CONCRETE RESEARCH LETTERS

www.crl.issres.net

Vol. 5(3) – Sept. 2014

Effect of Fly ash and Waste Rubber on Properties of Concrete composite

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Abstract

Increasing use of waste materials like flash, scrap tire rubber etc., in construction industry has reduced the handling and disposal problems of these wastes. Fly ash and scrap tire rubbers are generally, employed to develop light weight and low strength concrete composites. The present work discusses the influence of flash and waste tire rubber particles on the behavior of concrete composite. The rubber content has been taken in the range of 0 to 40% as replacement of fine and coarse aggregates while the flash has been varied from 0 to 30% for cement. Testing of the concrete specimen prepared under different percentage of flash and rubber waste was performed at 28 days of age for workability, density, compressive and bond strength. Experimental results show that the density, compressive strength and bond strength decreases while workability increases with increasing rubber content. Addition of flash also decreases the density and compressive strength.

Key words: light weight concrete composite, flash, scrap tire rubber.

1. Introduction

In recent years, light-weight concrete composite has become more popular constructional material owing to low density, reduction of dead load and low handling costs. The strength, durability and other characteristics of concrete depend upon the properties of its ingredients, size and proportions of mix, method of compaction and curing. The adoption of light weight concrete gives an outlet for industrial waste such as scrap rubber tires, flash, clinkers etc. which otherwise creates problem for disposal of waste [1]. Scrap tire rubber and flash are two major industrial wastes which are accumulating in huge volume every year [2-3]. Disposal of these organic and inorganic wastes is a serious problem due to severe environmental problems. With the development of technology, construction industry has opened a gateway for handling these industrial wastes.

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Fly ash is the end product of coal which is mostly generated by the thermal power plants in vast quantities. Utilization of fly ash in construction industry has gained popularity due to durable and sustainable option for a variety of concrete applications [4-6]. Most common use of fly ash is in cement industry because of reduction in water consumption, reduced heat of hydration and long term strength to cement [4].

Recycling of non-degradable wastes, particularly discarded rubbers tire has become a major issue since these materials have been banned from landfills and also incineration of these wastes is not environmental friendly. Since last few years, many attempts have been made to utilize scrap tire rubber after some processing, in composite concrete materials such as asphalt pavement, water proofing systems, and membrane liners [1, 3, 7-8]. Siddique *et al.* [3] used the scrap tire rubber in cement based materials, after recycling it in coarse or fine rubber particles. Results showed that the rubberized composite concrete possesses lower density, higher toughness and ductility, lower compressive and tensile strength and more effective insulation. Mechanical behavior of concrete containing rubber particles has been investigated by Eldin and Senouci [9].

Results showed that the concrete mixtures exhibits low mechanical strengths but follows a ductile and plastic failure. Effect of rubber particles size has been depicted by Topcu I.B. [10]. The observations showed that despite decrease in both unit weight and compressive strength, elastic behavior improved significantly. Raghavan D. *et al*. [11] reported that mortars incorporating rubber shreds achieve workability comparable to or better than a control mortar without rubber particles. Increasing the rubber content decreases the unit weight of rubberized mixture because of low specific gravity of rubber particles. Lee H. S. *et al*., [12] developed tire-added latex concrete (TALC) to incorporate recycled tire rubber as a part of concrete. TALC as a substitute for fine aggregates while maintaining the same water–cement ratio. Result showed the higher flexural and impact strengths than those of Portland cement, latex modified concrete and rubber-added concrete There was better bonding between crumb rubber and Portland cement.

According to Topcu and Avcular [13] impact resistance of rubberized concrete increases because of the enhanced ability of material to absorb shock energy which make it suitable for vibration damping applications. Balaha M. *et al*. [14] reported 63.2% increase in the damping ratio (self-capacity to decrease the amplitude of free vibration) for concrete containing 20% rubber particles. Atahan and Sevim [15] replaced the normal aggregates with shredded tire chips (11-22 mm) to produce concrete barriers. Static and dynamic tests showed that the plain rubberized concrete (PRC) containing up to 40% volume or high, as coarse aggregates replacement can be used in safety barrier production for highway application.

Turatsinze A. *et al*. [16-17] carried out free shrinkage test on rubberized concrete mixed with crumb rubber with MSA of about 4.0 mm. Replacement of plain concrete with rubberized concrete to the order of 20% to 30% resulted into increase in shrinkage. Benazzouk A. *et al*., [18] studied the effect of rubber particles on the thermal insulating performance of cementitious composite. The rubber particles were used as 10%, 20%, 30%, 40% and 50% by volume as replacement to cement. The experimental investigation revealed that the addition of rubber particles reduced the material unit weight, thermal conductivity, compressive and flexural strength. Meshgin and Xi [19] observed that with increase in phase change material and rubber content, compressive and flexural strength decreased.

More quantity of fine rubber particles result in lower thermal conductivity and drying shrinkage and it helps to increase the bond strength while phase change materials can improve heat capacity of mortar. Hsing C.L. *et al.* [20] reported the similar effect of decreasing mechanical properties of concrete by inclusion of rubber particles.

Based on previous literature, it is well observed that the mechanical properties of concrete composite decreases with increasing content of rubber particles. Also increase in content of rubber particles results into lower density, increased vibration damping and increased ductility. Significant research work had been carried out on rubberized concrete only; but very limited investigations have been carried out using fly ash along with waste rubber in cemented concrete. Unlike scrap tire wastes, fly ash can be directly used in cemented concrete without any processing. High volume of fly ash can enhance the required properties of concrete composite as advocated by Bilodeau and Malhotra [21].

In the present study the effect of waste materials i.e. tire rubber and fly ash on density, workability, compressive strength and bond strength of concrete composite has been evaluated. Fine and coarse aggregates were replaced with scrap tire rubber in 0%, 10%, 20%, 30% and 40% respectively while cement was replaced with fly ash in ratio of 0%, 10%, 20% and 30%.

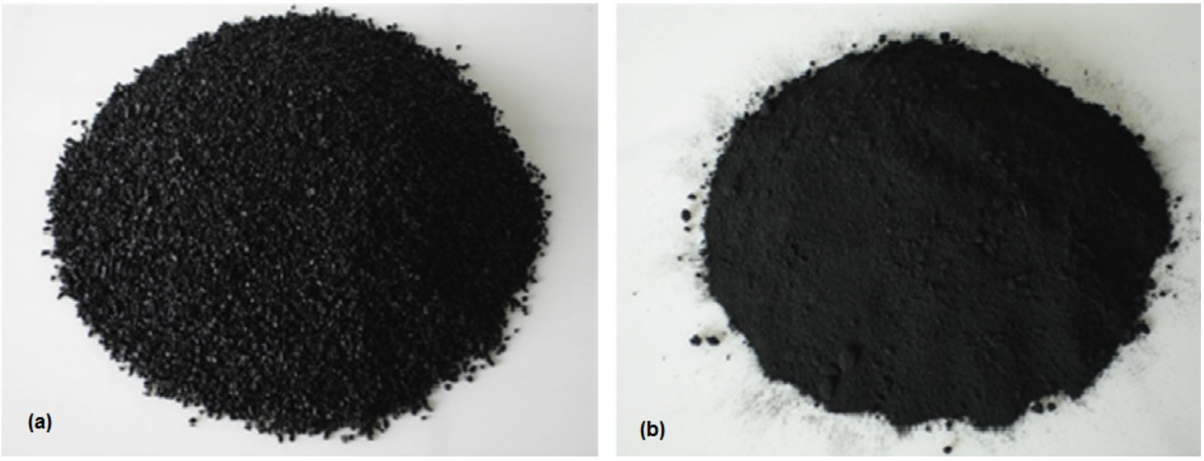

Figure 1: Form of crumb rubber: (a) coarse (b) fine.

2. Experimentation

2.1 Materials

Ordinary Portland cement with ASTM Type-1 standards, having compressive strength 44MPa at 28 days, was used. Natural River sand was the used for coarse (10mm and 20mm) and fine aggregates in concrete mixture. Scrap tire rubber was crumbed into three sizes same of which are shown in (Fig. 1), fine (< 4.75mm), coarse (4.75-10 mm) and coarse (10-20 mm) to replace with fine aggregates and coarse aggregates (10 mm and 20 mm) in concrete mixtures. Fly ash was used as the partial replacement of Ordinary Portland cement. It can have the same properties as cement used in concrete as per IS: 3812:1999 [22]. Some properties of aggregates, crumb rubber and the chemical composition of cement, fly ash have been shown in Tables 1 and 2, respectively.

Table 1: Properties of aggregates and crumb rubber types.

		Specific gravity	Fineness modulus	Water absorption
Aggregate	Fine	2.65	3.5	1.75
	Coarse(4.75 to10mm)	2.69	7.0	0.05
	Coarse (10-20mm)	2.69	8.0	0.01
Crumb rubber	Fine	1.12	3.02	0.03
	Coarse (4.75 to10mm)	1.12	7.0	0.03
	Coarse (10-20mm)	1.12	8.0	0.03
Cement		3.10	2.0	---
Fly ash		2.58	4.0	---

Table 2: Chemical composition of cement and fly ash.

Elements	Cement	Fly ash
CaO	63.56	4.54
SiO_2	19.3	56.26
Al_2O_3	5.57	28.54
Fe_2O_3	3.47	5.42
MgO	0.87	1.37
SO_3	2.95	0.28
K_2O	0.8	1.74
Na_2O	0.13	0.15
LOI	1.16	1.35

2.2 Mix proportion

Fine aggregate was mixed with the coarse aggregate as per IS 383:1970 [23] in 1:1 proportions to achieve the grading of sand which confirms to the Zone–II. The mix proportion for the control concrete was set at 1.0:0.5:1.5:3.0 (Cement: Water: Fine: Coarse aggregate).

In case of light weight concrete composite, the crumb rubber was used to replace fine and coarse aggregates (10 mm and 20 mm both) at 10%, 20%, 30% and 40% respectively by weight, while fly ash was used to replacement at 10%, 20% and 30% by weight. The mix proportion design is listed in Table 3.

2.3 Casting and testing methodology

In the mixing process, the concrete was dry-mixed using hand mixing for about 10 min, after then water was added gradually and mixed till the homogeneous mix was obtained. Specimens were obtained by compacting concrete mixture into rectangular rigid steel moulds of 150 mm × 150 mm × 150 mm and cylindrical moulds of 150 mm × 300 mm. In cylindrical specimens a steel rod of 10mm diameter was carefully embedded centrally at a depth of 200 mm from top. The specimens were removed from the mould after 24 hours and submerged in water for 28 days. Specimens were taken out of the water after 28 days and dried at room temperature.

Table 3: Mix Proportion design

Percentage of Replacement	Cement (1) kg/m³		FA (1.5) kg/m³		Coarse Aggregate (3.0) kg/m³			
	Cement	Fly ash	FA	RFA	CA RCA (10 mm)		CA RCA (20 mm)	
R=0%	383	-	546	-	594	-	594	-
R=10%	383	-	491.4	54.6	534.6	59.4	534.6	59.4
R=20%	383	-	436.8	109.2	475.2	118.8	475.2	118.8
R=30%	383	-	382.2	163.8	415.8	178.2	415.8	178.2
R=40%	383	-	327.6	218.4	356.4	237.6	356.4	237.6
R=0 % F=10 %	344.7	38.3	546	-	594	-	594	-
R=10% F=10%	344.7	38.3	491.4	54.6	534.6	59.4	534.6	59.4
R=20% F=10%	344.7	38.3	436.8	109.2	475.2	118.8	475.2	118.8
R=30% F=10%	344.7	38.3	382.2	163.8	415.8	178.2	415.8	178.2
R=40% F=10%	344.7	38.3	327.6	218.4	356.4	237.6	356.4	237.6
R=0 % F=20 %	306.4	76.6	546	-	594	-	594	-
R=10% F=20%	306.4	76.6	491.4	54.6	534.6	59.4	534.6	59.4
R=20% F=20%	306.4	76.6	436.8	109.2	475.2	118.8	475.2	118.8
R=30% F=20%	306.4	76.6	382.2	163.8	415.8	178.2	415.8	178.2
R=40% F=20%	306.4	76.6	327.6	218.4	356.4	237.6	356.4	237.6
R=0 % F=30 %	268	115	546	-	594	-	594	-
R=10% F=30%	268	115	491.4	54.6	534.6	59.4	534.6	59.4
R=20% F=30%	268	115	436.8	109.2	475.2	118.8	475.2	118.8
R=30% F=30%	268	115	382.2	163.8	415.8	178.2	415.8	178.2
R=40% F=30%	268	115	327.6	218.4	356.4	237.6	356.4	237.6

R%=Rubber Replacement, FA=Fine Aggregate, RFA= Rubber Fine Aggregate, CA = Coarse Aggregate, RCA = Rubber Coarse Aggregate and F = Fly ash, Water = 192 kg/m^3

Four important properties namely, density, compressive strength, bond strength and workability were measured for the prepared concrete composite. Cubes specimens of 150 mm x 150 mm x 150 mm, were prepared for each mix design and density test was conducted at 28 days of age. Workability of fresh concrete ensures the uniform quality and strength of concrete. Different methods are available for determining the workability of fresh concrete; but, none of them is wholly satisfactory. Each method measures only a particular aspect of it and there is really no single method which can measure the workability of all types of concrete. In the present work, two types of tests namely slump test and compaction factor test, were performed to determine the workability of concrete.

Compression test was conducted at 28 days of age, on Compressive Testing Machine (CTM) after drying at room temperature according to IS 516-1959 [24]. Load was applied continuously until the specimen failed and maximum load carried by the specimens was recorded. Fig. 2 shows the cube specimen under compression test.

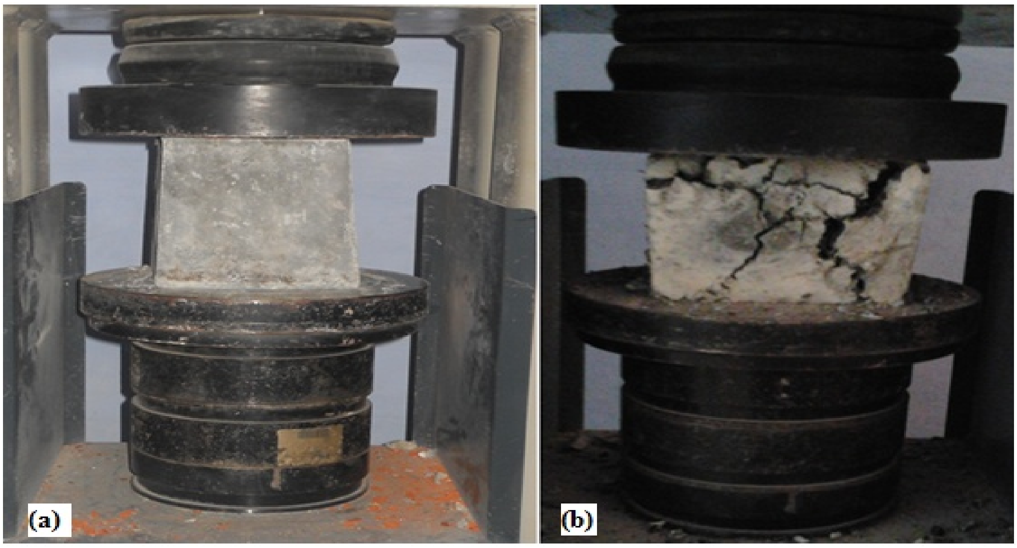

Figure 2: Cube specimen under compression testing before (a) failure (b) after failure.

In order to determine the bond strength, pull-out test were performed. The cylindrical specimens of dimension 150 mm x 300 mm, with 10 mm diameter bar embedded up to 200mm in depth were prepared. In pull out test, a direct tensile load was gradually applied at the free end of the bar.

The bond strength was the resistance offered by the composite to withdraw the embedded steel bar which was measured in terms of the ultimate load applied at the time of failure. The pull-out test were conducted at 28 days after casting, on 1000 KN capacity Universal Testing Machine (UTM). Fig. 3 shows the specimen after pull-out test.

Figure 3: Cylindrical specimens after pull-out tests.

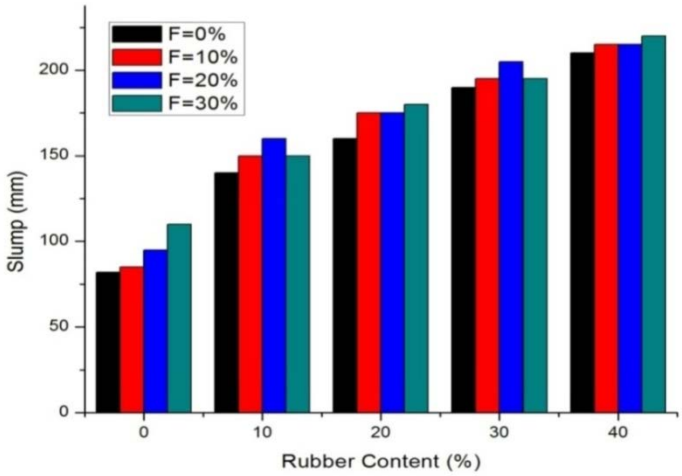

Figure 4: Variation of slump with rubber content at 0- 30% fly ash.

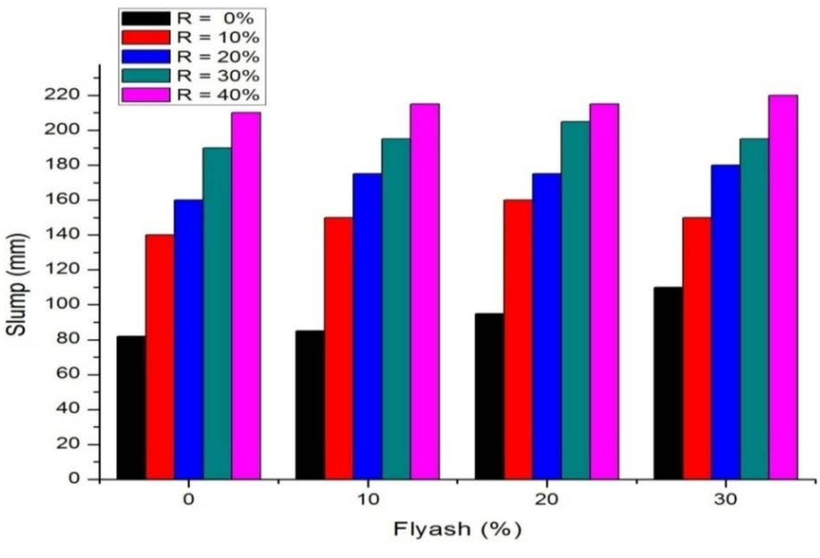

Figure 5: Variation of slump with fly ash at 0-40% rubber aggregate.

3. Results and discussions

3.1 Workability

Workability is the ability of the concrete to be easily moulded. Slump test was performed to evaluate the workability of selected mix proportion. Figs 4 and 5 show the variation of workability with change in fly ash and rubber contents. It was observed that in creasing percentage of crumb rubber aggregates and flyash leads to an increase in the workability. This was due to the round and uniform shape of the aggregates used in this study. Workability was mainly affected by the shape and size of rubber, aggregates size, bonding between rubber and cement mortar and water cement ratio.

The increase in slump value was obtained between 156 to 168.3%, with the addition of 0 to 40% of rubber content at different contents of flyash (0-30%). Influence of rubber particles was highly noticeable as compared to influence of flyash. The maximum slump height of the mix proportion was obtained with 30% fly ash and 40% rubber contents which was higher than the others.

3.2 Density

Figs 6 and 7 represent the variation of density with fly ash and crumb rubber. Results showed that increase in rubber contents decreases the density of concrete composite. The con trol mix (R=0%) had the highest density. Effect of crumb rubber was highly noticeable on density which was due to low specific gravity of the crumb rubber as compared to fine and coarse aggregates.

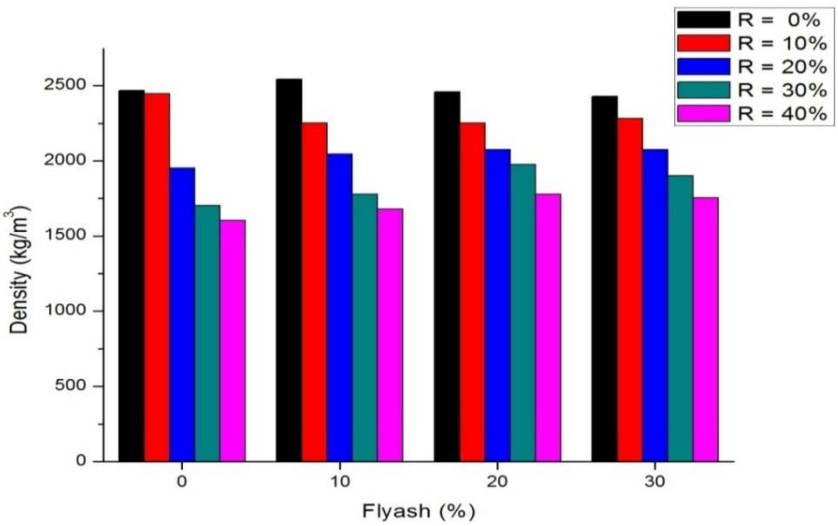

Figure 6: Effect of rubber aggregate and fly ash on density.

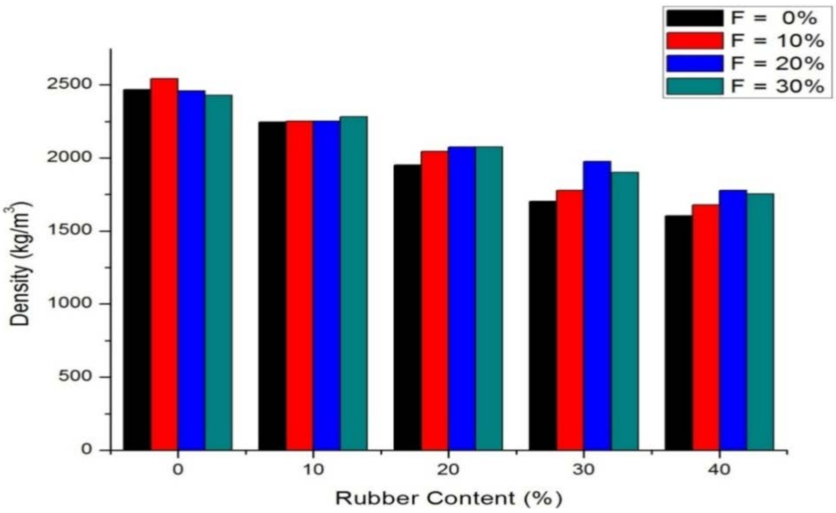

Figure 7: Effect of fly ash and rubber content on density.

Density of concrete was also pronounced when fine aggregates were more than coarse aggregates by weight. At the same percentage of replacement, concrete mixed with fine crumb rubber exhibits lower density than the coarse crumb rubber. Percentage reduction in density was 9, 21, 31 and 35 with 10%, 20%, 30% and 40% rubber respectively at 0% fly ash. Increasing contents of fly ash (replacement of cement) increases the density; but, in very small proportion. Maximum density is obtained at 10% flyash and 0% rubber. Maximu m reduction in density was obtained at composition having 0% flyash and 40% rubbe content.

3.3 Compressive strength

Figs 8 and 9 represent the influence of rubber contents and fly ash on compressive strength of mix concrete composite. Compressive strength of mix concrete composite reduced significantly with increase in rubber content and fly ash. Concrete strength mainly depends on the bonding between cement and aggregates, size and hardness of aggregates.

Since the aggregates (coarse and fine) were partially replaced by rubber and fly ash, bonding between cement and aggregates get weakens and hence strength reduced.

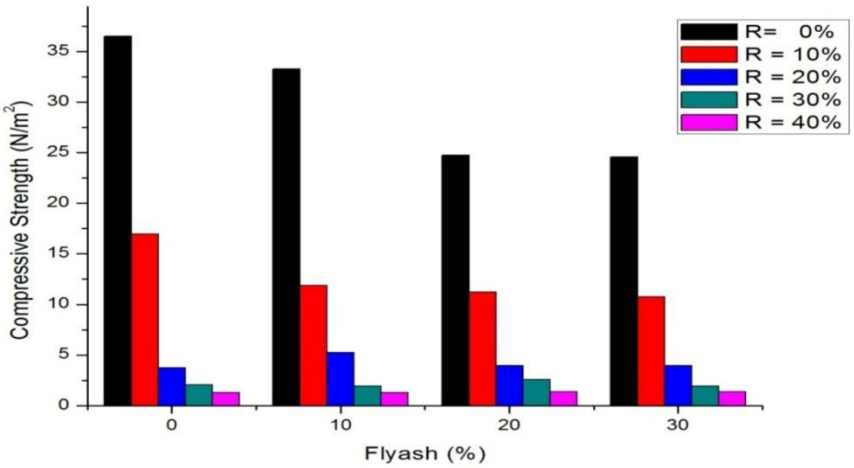

Figure 8: Influence of rubber contents on Compressive strength at 0-30% fly ash.

The addition of the scrap rubber in the concrete mix occupies the voids between coarse aggregates which lead to weaken the bond strength in concrete matrix. Compressive strength was highest without addition of rubber and fly ash. Percentage reduction in compressive strength varies from 53.6 % to 96.5% with addition of 10 to 40% scrap rubber at 0% fly ash.

Due to elastic nature of rubber, failure of the rubberized concrete is elastic i.e. it absorb high energy before failure. Rubberized concrete is tough as compared to concrete matrix without rubber. After loading the samples, cracks start first at the softest areas of the specimens. Increasing rubber contents increases the number of cracks and width of the crack which leads to collapse of the sample cube.

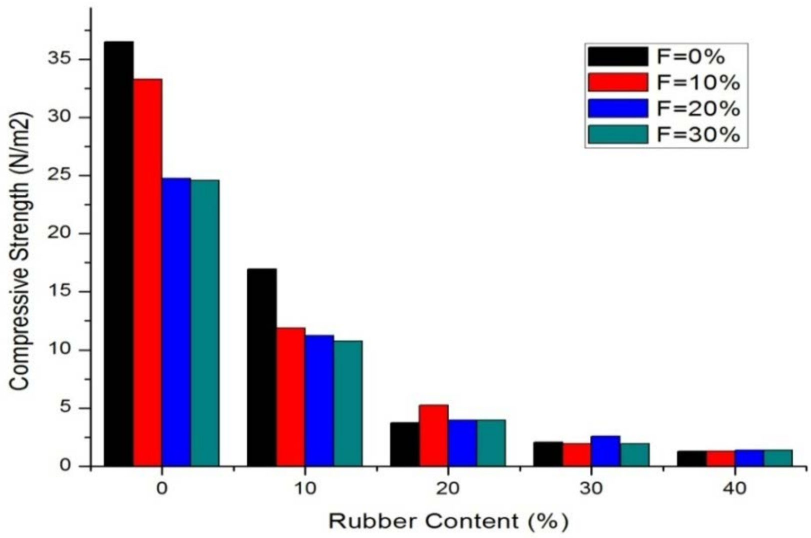

Figure 9: Influence of fly ash on compressive strength at 0-40% rubber.

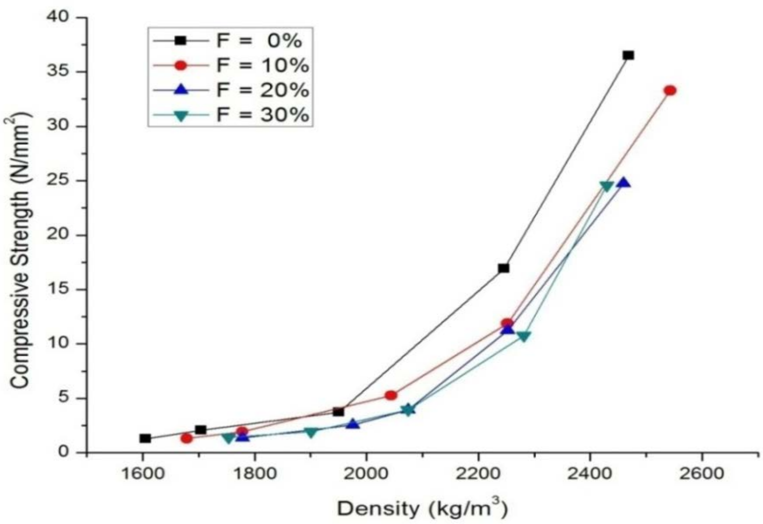

Figure 10: Compressive strength Vs density at 0-40% rubber content.

It can be seen from Fig. 10 that compressive strength increased with increase in density. Density of concrete mix varies from 2500 to 1600 kg/m^3 with 0 to 40% rubber addition. It can be observed from Figure 9 that nearly same density has obtained with 10 -30 % addition of fly ash at 10% rubber. Hence, it is more economical to add fly ash up to 30% with 10% rubber to obtain a good combination of strength and weight.

3.4 Bond Strength

Bond strength was tested by pull-out method at the age of 28 days in the Universal Testing Machine. A 10 mm diameter steel bar embedded up to 200 mm inside a cylindrical specimen was used for pull-out test. Bond strength was measured in terms of load required to pull-out the steel bar from cylindrical specimen. It was observed that increasing rubber content decreases the bond strength of concrete composite. The extension of bars in the control specimens was the minimum. But as the rubber content was increased, extension of bar increased.

At 30% and 40% rubber content, whole length of the bar was pulled-out from cylindrical specimen. Results of bond strength of different mixes with 0-30% replacement of cement by fly ash and 0-40% replacement of aggregates by waste rubber has been shown in Figs 11 and 12.

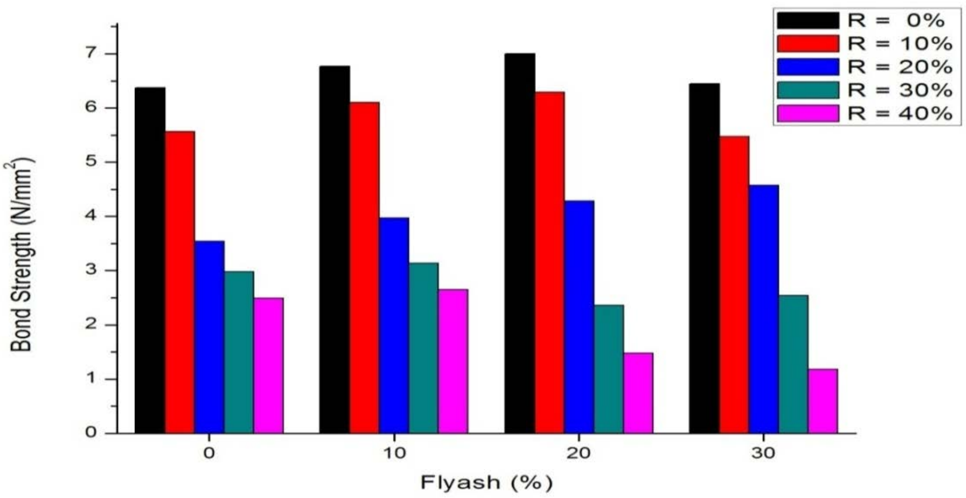

Figure 11: Variation of bond strength with fly ash content at 0-40% rubber content.

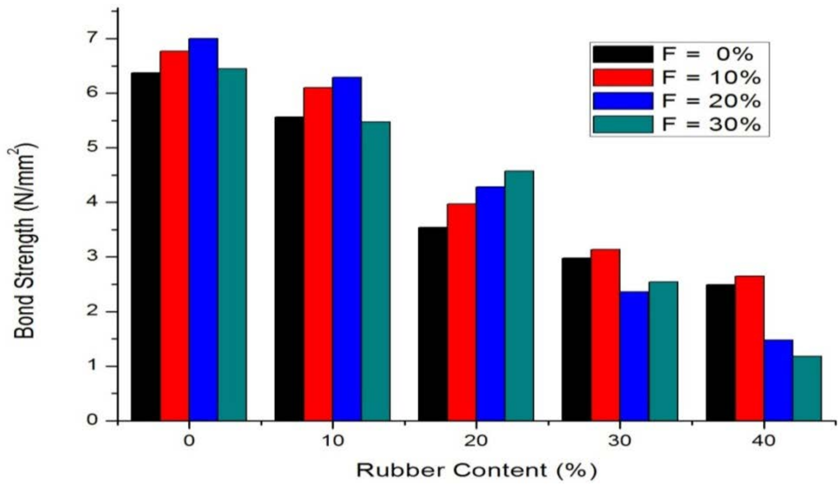

Figure 12: Variation of bond strength with rubber content at 0-30% fly ash content.

The weakness of the bond between scrap rubber and cement matrix can be seen by the ease with which rubber aggregates can be removed from the crushed sample by simply using one's fingers. It was observed from Figs 11-12 that there was decrease in bond strength with the increase in the rubber content in rubberized concrete batches. Bond strength was maximum for control mix with 20% fly ash. There was approximately 62.5%, 58.3%, 75% and 83.3% decrease in the bond strength with the addition 0%, 10%, 20% and 30% fly ash and with the 0%, 10%, 20%, 30% and 40% of rubber content respectively in the rubberized specimens at 28 days. The maximum reduction in bond strength was with th e 30% flyash and 40% rubber content. Results of the bond strength are given in Table 4 with varying percentage of the rubber content and fly ash.

Table 4: Results of slip and peak- load of the bond Strength.

Rubber content (%)	Flyash (%)	Peak load (KN)	Slip (mm)
0	0	40.00	5-15
0	10, 20, 30	42.52-44	4-16
10	0, 10, 20, 30	34.94-39.50	20-90
20	0, 10, 20, 30	22.22-28.72	90-150
30	0, 10, 20, 30	14.84-19.75	150-200
40	0, 10, 20, 30	7.43-16.65	200-290

4. Conclusions

The present work discusses the influence of fly ash and waste tire rubber particles on workability, density, compressive strength and bond strength of concrete composite. The rubber content has been varied from 0 to 40% as replacement of fine and coarse aggregates while fly ash has been varied from 0 to 30% for replacement of cement. Based on the experimental results, following conclusions have been drawn:

- Workability of the rubberized concrete increases with increasing rubber contents and fly ash and the maximum workability was obtained at 30% fly ash and 40% rubber content.
- The density of the rubberized concrete decreases with increasing rubber contents (from 0-40% of aggregate). Addition of fly ash as a replacement of cement, decreases the density; but, in very small proportion. The density with 10% fly ash was higher than that for the other combinations. But, the maximum reduction was obtained with 0% fly ash and 40% rubber replacement.
- Compressive strength decreases by 96.5%, 96.4%, 96.3% and 96.2% at 0%, 10%, 20%, 30% and 40% of rubber contents respectively at 0-30% of flyash.
- The toughness of scrap rubber modified concrete was much greater than the control mix. Due to the elastic nature of rubber, rubberized concrete is able to absorb more energy when loaded. After loading the samples, cracks starts first at the softest areas of the specimens. At higher contents of rubber (30-40%), the number of cracks and width of the crack increases which leads to collapse of the sample cube.
- Maximum decrease in bond strength is by 60.90%, 58.40%, 76.77% and 81.47% at 0%, 10%, 20%, 30% and 40% rubber content respectively. Maximum reduction in compressive strength was at 30% flyash and 40% rubber replacement.

Although compressive strength and bond strength is low for rubberized concrete mix;

but, low density of rubberized concrete reduces its dead load and self-weight of the structure. Also, rubberized concrete structure can sustain sufficient load even after crack generation. Addition of fly ash as a replacement of cement is much economical. According to the requirement, adequate percentage of rubber and fly ash can be replaced in concrete mix to obtain good combination of strength and weight.

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