Tyre Rubber as Aggregate in Concrete: A Possible Outlet for Used Tyres

Neela Deshpande, Nitish Desai, Payal Shah, Priyanka Kale, Yogesh Bhandalkar

Abstract--- About 80 million tyres are part of these 33 million vehicles manufactured in India in 2011. The usage of tyres for burning in cement kilns is up to 20000 tonnes per year. Landfill has been one of the methods for their disposal, however as rubber tyres are not biodegradable, they remain in the land for a long time causing environmental hazard. An alternative for this waste is use of the material in Concrete-A widely used material. In this paper an attempt is done to study the various properties of shredded rubber and crumb rubber. An attempt to design concrete of 25MPa using artificial sand and Shredded rubber as a source of aggregate is done, using IS 10262:2009. A comparison with control mix mainly their compressive strength, split tensile strength & flexural strength, which uses conventional material will allow assessing the suitability of using shredded aggregate in concrete in percentage, for structural applications. An attempt is also done to coat the Rubber particles with NAOH solution and use the same in concrete.

I. INTRODUCTION

About 80 million tyres are part of these 33 million vehicles manufactured in India in 2011.[1] After the use of these tyres, the waste generated are used typically for land filling, burning in cement kilns. However rubber tyre being a non biodegradable material and burning causes emission of harmful gases, they add towards environment hazard. In India the usage of tyres for burning in cement kilns is up to 20000 tonnes per year.[1,2] In industry large amount of waste tyres are utilized as fuel, pigment soot, in bitumen pastes, roof and floor covers and for paving industries.[2,3,4] In such a condition however, Recycled waste tire rubber is a promising material in the construction industry due to its lightweight, elasticity, energy absorption, sound and heat insulating properties by using rubber tyre waste in concrete as an alternative material. In this paper, an attempt is made to judge use of recycle tyre waste in concrete in percentages. These granulated rubber crumbs are achieved through a process called continuous shredding, which is necessary to create crumbs small enough to replace an aggregate as fine as sand. Such type of concrete is usually used in manufacturing of reinforced pavement and bridge structures which have better resistance to freeze and ice thawing salts.[5] Thus when use of rubberized concrete the following issues should be compared and evaluated when considering the application of such materials in the concrete: Collection, processing and transport costs of scrap tyres, Reduction in the environmental costs of land filling and increase in landfill voids and Saving in the virgin materials used to make concrete, by substituting tyre rubber.[6]

Compressive strength, split tensile strength and flexural strength of concrete utilizing waste tire rubber has been investigated and studied. Recycled waste tire rubber has been used in this study to replace the fine and coarse aggregate by weight using different percentages.

II. CRUMB RUBBER

Crumb rubbers are obtained by grinding. Crumb rubber-30 mesh is produced by passing rubber tires through a screen with 30 holes per inch resulting in rubber granulate that is slightly less than 1/30th of an inch.

![Figure 1, 2, 3: Crumb Rubber, Shredded Rubber, Shredded Rubber](image)

III. SHREDDED RUBBER

This fine grade reclaimed rubber product is manufactured from whole tyre scrap. These are the used tires from passenger car used tyres, primary shred size of pieces from 30 cm and below, the shred is the primary cut of used tires produced by eden primary chopper, container 40 ft load with 25 tons.

IV. LITERATURE REVIEW

The use of recycled tires as partial aggregate in concrete has been considered for several years. Previous research conducted show dramatic changes in the mechanical properties of concrete when rubber is introduced to the mix [2-11]. A tire is a composite of complex elastomer formulations, fibers and steel/fiber cord [1]. Rubber is the principal element of tire, making up about 85% of the tire where both synthetic

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and natural rubbers may be used. Natural rubber is an elastic hydrocarbon polymer which occurs as a milky colloidal secretion in the sap of several varieties of plants. Rubber can also be produced synthetically, as a thermoset polymeric material in which individual monomer chains are chemically linked by covalent bonds during polymerization [7]. Rubber filled concrete tends to have a reduction in slump, about 85% and density compared to ordinary concrete [2, 3, 7]. Several studies have shown that the compressive and tensile strength of rubber containing concrete is affected by the size, shape, and surface textures of the rubber as aggregate along with the volume being used indicating that the strength of concretes decreases as the volume of rubber aggregate increases [2-11]. Rostami [5] showed that the presence of rubber in concrete increases toughness. [6] Eshmaiel Ganjian et al [11] in their work the effect of replacing 5%, 7.5%, and 10% by weight of coarse aggregates by chipped tyres and the same replacement ratios for cement by powder tyre crumbs, were investigated. The results showed a reduction of 5% for 5% replacement. Replacement of 7% and 10% showed a reduction of 10-23% in compressive strength. The reason for reduction in the strength includes:

i. As the cement paste containing rubber particles surrounding the aggregates is much softer than hardened paste without rubber, the cracks would rapidly develop around the rubber particles during loading and expand quickly throughout the matrix, and eventually causing accelerated rupture in the concrete.

ii. Due to lack of proper bonding between rubber particles and the cement paste (as compared to cement paste and aggregates), a continuous and integrated matrix against exerted loads is not available. Hence applied stresses are not uniformly distributed in the paste. This is causing cracks at the boundary between aggregate and cement.

iii. During casting and vibrating the rubber particles tend to move upwards. A high concentration of these particles do happen on the top surface because of low specific gravity. On-uniform distribution of these particles at the top surface tend to produce non homogenous samples and leads to reduction in concrete strength at those parts resulting in failure at lower stresses.

iv. As rubber has lower stiffness compared to aggregates, presence of rubber particles in concrete reduces concrete mass stiffness and lowers its load bearing capacity. The slight increase in compressive strength of sample containing 5% chipped rubber can be due to improvement of the coarse and fine aggregates grading [7]. Segre and Joekes, in their study, added rubber particles in cement paste (rubber particle had a size with maximum 500μm). In order to decrease hydrophobic nature of rubber surface, NAOH solution was chosen. At first, the surface of rubber particles were modified by saturated NAOH solution for 20 min. They concluded that the rubber particles treated by NAOH show better cohesion with cement paste. The results indicate that there was an improvement in flexural strength by this procedure, but a 33% decrease occurred in compressive strength [15].

V. EXPERIMENTAL RESEARCH PROGRAMME AND MIX DESIGN

An experimental program was undertaken which consisted of testing properties of shredded rubber tyre as aggregates, and properties of fresh and hardened concrete specimens using shredded rubber tyre. The procedures for the programme were followed according to relevant BIS. The materials used were:

v. Conventional materials- Cement (C), Artificial aggregates (AFA) and coarse aggregates (RA-20mm) were purchased from the local vendors. Shredded tyre rubber were purchased from a factory of sizes 30 cm and below.

vi. Shredded tyre: This fine grade reclaim rubber product is manufactured from whole tyre scrap. These are the used tires from passenger car used tyres, primary shred size of pieces from 30 cm and below. The shred is the primary cut of used tires produced by eden primary chopper, container 40 ft load with 25 tons.


viii. The various mixes designed were as per the guideline laid down by IS 10262:2009 for M25 grade concrete with target strength as 31.6 N/mm2.

The mixes designed were

- Mix 1: C + AFA + RA-20mm) + A
- Mix 2: C + AFA + RA-20mm + 5% SR + A
- Mix 3: C + AFA + RA-20mm + 10% SR + A
- Mix 4: C + AFA + RA-20mm + 1% SR + A
- Mix 5: C + AFA + RA-20mm + 1% SR (treated with NAOH) + A

VI. RESULTS AND DISCUSSION

A. Properties of Materials

The surface texture of shredded rubber (SR) can be seen in the fig 1. It is smooth, irregular and having nylon fibers imbedded in the rubber. The structure of SR depends upon the method of shredding tyres and also the type of tyre which is being shredded. The fineness modulus, which is the indication of coarseness or fineness of a sample, of AS and SR was found which yielded the results as 3.05 and 4.641 respectively. The results indicate that SR is much coarser. An attempt to use SR as aggregate in concrete needs proper designing and also can be done in percentages and 100% replacement may not be done. Specific gravity of SR and AS are 0.967 and 2.89 respectively. This indicates that the SR are lighter than that of Artificial aggregates or conventional coarse aggregates. The main reason for this is the structure and presence of nylon fibers in SR. There is compared to AS, SR has an 15% decrease in water absorption. Bulk density of SR is 0.49 kg/lit and for AS is 1.35 kg/lit. The lesser value of loose bulk density of SR is attributed to the structure of SR.
Table 1: Properties of Fine Aggregate

<table>
<thead>
<tr>
<th>Property of Aggregate</th>
<th>AFA</th>
<th>SR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.89</td>
<td>0.967</td>
</tr>
<tr>
<td>Fineness Modulus</td>
<td>3.05</td>
<td>4.641</td>
</tr>
<tr>
<td>Moisture Content</td>
<td>2.83</td>
<td>-</td>
</tr>
<tr>
<td>Loose Bulk Density</td>
<td>1.94kg/lit</td>
<td>1.35Kg/lit</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>3.86%</td>
<td>-</td>
</tr>
<tr>
<td>Material finer than 75μ</td>
<td>2.85%</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 2: Properties of Coarse Aggregates

<table>
<thead>
<tr>
<th>Property of Aggregate</th>
<th>NCA-20mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific Gravity</td>
<td>2.86</td>
</tr>
<tr>
<td>Elongation Index</td>
<td>34.82%</td>
</tr>
<tr>
<td>Flakiness Index</td>
<td>14.7%</td>
</tr>
<tr>
<td>Loose Bulk Density</td>
<td>1.41kg/lit</td>
</tr>
<tr>
<td>Water Absorption</td>
<td>1.37%</td>
</tr>
<tr>
<td>Impact Value</td>
<td>16.22%</td>
</tr>
<tr>
<td>Crushing Value</td>
<td>21.67%</td>
</tr>
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</table>

VII. PROPERTIES OF FRESH CONCRETE

Properties of fresh concrete were mainly judged by workability by slump test. The values of slump tests for control mix and each replacement of shredded rubber are as shown in the table 3. The results shows that use of superplasticiser contributed towards better workability with the same w/c ratio. However with each increase of rubber content the workability as in terms of measurement showed a slump of 300mm. However further observation showed that the 300mm slump showed a little buckling pattern, the fact that the shape of shredded rubber-interlocking actions of wire, contributed towards holding the concrete and thus avoid the collapse of concrete. In contrast to the fact that 300mm slump yields poor workability, in general, the rubberized concrete samples showed acceptable workability in terms of ease of handling, trowelling, placement and finishing. The reduction in the workability of the concrete can be attributed to a combination of the lower unit weight of the wet mix and higher friction between the rubber aggregate and the mixture due the rough surface texture of the rubber aggregate particles. Fig 4 and Fig:5

Figure 4: Slump Obtained for Concrete with 5% Rubber

Figure 5: Slump Obtained for Concrete with 1% Rubber

VIII. PROPERTIES OF HARDENED CONCRETE

B. Density

The low specific gravity of the rubber chips produced a decrease in the unit weight of the rubberized concrete. The decreasing in unit weight of rubberized concrete when rubber content is lower than 10-20% of total aggregate volume [Khatib and Bayomy, 1999]. In the present study the specific gravity of shredded rubber is 0.946 which yielded the concrete with density 2480kg/m³ for 5%, 2195.55 kg/m³ for 10% and 2560.98 kg/m³ for 1% without NAOH and 2660.74 kg/m³ with NAOH. This is because of the low specific gravity of the rubber chips produced a decrease in unit weight of rubberized concrete when rubber content is lower than 10-20% of total aggregate volume. In the present study the specific gravity of shredded rubber is 0.946 which yielded the concrete with density 2480kg/m³ for 5%, 2195.55 kg/m³ for 10% and 2560.98 kg/m³ for 1% without NAOH and 2660.74 kg/m³ with NAOH. Vis a Vis for control mix the density attributes to 2715.06 kg/m³.

C. Compressive Strength

The compressive strength of concrete is an important parameter which is a main factor for accepting or rejecting concrete. The compressive strength was tested at 3, 7 and 28 days. The results were as shown in the table and in the graph. Each value is an average of 3 specimens. It is observed that a reduction of 5.43% in compressive strength as compared to control mix. An huge reduction of 76.14% for 10% of replacement with shredded rubber and 52.50% reduction with 5% replacement of shredded rubber with reference to the control mix. With reference to the past experiments done by authors, an attempt was made to use NAOH solution to coat the shredded rubber and use the same with 1% replacement in the concrete mix. The shredded rubber chips were dip in saturated NAOH solution for 20 min. They were dried and then washed in running tap water and used in concrete with 1% replacement in concrete. The test results at 28 days showed a small increase in compressive strength. As shown in Table 3 and Fig 5. The inclusion of the waste tires rubber in concrete acted like voids in the matrix. This is because of the weak bond between the waste tires rubber aggregates and concrete matrix. Basic three reasons can be attributed towards the reduction in strength:

1. With the increase in the voids in concrete with maximum replacement of rubber aggregates the decrease in strength was obvious.

2. Shredded rubber act as inclusion in the hardened concrete mass and as a result produced high internal stress that are perpendicular to the direction of applied load.

3. Failure of the sample is due to the waste tire being more elastically deformable than the matrix. When the sample was loaded the crack appears at these softest areas [13].
4. The presence of rubber aggregate tends to hold the sample fragments together at failure. This trend becomes more marked as the rubber content increases. This property can be highlighted, researched and can be used for structural applications.

Figure 6: Cube with 5% Replacement of SR

Figure 7: Interlocking of SR

Figure 8: Failure Pattern of Concrete Cylinder

D. Splitting Tensile Strength

The split tensile strength of various mixes are as shown in the fig and graph. A huge reduction in split tensile strength up to 76.59% is observed with concrete with 10% replacement of shredded rubber, similarly an reduction of 55.42% with 5% replacement of shredded rubber. A small reduction of 7.62% is observed when total aggregate content was replaced with 1% shredded tyre rubber. A reduction of 5.24% is observed when total aggregates in concrete were replaced by 1% of shredded rubber treated with NAOH. However in this study the use of NAOH has also contributed in increasing the compressive strength of concrete with 1% replacement of shredded tyre as aggregates in concrete.

However, there was a smaller reduction in splitting tensile strength compared to the reduction in the compressive strength.

E. Flexural Strength

The tests results for flexural strength of concrete control mix and percentage replacement of shredded rubber is as shown in the table 3and graph. It shows that the flexural strength of concrete has increases as compared to the control mix. An increase of 12% is observed in Flexural strength when shredded rubber was coated with NAOH solution, contradicting many experiments done by authors in the past. A reduction of 9.25 % was observed when shredded rubber without NAOH treatment was replaced by 1%. Due to low tensile strength of concrete as compared to its compressive strength, in lower stresses and before concrete reaches its ultimate strength in the compression region, failure will occur. A lack of good bonding between the rubber particles and the concrete are the reason for failure.[6 - 17] However in this study the use of NAOH has also contributed in increasing the compressive strength of concrete with 1% replacement of shredded tyre as aggregates in concrete.

Table 3: Results of Mixes

<table>
<thead>
<tr>
<th>ID</th>
<th>Mix proportions (M25) Kg/m3</th>
<th>Slump mm</th>
<th>Average compressive strength N/mm2</th>
<th>Split tensile strength at 28 Days N/mm2</th>
<th>Modulus of rupture at 28 Days N/mm2</th>
<th>Density Kg/m3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mix 1</td>
<td>C – 325 Kg/m3 AFA–724.63 Kg/m3 CA-20mm–1322.39 Water – Lit W/C – 0.47</td>
<td>68</td>
<td>16.90</td>
<td>19.99</td>
<td>32.66</td>
<td>3.41</td>
</tr>
<tr>
<td>Mix 2</td>
<td>5% Replacement of SR with total aggregate content</td>
<td>-</td>
<td>6.02</td>
<td>9.033</td>
<td>15.57</td>
<td>1.52</td>
</tr>
<tr>
<td>Mix 3</td>
<td>10% Replacement of SR with total aggregate content</td>
<td>-</td>
<td>4.2</td>
<td>5.46</td>
<td>7.82</td>
<td>0.80</td>
</tr>
<tr>
<td>Mix 4</td>
<td>1% Replacement of SR with total aggregate content.(without NAOH)</td>
<td>-</td>
<td>15.06</td>
<td>20.23</td>
<td>30.98</td>
<td>3.15</td>
</tr>
<tr>
<td>Mix 5</td>
<td>1% Replacement of SR with total aggregate content.(With NAOH)</td>
<td>15.53</td>
<td>19.50</td>
<td>31</td>
<td>3.23</td>
<td>3.9</td>
</tr>
</tbody>
</table>
It was found that rubberized concrete mixes did not pose any difficulties in term of finishing, casting, or placement, and that a good quality finish can be achieved although additional effort is required to smooth the finish surface. However, increasing the rubber aggregate content reduces the workability of the mix.

iii. The tests done on hardened concrete show that the use of rubber aggregate in concrete mixes produces a significant reduction in concrete compressive strength with increasing rubber aggregate content. However, if the amount of rubber in the concrete is limited (1% in the project), a normal strength concrete can still be produced. Use of NAOH to coat the shredded rubber contributes to a slight higher compressive strength which can be thought about for potential use in structural applications.

iv. Split tensile strength of concrete with shredded rubber showed a reduction. However 1% replacement of shredded rubber in total aggregate content can be for a concrete with M25 grade. A typical pattern of failure was also observed in cylinders wherein two separate halves were not seen as expected. However, the results also showed an enhancement of concrete flexural strength which could be beneficial in some applications.

v. Flexural strength of concrete with percentage replacement tends to increase with decrease in the percentage replacement of SR. However a greater advantage is observed when SR are treated with NAOH. This can be a encouraging study which can lead to use of SR for higher structural applications.

IX. CONCLUSION

The above work was an attempt to use SR in concrete with percentage replacement to the total aggregate content. The following points can summarize the findings of the work.

i. Properties of shredded rubber as compared to the artificial fine aggregate or Conventional coarse aggregate are not very encouraging. However an attempt to use them in concrete as percentage replacement can be done.

ii. In the present study, slump is not obtained for the mix with 5%, 10% and 1% Sr as a replacement to total aggregate content. A trend of buckling can also be viewed. However as contrast to the specifications given by IS 100262:2009, all the mixes were easy to work with.

X. REFERENCES


