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Effect of partial replacement of coarse aggregates in concrete by untreated and treated tyre rubber aggregates

Shahid Rasool Tarry
Department of Civil Engineering, Lovely Professional University, Phagwara, Punjab, India

Abstract

Objective: Our present study intends to explore the most effective use of the waste tyre rubber as a constituent of concrete mix replacing the coarse aggregate partially.

Methods/Statistical Analysis: In this research work, emphasis is given on the pre-treating of the rubber particles and then using them as the partial replacement of the conventional rock aggregates. To get the best results, the rubber aggregates used are surface treated by sodium hydroxide and cement paste before using them in the concrete.M20 grade concrete is used.

Findings: Using untreated rubber aggregates, the compressive strength of the resultant concrete reduced rapidly, but when treated rubber aggregates were introduced, it resulted in the regaining of more than 90% of the 28 day compressive strength of normal concrete which can be considered quite satisfactory considering the easy and cheap availability of the used tyres and the negative impacts it can have on the environment if left unused. This much compressive strength is enough for treated-rubberized concrete for its use in different areas where compressive strength is not much important like in floors and concrete road pavements. Flexural and split tensile strength is found to be higher than that of the normal concrete but only when treatment is given to the rubber aggregates before using them. Workability is decreased. Flexibility gets increased and due to the lower unit weight of the rubber particles, it is also lighter than the normal concrete. These enhanced properties can be helpful in using this concrete in flexible slabs and as light weight concretes.

Improvement: Appreciable compressive strength, more flexural and split tensile strength, light weight, higher impact and toughness resistance which means prolonged and better resistance to formation of cracks, upgraded ductility, etc.

Keywords: rubber aggregates, rubberized concrete, sodium hydroxide (NaOH), cement paste, tread

1. Introduction

Waste Rubber tyres have a little scope of being recycled and mostly end up forming a landfill and degrading the environment. There is a great potential for rubber to be used in concrete, thus saves area from becoming landfill, which means eco-friendly. Rubber is easily available in the form of used tyres and is not as costly as other constituents of the concrete. Thus if it is used, it will result in more economical concrete. Rubber has better flexibility and has lower unit weight than the natural rock aggregates used in conventional normal concrete. Thus rubberized concrete will be very useful in places where more flexibility is required. Also, rubberized concrete can be used as light weight concrete. All the previous research done on this topic gives almost the same results which is decrease in compressive strength and weight, increase in flexibility, ductility, impact and toughness resistance and enhanced and better sound insulation. These results are however due to the use of untreated rubber. Very less work has been done on the treated rubber being introduced into the concrete. The rubber used in most of the previous research works has been used as such, which may be the reason for the negative results obtained by most of them because untreated rubber shows a weak bond formation with the cement paste and other constituents of the concrete. The problem relating to the decrease in the workability can be dealt with the help of addition of certain plasticizers. The shredded tyre rubber as the replacement of conventional rock aggregates should not be preferred for structural uses and should only be used in non load bearing places [1]. A good amount of compressibility allows the specimen to absorb more energy under compressive loads. Even when the specimen has failed under the ultimate load, it somewhat remains fixed together and does not get completely dismantled. Therefore we can conclude that the ductility of the concrete is increased [2]. With the intention of increasing the compressive strength, surface treatment of rubber particles just before use, by silica fume has also been tried in past. Development of ductile behavior was observed in concrete before it fails. The density gets decreased when percentage of rubber is increased in the concrete. It is because of the fact that the specific weight of the rubber is lesser than that of the natural rock aggregates. If some bonding material is used and pre treatment is given to the rubber aggregates, the strength is sure to improve. The flexural and impact strength of the crumb rubber filled concrete has been found to be more than latex modified and Portland cement concrete [3]. When the crumb rubber content is increased from 0-30%, there is a clear increase in the workability as well. Crumb rubber being more workable than the conventional/normal concrete can thus be very use full in certain conditions, where less workability is needed. The replacement of aggregates by crumb rubber also reduces the static modulus of elasticity and increases its deformability [4]. It can be used as light weight concrete though it shows less strength than the normal concrete. The rubberized concrete shows better ductility and flexibility than normal concrete which is very use full at the time of earth quakes. When 100% of aggregate is replaced by the rubber aggregates, there is a huge reduction of 75% of compressive strength which is extremely poor and highly non recommended [5]. Sodium hydroxide treatment increases the compressive strength of rubberized concrete and up to the replacement level of 25% by treated rubber, the requirements of a rigid pavement concrete can still be fulfilled [6]. Mechanical properties of $KMnO_4$ and $NaHSO_3$ treated crumb rubber concrete are better than the untreated rubberized concrete [7]. Surface treatment of crumb rubber by Lime stone powder and replacement of cement by silica fume enhanced the mechanical properties of the resultant mix by great extent [8]. It has also been found that by using silica fume in rubberized concrete, the resistance to the sulphate, acid and chlorine attacks can be largely increased [9].

2. Materials

Tyre Rubber Aggregates: The rubber used in this research work is from the tread of a truck tyre which is the part of the tyre that actually touches the ground or road. It literally covers the tyre. It is cut down manually to the size coarse aggregates. The size of the rubber aggregates is kept around 20mm.

Natural Aggregates: Fine aggregates used in the present research work are as per IS: 383-1970 which corresponds to zone II. Coarse aggregates are used in the sizes of 20mm and 10mm with a ratio of 60:40 having a specific gravity of 2.81 and 2.75 respectively.

Cement: The cement with which the mix design is done is OPC 53 grade.

3. Experimental Setup/Methodology

The moulds used for the preparation of samples were cubes of size (15cm x15cm x 15cm) for compressive strength testing, the beams of size (50cm x 10cm x 10cm) for flexural testing and the cylinders of size (10cm x 20cm) for split tensile strength testing.

Treatment of rubber: Treatment of rubber wastes involves its surface modification to improve the bond between rubber and the concrete components like cement paste and aggregates and it was done by soaking rubber particles in 0.1 molar solution of NaOH and in cemented suspension for about 20 minutes just before using them in concrete. When treated with cement paste showed that addition of rubber particles improved toughness and reduced the porosity of the specimens. SEM showed that NaOH surface treated rubber improved the rubber matrix bonding and also increased flexural strength and fracture energy. When the rubber particles are dipped in cement water suspension, cement adheres to its surface thus developed adhesive properties in it and helped in improving the bond in concrete.

3.1 Mix Proportion

The cement: sand: aggregate ratio of 1:1.5:3 is taken and the calculations of each constituent were done by weight analysis. For replacements, the aggregate replacement %age is taken as in Table 1. Water/cement ratio is kept as 0.45 for all samples.

Table 1: Mix proportion

S. No	Mix ID	Cement (Kg/m^3)	Fine aggregate(Kg/m^3)	Coarse aggregate (Kg/m^3)		Percent replacement by Rubber	Water cement ratio
				gravel	rubber		
1	PC	436	654	1309	00	00	0.45
2	UTR-5	436	654	1243	66	05	0.45
3	UTR-10	436	654	1178	131	10	0.45
4	UTR-15	436	654	1112	196	15	0.45
5	NTR-5	436	654	1243	66	05	0.45
6	NTR-10	436	654	1178	131	10	0.45
7	NTR-15	436	654	1112	196	15	0.45
8	CTR-5	436	654	1243	66	05	0.45
9	CTR-10	436	654	1178	131	10	0.45
10	CTR-15	436	654	1112	196	15	0.45

Where,
UTR-5 represents untreated 5% rubber.
NTR-5 represents sodium hydroxide treated rubber.
CTR-5 represents cement treated rubber.
PC represents plain concrete.

4. Results and Discussion

All the detailed test results are mentioned in Table 2 and their comparisons through graphs and charts are done in Figure 1, Figure 2, Figure 3, Figure 4 and Figure 5. Ultimate load and the corresponding displacement is also given

Table 2: Properties of rubberized concrete after 7 and 28 days

Sample	7-Day Compressive Strength-Cube (N/mm²)	28-Day Compressive Strength Cube (N/mm²)	28-Day Flexural Strength Beam (N/mm²)	28-Day Split Tensile Strength Cylinder(N/mm²)	Slump Value (mm)	Percent Reduction of Slump	Ultimate Load (KN)	Displacement (mm)
PC	19.11	27.33	8.10	2.38	50	0	16.20	0.96
UTR-5	13.87	19.80	7.95	2.10	47	6	15.90	1.12
UTR-10	16.44	23.50	6.90	1.90	45	10	13.80	1.10
UTR-15	15.60	20.40	6.40	1.60	43	14	14.80	0.80
NTR-5	16.40	23.30	9.30	3.82	48	4	18.60	1.30
NTR-10	17.70	25.30	8.75	5.72	44	12	17.50	1.50
NTR-15	11.11	15.60	7.51	6.36	40	20	15.02	1.38
CTR-5	15.60	22.2	9.25	4.76	45	10	18.50	1.60
CTR-10	12.11	15.50	8.51	4.28	42	16	17.02	1.45
CTR-15	17.33	21.70	8.00	4.07	35	30	16.00	1.30

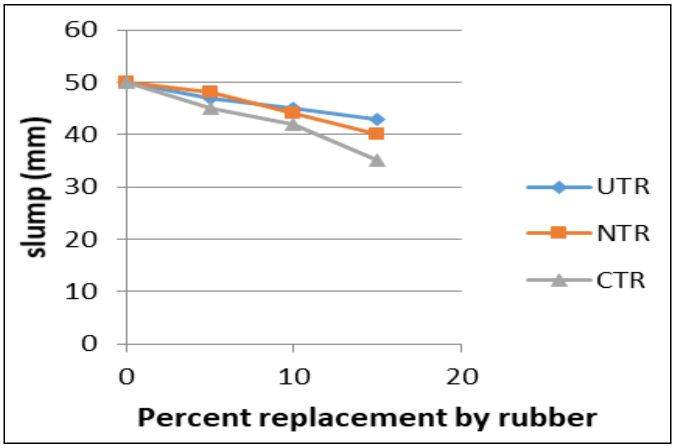

Fig 1: Slump vs percent replacement by rubber

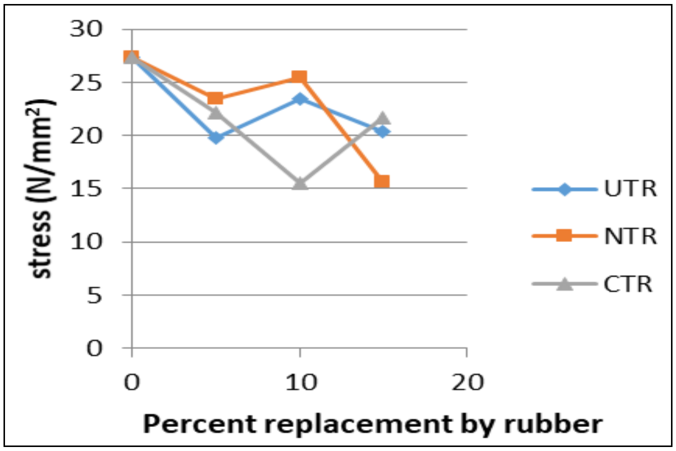

Fig 2: Variation of 28 day compressive strength vs percent replacement by rubber

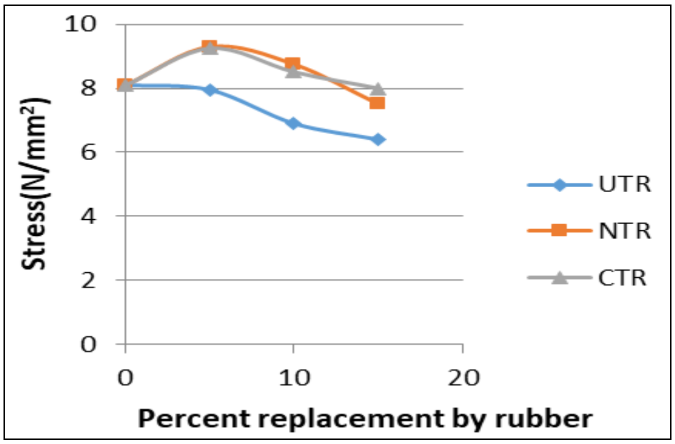

Fig 3: Variation of 28 day flexural strength vs percent replacement by rubber

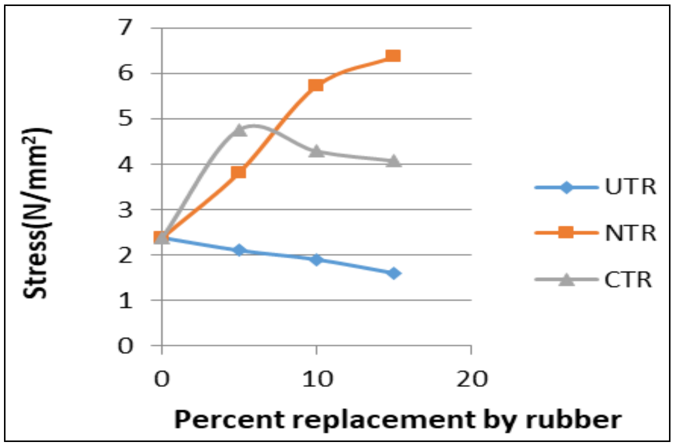

Fig 4: Variation of 28 day split tensile strength vs percent replacement by rubber

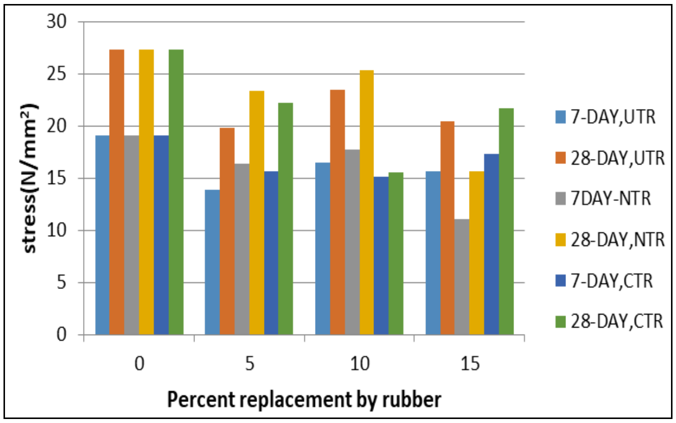

Fig 5: Comparison between 7 and 28 day compressive strength on varying percentages of rubber

4.1 Workability
The workability of both the treated and untreated rubberized concrete is found to be less than the plain concrete and decreases with the increase in percentage replacement of aggregates. As seen in the graph in Figure 1, apart from NTR-5, which has a slight increase of 1mm in slump value than the UTR-5, all other replacement levels and treatments show a decrease in the workability as the percentage replacement is increased. Low workability of rubberized concrete (untreated) is due to hindrance of movement of concrete paste and natural aggregates by rubber aggregates and due to improper bonding. When bonding is improved by NaOH treatment, decrease in workability is due to increase in viscosity. When cement paste treatment is given to rubber, workability decreases due to adherence of cement particles on rubber particles which absorb water from concrete and make less water available to provide workability.

4.2 Compressive strength
7 days compressive strength of NTR-10 is found to be highest among all the replaced mixes but lower than plain concrete. However 92.62% compressive strength of plain concrete is regained in this case which is quite satisfactory considering the material used. Similarly, 28 days compressive strength is found to be highest for NTR-10 but again lower than plain concrete. It accounts for 92.57% compressive strength of the conventional normal concrete which is quite considered satisfactory. The compressive strengths of untreated and cement treated rubberized concrete as compared to NTR-10 and plain concrete is found to be very less. Huge difference of elastic modules, lack of decent bonding and low adhesion between concrete constituents and untreated rubber particles may be attributed for less compressive strength. It is also due to low strength of rubber particles than concrete matrix around them and thus when force is applied; cracks first of all appear in contact zone of rubber and concrete matrix.

4.3 Flexural strength
Flexural strength shows a varying trend in our present study. 28 days flexural strength of NTR-5 is found to be highest among all replacement mixes as well as plain concrete. Untreated rubber concrete showed decrease in flexure strength while as treated rubber showed varying trend. In case of the treated rubberized concretes, the maximum flexural strength corresponds to 5% replacement level while as minimum flexural strength corresponds to 15% replacement. The increase in strength as compared to the normal conventional concrete at 5% replacement by treated rubber, is found to be around 13%. The mixtures with less cement content are less stiff. As the rubber aggregates can bridge cracks caused by flexural loading, the less stiff specimens with rubber aggregates can withstand additional loading after cracking. Thus increase in treated rubber aggregate content increases the flexural strength but only up to a replacement range of 5%.

4.4 Split tensile strength
Split tensile strength after 28 days is found to be greater in each case where treated rubber is used, and it is found to be highest at NTR-15(Sodium hydroxide treated with 15% replacement). At this replacement level, the split tensile strength is 2.67 times strength of normal concrete which is very huge and encouraging. This Increase in split tensile strength after giving treatment to rubber is due to combined effect of improved bonding by treatment and flexible nature gained by concrete due to rubber particle.

5. Conclusion
1. Rubber has great capability of becoming a permanent member of concrete family because of its wide variety of decent properties like better flexibility, light weight and easy availability. It can be very environmental friendly to use this waste material in construction industry.
2. Treated rubberized concrete possesses more compressive strength as compared to the untreated rubberized concrete. However, even after the surface treatment is given to the rubber, only 92.57% compressive strength of normal conventional concrete is regained.
3. Flexural and split tensile strength of almost all replacement levels of treated rubberized concrete is found to be more than in the normal conventional concretes. 28 day flexural and split tensile strength is found to be highest at NTR-5 and NTR-15 respectively.
4. The purpose of this study was to determine if a waste material like worn out tyres enhance the basic properties of concrete. The data presented in this research shows that there is great potential for the utilization of tyres as aggregates. It is considered that used tyres would provide much greater opportunities for value adding and cost recovery, as it could be used as a replacement for more expensive material such as rock aggregate.
5. Using rubber aggregates decreases the workability of the resultant mix, but this problem can be dealt with the use of the certain plasticizers.

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