International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 **Issue:** VII **Month of publication:** July 2017

DOI:

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue VII, July 2017- Available at www.ijraset.com

Improving The Strength Properties Of Rubber Modified Concrete Using Synthetic Resin

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Abstract: Utilization of scrap rubber tyre aggregates in concrete as a replacement to natural aggregates has proved to be an efficient alternative way to dispose of the waste rubber tyres safely. However, it was found that there is a significant loss in the strength of rubberized concrete with increasing tyre content. Therefore, it is necessary to reduce/control this loss of strength in concrete on using rubber aggregates as a replacement to natural aggregate. In the present research study, rubber modified concrete was made by two different ways: 1) by replacing natural fine aggregate in normal concrete of M 35 grade with untreated crumb waste tyre particles and 2) by replacing natural fine aggregate in normal concrete of M 35 grade with crumb rubber particles treated with synthetic resin (PVA). The replacement of fine aggregates in both the cases was done at 5 %, 10 % and 15 %. The size of crumb rubber varies from 4.75 mm to 0.15 mm. Slump and bulk density test were conducted on fresh concrete mix groups of untreated and treated rubber modified concrete. Hardened properties like compressive strength were determined for both the case and the results obtained from various laboratory tests were analyzed and comparative discussions were done. Improvement in compressive and split tensile strength has been seen on use of treated rubber aggregates.
Keywords: treated rubber modified concrete, untreated rubber modified concrete, crumb rubber, pre-treatment, synthetic resin

I. INTRODUCTION

Utilization of scrap/waste tires proved to be a convincible and effective solution for waste rubber tyres disposal as per the studies carried out by researchers. Incorporating waste rubber tire aggregates in concrete may modify the brittle failure of concrete enhancing its capability to absorb high amount of energy before undergoing failure [1]. Properties like sound insulation, thermal insulation, and impact resistance have been enhanced by the addition of scarp/waste rubber tyres in the concrete mix, [2, 3]. Rubberized concrete can find its successful application in non-structural components such as crash barriers, pavement blocks, Sidewalks, culverts in road construction, precast roofs for green buildings and roofing tiles with lighter weight. However, it has been reported by many researchers that the concrete strength reduces with the higher rubber aggregate percentage in the concrete mix [4, 5].

This reduction in strength of rubberized concrete may occur due to different reasons as investigated by experts, such as, 1) high difference in specific gravity of waste rubber aggregate and other constituent materials of concrete, 2) rubber particles when introduced in concrete entraps air due to its hydrophobic nature, causing increase in air content, leading to the reduction of concrete strength and decrease in unit weight and 3) low adhesion or weak bond between the cement matrix and the rubber particles, which results in the acceleration of crack propagation through rubber-cement paste interface, when load acts upon the concrete. Realizing the problem of strength reduction on the inclusion of tyre particles in concrete, appropriate measures are needed in order to improve the strength of rubber modified concrete.

Osama Youssf et al., [6], implemented three methods to improvise the mechanical properties of CRC namely; pre-treatment of waste rubber aggregate by sodium hydroxide (NaOH) solution, using additives like silica fume, and increasing cement content in concrete. The pre-treatment of rubber particles with NaOH was able to regain part of the lost strength.

Iman Mohammadi et al., [7], assessed the rubberized concrete strength performance in which rubber aggregates were pre-treated chemically with sodium hydroxide (NaOH). Results showed that there has been an improvement in compressive and flexure strength. The maximum compressive strength was obtained when rubber aggregates were treated for duration of 24 h compared to the other durations of treatment; the improvement obtained on strength was more significant for compressive strength results than flexural strength.

Lee et al., [8], showed that on adding SBR latex to the rubber tyre aggregate, the strength and durability of rubberized concrete got improved. Microscopic pictures taken using the scanning electron microscope depicted that there was better bonding between crumb rubbers and cement matrix due to SBR Latex.

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Though, researchers have made some progress in improving the strength of rubberized concrete, yet only few methods of surface pre-treatment, most commonly which include treatment of rubber aggregates with NaOH have been adopted. No other method of surface pre-treatment has been studied in detail.

In the present research work, pre-treatment of waste/ scrap crumb rubber aggregates was done with synthetic resin and treated rubber modified concrete was developed by replacing fine aggregate with these treated crumb rubber aggregates. After that, fresh and hardened properties of concrete were studied and comparative analysis done with control concrete and untreated rubber modified concrete.

II. EXPERIMENTAL PROGRAMME

A. Constituent Materials

Ordinary portland cement of 43 grade was used matching the requirements as per IS: 8112-1989. Crushed aggregates, angular in shape have been used in the experimental work having a nominal maximum size of 20 mm. Crusher sand was used as fine aggregate belonging to Zone II having specific gravity 2.63 and fineness modulus 2.82.

Crumb rubber was added to the concrete mix at replacement level of 5, 10, and 15 % by weight of fine aggregates. Crumb rubber of size varying from 4.75 mm to 0.15 mm was used for the experimental work. Physical properties of fine aggregate and crumb rubber is given below in Table - 1. Particle size distribution curve has been shown for crusher sand and crumb rubber in Fig. 1.

Table – 1: Physical Properties of Crusher Sand and Crumb Rubber

Properties	Crusher sand	Crumb rubber
Specific Gravity	2.63	1.15
Fineness modulus	2.82	3.14
Water Absorption	1.1 %	0.89 %

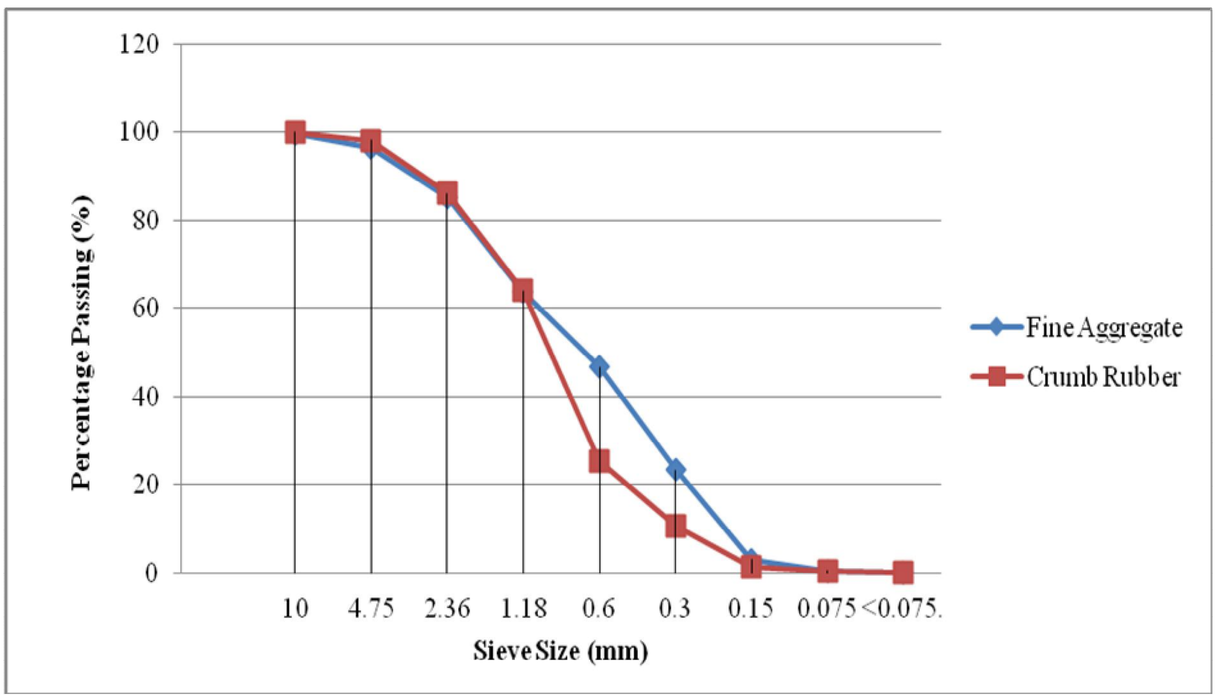

Fig. 1: Particle Size Distribution Curve for Fine Aggregate and Crumb Rubber

Polyvinyl acetate (PVA) based adhesive/emulsion which is generally made from the synthetic resin was used for the pre- surface treatment of crumb rubber aggregates in order to develop treated rubber modified concrete. “Auramix 300” super plasticizer was used to achieve homogeneous and workable concrete.

B. Mixture Proportion

Firstly, reference concrete mix (C) of M 35 grade was designed as per IS 10262: 2009. After this, proportioning for treated and untreated rubber modified concrete mixes at 5 %, 10 % and 15 % replacement of fine aggregate (by weight) with crumb rubber was carried out respectively and the proportion obtained are placed in Table - 2. The cement content and water cement ratio was kept 400 kg/m^3 and 0.40 in all the mixes of rubber modified concrete. The coarse aggregate content was also same (1254 kg/m^3) in all the concrete mix groups. The Super plasticizer was added at the rate of 1 % by weight of cement. The control concrete is denoted by "C", untreated rubber modified concrete mix by "CR_X" and treated rubber modified concrete mix by "TCR_X". Where "x" denotes the percentage replacement of fine aggregate with crumb rubber**.**

C. Pre-treatment of Crumb Rubber

Pre- treatment of crumb rubber aggregate was done before mixing process for preparing treated rubber modified concrete mix. The pre-treatment of crumb rubber was done with synthetic resin. Crumb rubber was first washed with clean water and then allowed to dry completely. After this, weighted untreated crumb rubber aggregates were added to the container containing synthetic resin and mixed thoroughly. The mixture was stirred continuously for about 8 to 10 minute so that proper well-coated crumb rubber particles are obtained. Crumb rubber Aggregates were then taken out and spread out on the floor, allowing them to dry completely in the air.
Now, these treated crumb rubber aggregates were added to the concrete mix during mixing process for casting treated rubber modified concrete.

Table – 2: Mix proportioning for rubber modified concrete mix

Mix Group (Untreated / Treated)	Cement Content (Kg/m^3)	w/c	Water Content (Kg/m^3)	Crumb Rubber Replacement (%)	Fine Aggregate (Kg/m^3)		Coarse Aggregate (Kg/m^3)		Super Plasticizer @ 1% by weight of cement (Kg/m^3)
					Crusher Sand	Crumb Rubber	20 mm	10 mm	
C	400	0.40	160	0.0	672	0.0	836	418	4
CR_5 / TCR_5	400	0.40	160	5.0	638.4	33.6	836	418	4
CR_{10} / TCR_{10}	400	0.40	160	10	604.8	67.2	836	418	4
CR_{15} / TCR_{15}	400	0.40	160	15	571.2	100.8	836	418	4

D. Testing

Consistency and bulk density of untreated and treated rubber modified concrete mix groups having replacement percentage 5 %, 10 % and 15 % were determined in accordance with IS: 1199-1959. Testing for compressive strength of control and rubber modified concrete (treated and untreated) was carried out as per IS: 516-1959. For each mix group of treated and untreated rubber modified concrete, a set of three cubes of 150×150×150 mm were prepared for testing at 7 , 28 and 56 days of curing respectively; this way a total of 63 cubes were cast. The specimens were tested in Compression testing machine (CTM) of 3000 KN capacity. Minimum of 3 cubes specimens for each mix group of treated and un-treated rubber modified concrete were cast for testing at each stage curing. The load was applied gradually and increased continuously at a rate of approximately 140 Kg/cm^2/min.

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III. RESULTS AND DISCUSSION

A. Effect on Bulk Density

The test results obtained for each mix group of rubber modified concrete are shown in Table - 3; The use of crumb rubber as a replacement of fine aggregates resulted in a reduction of the bulk density of fresh concrete.

Table – 3: Bulk Density for rubber modified concrete mix

Mix Group Untreated / Treated	Crumb Rubber Replacement (%)	Bulk Density (Kg/m3)
C	0.0	2466
CR_5	5.0	2322.59
TCR_5	5.0	2322.61
CR_{10}	10	2236.58
TCR_{10}	10	2236.60
CR_{15}	15	2134.40
TCR_{15}	15	2134.43

Effect of natural aggregate replacement with crumb rubber aggregate on the bulk density of concrete mix has been shown graphically in Fig. 2. From the figure, it can be observed that the reduction in bulk density was increased with the increase in the replacement percentage level. Moreover, for both untreated and treated rubber modified concrete mix the bulk density was approximately same.

Replacement of fine aggregate with 5%, 10 % and 15% of crumb rubber particles resulted in the loss of bulk density by 5%, 9.30 % and 13.44% respectively. Thus, reduction in bulk density was maximum for 15 % replacement of fine aggregate with crumb rubber aggregates. The reduction in bulk density of concrete mix can be attributed to the low specific gravity of the crumb rubber aggregate as compared to the natural fine aggregate (crusher sand).

However, another factor responsible for the reduction in bulk density could be because of increase in air void percentage when rubber aggregates are used because of the entrapment of air bubbles due to the hydrophobic nature of rubber aggregates and is well supported by the findings of other researchers as Siddique and Naik, 2004; Hernandez-Olivares and Barluenga, 2004, [9, 2].

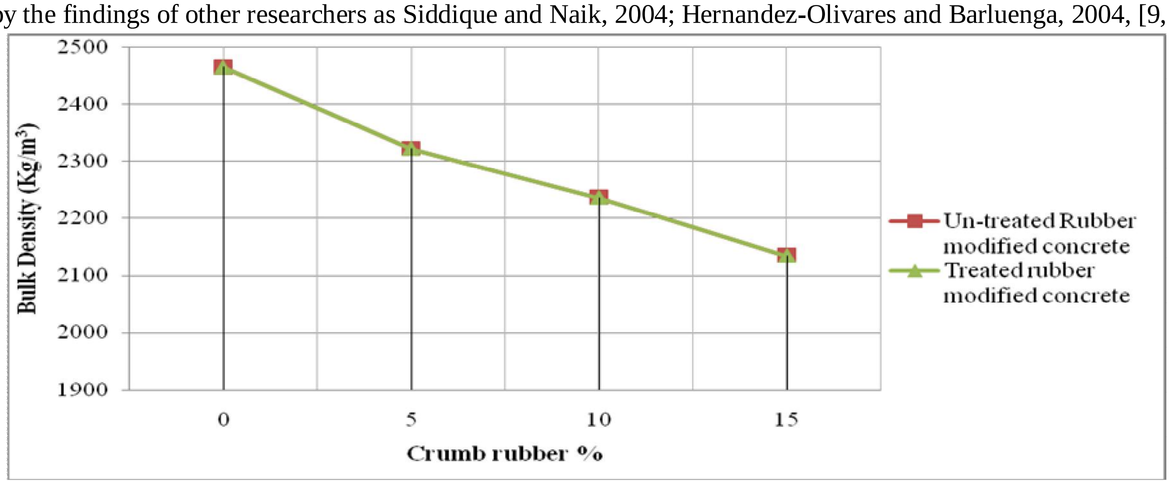

Fig. 2: Effect of crumb rubber content on bulk density of rubber modified concrete

B. Effect on Workability

The test results for workability of untreated and treated rubber modified concrete mix at replacement percentage of 0 %, 5 %, 10 % and 15 % are shown in Table - 4.

Table - 4: Slump Values for Treated and Un-treated Concrete Mix

Mix Group	Replacement percentage (%)	Slump (mm)
C	00	75
CR_5	5.0	65
TCR_5	5.0	70
CR_{10}	10	50
TCR_{10}	10	54
CR_{15}	15	40
TCR_{15}	15	45

From Fig. 3, it can be seen that the increment in the content of crumb rubber (treated / un-treated) in concrete mix caused the decrease in the concrete slump. Observation during mixing and casting showed that despite of decrease in the slump, workable mix was produced at all replacement percentage level. However, some difficulty in finishing was experienced in case of casting of rubber modified concrete mix CR_{15} and TCR_{15} as concrete mix became harsh. For concrete mix having treated crumb-rubber aggregate the slump reduction was slightly less as compared to the concrete mix having un-treated crumb rubber aggregates.

The reduction in the workability of untreated and treated crumb rubber modified concrete mix might be attributed to the following factors: 1), the rubber aggregates had rougher texture as compared to the natural fine aggregate which lead to increased friction between cement matrix and rubber aggregate and 2) Increase in percentage of Air Voids.

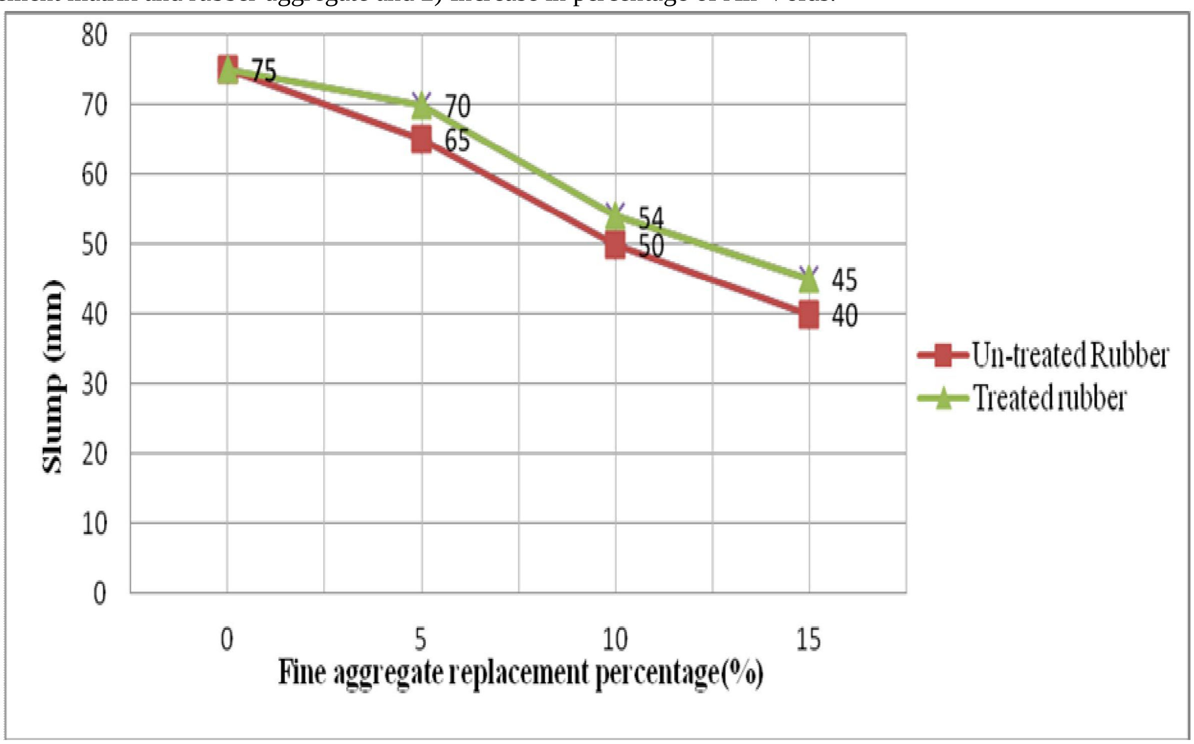

Fig. 3: Effect of fine aggregate replacement on slump of rubber modified concrete

C. Effect on Compressive Strength

The test results of compressive strength are shown in Table – 5. From the test results, it has been found that on replacing natural fine aggregate with the crumb rubber, there is significant reduction in compressive strength of concrete with respect to control concrete.

The loss of compressive strength might be attributed to: 1) low specific gravity of crumb rubber as compared to the natural fine aggregate, 2) increase in percentage air void, 3) low adhesion between crumb rubber aggregate and cement matrix and 4), possible reduction in concrete bulk density.

Table – 5: Compressive strength of treated and un-treated rubber modified concrete

Mix Group	Replacement percentage (%)	Compressive strength (N/mm^2)		
		7 days	28 days	56 days
C	0.0	35.46	48.07	53.57
CR_5	5.0	28.33	37.56	43.06
TCR_5	5.0	33.63	43.36	48.46
CR_{10}	10	22.24	28.06	33.56
TCR_{10}	10	27.64	34.06	38.96
CR_{15}	15	14.12	20.37	25.87
TCR_{15}	15	19.52	26.27	31.17

Fig. 4 shows the variation in compressive strength of untreated rubber modified concrete with the increase in crumb rubber content at 7 days, 28 days and 56 days. The reduction in compressive strength increased with the increase in percentage replacement of fine aggregate with crumb rubber, as shown in Fig. 4. Also, it illustrates that the compressive strength of untreated rubber modified concrete increases with the increase in curing time.

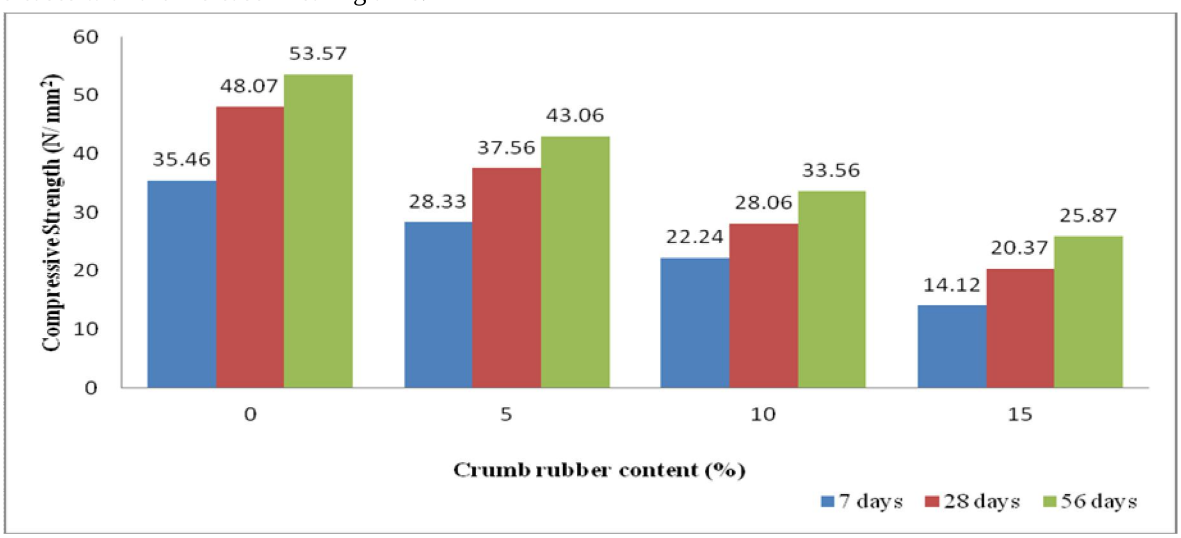

Fig. 4: variation of compressive strength of untreated rubber modified concrete with crumb rubber content

Furthermore, for treated rubber modified concrete also, the compressive strength of concrete decreases, but the reduction in compressive strength was less significant as compared to untreated rubber modified concrete for 7 days, 28 days and 56 days, as shown in Table - 5. The variation in compressive strength of treated rubber modified concrete with crumb rubber content has been shown in Fig. 5. The strength of treated rubber modified concrete also increases with the increase in curing time but decreases with the increase in crumb rubber content, as found in case of untreated rubber modified concrete.

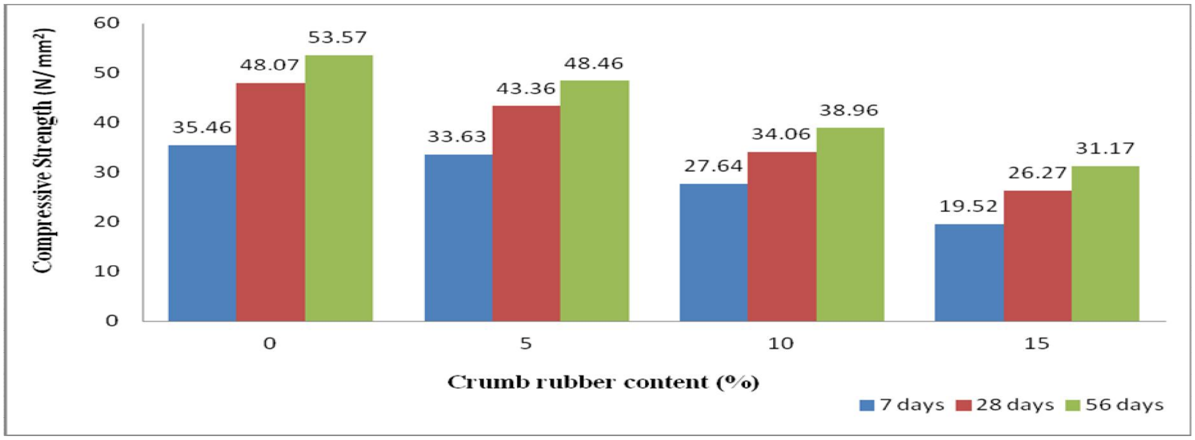

Fig. 5: Variation of compressive strength of treated rubber modified concrete with crumb rubber content

A comparative analysis of percentage compressive strength reduction with respect to control concrete in untreated and treated rubber modified concrete with the increase in crumb rubber content for 7 and 28days each, has been illustrated graphically in Fig. 6 and Fig. 7.

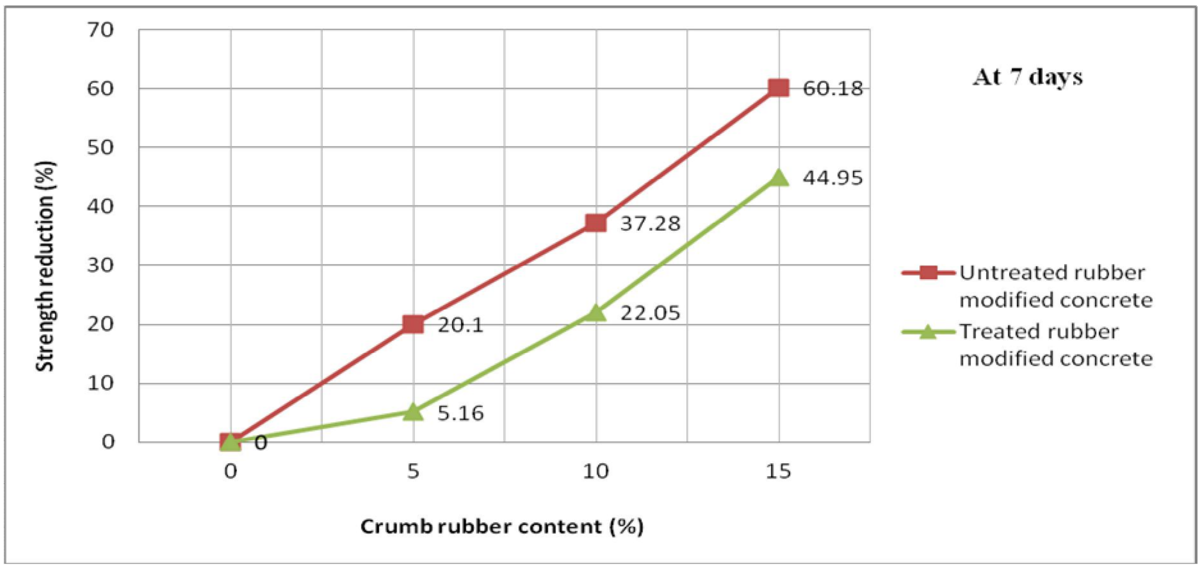

Fig. 6: Strength reduction in untreated and treated rubber modified concrete at 7 days

From Fig. 6, Using untreated crumb rubber aggregate to replace fine aggregate resulted in the strength reduction at 7 days by 20.1, 37.28 and 60.18 % for replacement percentage of 5, 10 and 15 %. While using treated crumb rubber aggregate to replace fine aggregate resulted in the strength reduction at 7 days by 5.16, 22.05 and 44.95 % for replacement percentage of 5, 10 and 15 %.

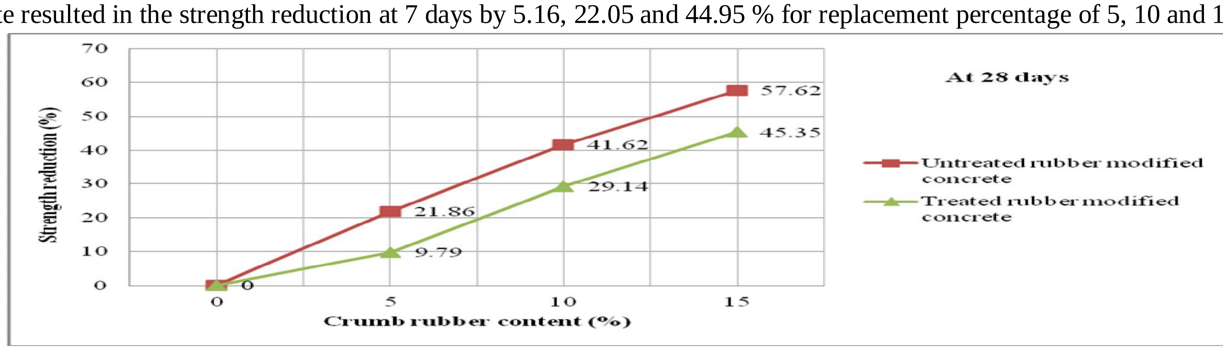

Fig. 7: Strength reduction in untreated and treated rubber modified concrete at 28 days

Fig. 7, using untreated crumb rubber aggregate to replace fine aggregate resulted in the strength reduction at 28 days by 21.86, 41.62 and 57.62 % for replacement percentage of 5, 10 and 15 %. While using treated crumb rubber aggregate to replace fine aggregate resulted in the strength reduction at 28 days by 9.79, 29.14 and 45.35 % for replacement percentage of 5, 10 and 15 %. The compressive strength of rubber modified concrete for 5, 10 and 15 % replacement level has been increased by 12.07, 12.48 and 12.27 % at 28 days on using treated crumb rubber aggregates over untreated crumb rubber aggregates.

All these results indicate that percentage strength reduction for treated rubber modified concrete is less than the untreated rubber modified concrete at all replacement percentages. Therefore, there is an improvement in the compressive strength of rubber modified concrete when pre-treated crumb rubber aggregate were used.

Furthermore, at 15 % replacement of fine aggregate with untreated crumb rubber aggregate, the compressive strength loss was more than 50%, which limits its application at this replacement level, when strength is of prime importance. In contrast, on replacing 15 % fine aggregate with treated crumb rubber particles the strength loss was less than 50 %, hence allows for its application in areas where desirable strength is required.

Also, as per Neville (1995) [10], the minimum strength of 17 Mpa and density range of 1350 - 1900 Kg / m3 is the criteria for Light weight concrete. Therefore, as per the results of present study, both untreated and treated rubber modified concrete might be used as light weight structural concrete at 15 % replacement of fine aggregate with crumb rubber aggregate. However, in order to fulfill the criteria for light weight concrete at replacement greater than 15 %, the pre-treatment of crumb rubber aggregates may become necessary.

The improvement in the compressive strength of rubber modified concrete can be attributed to the fact that pre-treatment of crumb rubber aggregate with synthetic resin lead to the strong adhesion or bond between crumb rubber aggregate and cement matrix.

IV. CONCLUSIONS

From the results and analysis of this experimental work, carried out, the following conclusions were arrived:

A. Replacement of fine aggregate with untreated / treated crumb rubber aggregate by 5, 10 and 15 % weight of fine aggregate in normal concrete resulted in decline of bulk density of concrete mix by approximately 5%, 9.30 % and 13.44% respectively in both the cases.

B. With the increase in untreated / treated crumb rubber aggregate content in the concrete mix, workability decreases. However, the loss of slump in treated rubber modified concrete mix at all replacement levels was slightly less than untreated rubber modified concrete mix. Workable mix was achieved at 5, 10 and 15 % replacement; but both untreated and treated rubber modified concrete mix became little harsh at 15 % replacement level.

C. The compressive strength showed decline in its value when untreated / treated crumb rubber particles were added. Reduction in strength increased with increase in the percentage replacement of fine aggregate with crumb rubber particles.

D. The strength reduction at 5, 10 and 15 % was less in treated rubber modified concrete as compared to untreated rubber modified concrete. The compressive strength of rubber modified concrete for 5, 10 and 15 % replacement level has been increased by 12.07, 12.48 and 12.27 % at 28 days on using treated crumb rubber aggregates. This shows that pre-treatment of crumb rubber aggregates with synthetic resin has improved the compressive strength of rubber modified concrete. The reason for improvement in strength might be attributed to the improved and greater adhesion between cement matrix and crumb rubber aggregates which lead to better interfacial interaction.

E. Untreated rubber modified concrete can find its application as standard concrete, up to 10 % replacement of fine aggregate; Whereas, for treated rubber modified concrete this replacement value has increased to 15 %.

F. Untreated rubber modified concrete satisfy the criteria up to 15 % replacement level for its application in light weight structural elements. But, above 15 % replacement, pre-treatment of crumb rubber aggregates might be necessary for satisfying the criteria of light weight concrete.

V. LIMITATIONS OF THE STUDY

Most of the factors in present study have been considered and taken care of in order to address various aspects and problems related to rubber modified concrete through pre-treatment of crumb rubber aggregates. However, there are some limitations related to present study which are highlighted as follows:

A. The type and quality of tyres which are used to manufacture the crumb rubber used in present study were not taken into account.

B. Pre-treatment of crumb rubber with Synthetic resin of other types may behave in different manner with concrete mix, and may have same or different impact on the strength parameters**.**

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