber fiber concrete (30% rubber fiber) increases marginally from 4.06 J to 4.55 J, and 3.73 J to 4.32 J for w/c ratios 0.4 and 0.5 respectively on 10% replacement of cement by silica fume.

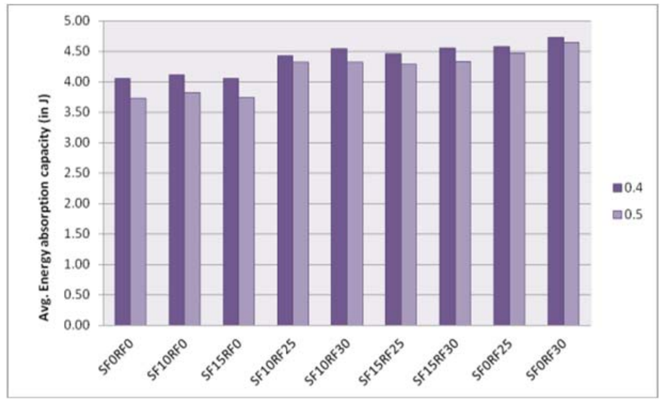

Fig. 8: Energy Absorption Capacity (Rebound Test)

5. CONCLUSION

In the present study, the impact resistance of concrete containing waste rubber fibers and silica fume was evaluated by carrying out experimental studies. Waste rubber tyres converted to the form of rubber fibers were used to partially replace the fine aggregate whereas silica fume was used to partially replace the cement. Three replacement levels of rubber fibers (0%, 25%, and 30%) and three replacement levels of silica fume (0%, 10% and 15%) were considered. Drop weight test, flexural loading test and rebound test were carried out as per relevant standards for two different w/c ratios (0.4 and 0.5). Based on the test results and discussions, following conclusions are drawn:

1. The impact resistance of concrete improves on replacement of fine aggregate by rubber fibers and mechanical strength increases on replacement of cement by silica fume.
2. Compressive Strength increased around 10% to 15% with using Silica Fume in place of Cement as well as observed that Compressive Strength is decreased around 30% when Rubber Fiber added in place of Fine Aggregate.
3. Impact Energy as well as Potential Energy is increased upto 60% with increasing the percentage of Rubber Fiber under Drop Weight Test for both the w/c ratio 0.4 & 0.5.
4. The difference between number of blows for ultimate failure and first crack increases significantly with the increase in replacement level of rubber fibers, which indicate the reduction in brittleness of concrete or increase in ductility of waste rubber fiber concrete.
5. The Energy Absorption Capacity of rubber fiber concrete is increased from 15% to 20% with using rubber fibers in place of fine aggregate in rebound test.

Further studies can be carried out for higher replacement levels of rubber fibers and silica fumes. Studies can also be carried out in future using the bigger impact or sand higher heights along with the measurement of impact force and acceleration of the sample/ impactor.

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