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Improvement in Impact Resisting Capacity of Concrete Using Tyre Rubber Dust

Awadhesh Kumar, Mohit Lamba
Department of Civil Engineering, Delhi Technological University, Delhi, India
Email : awadheshg@gmail.com

Abstract : In concrete, the most voluminous constituent is aggregate and depleting resources of aggregate compels us to think about its substitute which may be a recycled or waste material. On the other hand, huge quantity of used tyres from vehicles, are causing problems in their disposal. Therefore, in present study, an effort has been made on the use of waste rubber dust as partial replacement of fine aggregate in concrete for improving its impact resistance. Four concrete designs were prepared for M20, M25, M30 and M35 using IS: 10262-2009 guidelines. Specimens were produced control mixes and %, 10 and 15% replacement of fine aggregates by rubber dust. The specimens were concrete cubes of 150 mm size for compressive strength tests and circular disc for impact tests. The rubber surface was pre treated with sodium hydroxide (NaOH) of 1N solution for 20 minute and then left to surface dry prior to mixing in concrete. This treatment modified the rubber surface, allowing the rubber to better adhere with cement paste. Various tests were carried out and results were compared between control concrete and concrete prepared with various percentage of fine aggregates replaced with rubber dust. Results show that as the replacement percentage of fine aggregate increases, compressive strength of concrete decreases and a maximum reduction of 42% in compressive strength is found in concrete, made with 15% replacement of fine aggregate by rubber dust. Also, the workability of fresh concrete diminishes drastically. However, with the increase in rubber dust percentage, impact resisting capacity of the concrete improved.

Keywords: Rubber dust, impact resistance, reduced elasticity, ductility and treatment of rubber dust with NaOH, better rubber surface adherence.

Introduction

Concrete is most widely used construction material in the world of which cement and aggregates are major constituents. Increasing utilization of natural resources in manufacturing of cement and aggregates is imposing a threat therefore a need to preserve natural resources has arisen by using alternative materials such as recycled or waste materials.

Also, there is huge concern over the disposal of non-degradable wastes such as tyres which are being dumped in landfills all over the world. This has posed a great health and environmental threat as it leads to increased breading of mosquitoes and other insects and rodents or increase in fire hazards at their dumping locations. Also, it affects the fertility of the soil if dumped into the ground.

Waste tyres also pose great fire hazard. Waste tyres stock piles are difficult to ignite, but if once ignited their fire is very difficult to extinguish. Tyres, if burned, release toxic product and may harm society by emitting green house gases and increasing air pollution. Moreover, it can lead to uncontrolled fire. Hence, there is a strong need to dispose of such materials in an environmental friendly way, The most promising use of these waste/ recycled tyres is in engineering applications like artificial reefs, erosion control and as an aggregate in concrete and asphalt.

Over the years, different kind of tyres have been employed as partial replacement of aggregates in concrete like scrap tyre crumb obtained by simple grinding without further purifications thus including steel and textile fibres in their composition, crumb rubber obtained by cryogenic process, milled tyre rubbers treated with sodium hydroxide solution to achieve a better adhesion with the cement paste, scrap truck tyre rubber, tyres tread etc. However, regardless the different nature, size and composition of used tyre rubbers, a meaningful decrease in compressive strength of concrete with the increasing amount of rubber in the mixture was always detected. The reason been reported is weak adhesion between rubber particles and cement paste, for which various treatment have been suggested to modify rubber surface.

Sodium Hydroxide (NaOH), also known as caustic soda is one such material considered best for the treatment of rubber surface for better bonding of rubber particles with cement paste.

Concrete strength is greatly affected by the properties of its constituents and the mix design parameters. Because aggregates represent major constituent of the bulk of a concrete mixture, its properties affect properties of the final product. There is huge debate still going on whether rubber aggregates in concrete are better as fine aggregate or coarse aggregate replacement. In fact one thing is clear that introduction of recycled rubber does change the properties of concrete.

Several studies have reported that rubber concrete tends to have lower workability, reduced density and higher air content. The tensile and compressive strength of rubber concrete is affected by size, shape, surface texture and quantity of replacement being used. Higher the volume of rubber in concrete, lesser is the strength properties. The reason of reduced strength has been reported as weak bond between rubber particles and cement paste.

The aggregate of rubber will however increase concrete's flexibility and elasticity. The altered characteristics of aggregated rubber may give concrete flexibility. Hence this study has been planned to check feasibility of using crumb rubber dust as a partial replacement for fine aggregate in concrete.

As the increase in urbanization, number of cars and wastage of used tyres impose a potential threat. Therefore the objective of this study was to look into feasibility of using crumb rubber dust

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in concrete and to evaluate the fresh and hardened properties of concrete produced by replacing part of natural fine aggregate with tyre rubber dust, so that this environmental friendly technology could give benefit to the society and nation.

Literature Review

New techniques and methods are continuously being worked upon to utilize various industrial wastes and other wastes to help the society and or improve the various properties of concrete. Utilization of flyash and ground granulated blast furnace slag in concrete addresses this issue in addition to improve concrete properties. Similarly, possibility of using solid waste as aggregate in concrete serves as one promising solution to the escalating solid waste problem. The use of concrete for disposal of solid waste has concentrated mostly as aggregates, because in that way a large quantity of solid waste could be used in concrete. The effect of waste materials on concrete properties must be considered. For example, lower modulus of elasticity of glass compared to that of good quality rock will lower the elastic modulus of concrete. Crushed recycled concrete has been used as an aggregate, producing concrete with strength and stiffness equal to about two-third of that obtained using natural aggregates.

Rubber aggregates are obtained by reduction of scrap tyres into aggregate sizes using two general processing technologies: Mechanical grinding and cryogenic grinding.

Mechanical grinding is the most common process in which a number of grinding techniques are used like ‘cracker mills’ and ‘granulators’. They break down the rubber shred into smaller particle sizes ranging from several centimetres to fraction of a centimeter. The steel bead and wire mesh in the tyres are magnetically separated from the crumb during various stages of granulation and sieve shaker separate the fibres.

Cryogenic processing is performed at a temperature below the glass transition temperature. This is usually accomplished by freezing of scrap tyre rubber using liquid nitrogen. The cooled rubber is extremely brittle and is fed directly into a cooled closed loop hammer mill, to be crushed into small particles, with the fibre and steel removed in the same way as in mechanical grinding. The whole process take place in absence of oxygen, so surface oxidation is not a consideration. Because of low temperature used in the process, the crumb rubber derived from the process is not altered from the original material.

To obtain rougher surface of rubber aggregate for better bonding with concrete matrix, the rubber surface should be treated with water to acid etching prior to mixing in concrete, and therefore higher compressive strength can be achieved.

The acid pre-treatment involves soaking of rubber aggregate in an acid solution for 20 minutes and then rinsing it in water. On observing through microscope, it increased the surface roughness of the rubber, which had improved its attachment to the cement paste. Neville [1] suggested that it is generally found that as the paste aggregate bond increases so does the strength.

Saturated NaOH solution can also be used to treat rubber particles. It does the same treatment as done by acids i.e. it makes the surface of rubber particle rough to improve its bond with concrete and thus improving the strength. Michelle et. al. [2] pre treated the rubber aggregates with a sodium hydroxide solution to modify its surface, affecting the interfacial transition zone and allowing the rubber to better adhere with cement paste. The use of treated tyre rubber as addition to cement paste shows satisfactory results in concrete mechanical properties.

Carbon tetrachloride can also be utilized for pre-treatment of rubber aggregates. It was found in various studies that when rubber aggregates were treated with carbon tetrachloride, compressive strength was improved by 57% as compared to the concrete containing untreated rubber particles.

A decrease in slump was observed with increase in rubber aggregates content as reported by Khatib and Bayomi [3]. They also mentioned that at 40% rubber aggregates of total aggregate by volume, slump was almost zero and concrete was not workable manually. Mixtures containing fine crumb rubber were however more workable than the mixture containing coarse rubber aggregate or a combination of crumb rubber and tyre chips. They found that increase in size or percentage of rubber aggregate decreased the workability of the mix and subsequently caused a reduction in the slump values.

Khatib and Bayomy [3] also found that there is a higher air content in concrete mixtures containing rubber aggregate when compared to control mixtures. It has been reported that even without any air-entrainment of admixtures the air content is significant. This may be due to non polar nature of rubber particles, when it is added in concrete mixture, it may attract air as it has tendency to repel water. In this way air may adhere to rubber particles. Increase in rubber content increases the air content, due to relative smaller density of rubber particles and incorporation of air in concrete, reduces the unit weight of mixtures. Khatib and Bayomy [3] also reported in his report that decrease in unit weight of rubber concrete is negligible when rubber content is lower than 10-20% of total aggregate by volume.

Lots of study has been carried out over compressive strength of concrete with rubber aggregates [4-9]. Earlier studies show that the compressive strength decreased as the rubber content increased. Eldin and Senouci [10] reported that there was up to 85% reduction in compressive strength when coarse aggregate was completely replaced by rubber chips and rubber crumb. However, when fine aggregate was completely replaced with fine rubber crumb, compressive strength was reduced up to 65%. Topcu [11] showed in his research that coarse rubber chips reduced the strength more than the addition of fine crumb rubber.

The strength reduction was mainly contributed by entrapped air and weak bond of rubber particles with concrete. Investigated efforts showed that the reduction in strength could be substantially reduced by adding a de-airing agent just prior to placement of concrete. It was indicated in studies that if rubber particles are pre-treated to make the rubber surface rougher, improved bonding may be developed and hence reduction in strength can be controlled up to some extent. Biel and Lee [12] mentioned in their report that magnesium oxychloride cement may provide higher strength and better bonding to rubber concrete as compared to Portland cement.

Michelle et. al. [2] reported that tensile strength of rubber containing concrete is affected by the size, shape and surface textures of the aggregate along with the volume being used,

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indicating that the strength of concrete decreases as the volume of rubber aggregate increases. As the rubber content increased, tensile strength of concrete decreased, but strain at failure was increased. This higher strain at failure is indication of more energy absorbent mix with rubber aggregate.

Rubber concrete exhibits good thermal and sound properties as compared to plain concrete by decrease in thermal conductivity co-efficient and increase in sound absorbing coefficient as reported by Sukontasukkul [13, 14] in his study. Also, in another study conducted by Han et. al. [15], it was shown that crumb rubber panels can be effectively used as traffic noise barriers.

Rubber concrete can possibly be used in the areas where vibration damping is required like foundation pads for machinery and railway stations or in areas where resistance for impact or blast is required e.g. railway buffers and bunkers. Due to lightweight, rubber concrete can also be suitable for architectural applications like nailing concrete, false facade and interior decorations. Shock absorbing property of rubber concrete can be utilized in highway construction as a shock absorber in sound barriers and also in buildings as an earthquake shock wave absorber.

Experimental Investigation

Materials

Cement

Ordinary Portland cement of 43 grade was used in the experimental work. The specific gravity of cement was 3.12.

Aggregates

Crushed coarse and natural fine aggregates were used in the study. Particle size distribution of the aggregates was determined using sieve analysis. Fineness modulus of the aggregates was also determined from the test results of sieve analysis. Sieve analysis test results of fine and coarse aggregates are given in Tables 1 and 2 respectively.

Specific gravity and water absorption of fine aggregate was determined in accordance with IS: 2386 (Part 3) – 1963 (Reaffirmed 1997) [17] and was found as 2.69 and 4.38 % respectively.

Similarly, specific gravity and water absorption of coarse aggregate was determined in accordance with 2386 (Part 3) – 1963 (Reaffirmed 1997) and was found as 2.80 and 0.52% respectively. Fineness modulus of coarse aggregate was determined by summing cumulative % of weight retained on sieves of 20mm, 10mm, 4.75 mm, 2.36 mm, 1.18 mm, 0.6 mm, 0.3 mm and 0.15 mm divided by 100 which is 7.13.

The crumb rubber samples were collected from A.P. Rubber Industries, Haridwar. The sizes of rubber particles were 30-mesh (595 μ), 60-mesh (250 μ) and 80-mesh (177 μ).

Table 1 Sieve analysis test results of fine aggregates

Sieve size (mm)	weight retained (g)	% weight retained	cumulative % of weight retained	% passing
4.75	37.7	3.77	3.77	96.23
2.36	180.3	18.03	21.80	78.20
1.18	231.1	23.11	44.91	55.09
0.6	137.3	13.73	58.64	41.36
0.3	145.6	14.56	73.20	26.80
0.15	208.0	20.8	94.00	6.00
Pan	60.0	6.00	-	-

Fineness modulus (F.M.) = Σ (cumulative % of weight retained) / 100 = 2.96

Mix proportions

Four concrete mix designs of M20, M25, M30 and M35 grade were finalised using IS: 10262 - 2009 [16] and the specimens were prepared with 0, 5, 10 and 15% replacement of fine aggregate by crumb rubber dust. The prepared specimens were cubes for compressive strength test and circular discs for impact tests. The rubber surface was pre treated with sodium hydroxide (NaOH of 1N) solution for 20 minutes and then left to dry prior to mixing in concrete. This treatment modified the rubber surface for better adherence to concrete matrix. The requirement of constituent materials for one m^3 of concrete, are given in Tables 3-6.

Table 1 Sieve analysis test results of coarse aggregates

Sieve size (mm)	weight retained (g)	% weight retained	cumulative % of weight retained	% passing
20	308.1	15.41	15.41	84.59
16	804.0	40.20	55.61	44.39
12.5	643.8	32.19	87.80	12.20
10	199.4	9.97	97.77	2.23
4.75	38.0	1.90	99.67	0.33
Pan	6.7	0.33	-	-

Table 3 Quantity of materials required for various mixes of M20 concrete

Material	Control mix (0% replacement)	5 % replacement	10 % replacement	15 % replacement
Cement (kg)	300	300	300	300
W/C ratio	0.45	0.45	0.45	0.45
Water (litres)	135	135	135	135
Super-plasticizer (kg)	Nil	Nil	Nil	Nil
Fine Aggregate (kg)	828.5	787.07	745.65	704.225
Coarse Aggregate (kg)	1293.6	1293.6	1293.6	1293.6
Rubber (kg)	Nil	41.42	82.85	124.27

Table 4 Quantity of materials required for various mixes of M25 concrete

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Material	Control mix (0% replace ment)	5 % replace ment	10 % replace ment	15 % replace ment
Cement (kg)	330	330	330	330
W/C ratio	0.45	0.45	0.45	0.45
Water (litres)	148.5	148.5	148.5	148.5
Super-plasticizer (kg)	1.65	1.65	1.65	1.65
Fine Aggregate (kg)	804.31	764.09	723.88	683.66
Coarse Aggregate (kg)	1255.8	1255.8	1255.8	1255.8
Rubber (kg)	Nil	40.22	80.43	120.65

Casting and Testing of Specimens

After priming, the solid constituent materials i.e. cement and aggregate were first mixed dry thoroughly in the batch mixer available in the laboratory thereafter three-fourth water was added and wet mixed. Finally remaining water and super plasticizer was added and mixed. Each batch of concrete was of such a size, as to leave small concrete after filling the desired number of moulds for test specimens. A coat of mould release oil was applied after clamping the moulds rigidly. These moulds were placed on vibrating table and filled two-third with fresh concrete. Thereafter, vibrating table was started and concrete was filled in the moulds a little later. The compaction was considered adequate when concrete started showing movement as a whole mass when top surface of concrete is pressed strongly by trowel and moved.

Table 5 Quantity of materials required for various mixes of M30 concrete

Material	Control mix (0% replace ment)	5 % replacem ent	10 % replace ment	15 % replacem ent
Cement (kg)	360	360	360	360
W/C ratio	0.45	0.45	0.45	0.45
Water (litres)	162	162	162	162
Super-plasticizer (kg)	1.80	1.80	1.80	1.80
Fine Aggregate (kg)	779.00	740.05	701.10	662.15
Coarse Aggregate (kg)	1216.32	1216.32	1216.3 2	1216.32
Rubber (kg)	Nil	38.95	77.90	116.85

Table 6 Quantity of materials required for various mixes of M35 concrete

Material	Control mix (0% replacem ent)	5 % replacem ent	10 % replaceme nt	15 % replacem ent
Cement (kg)	400	400	400	400
W/C ratio	0.45	0.45	0.45	0.45
Water (litres)	180	180	180	180
Super-plasticizer (kg)	2.00	2.00	2.00	2.00
Fine Aggregate (kg)	746.70	709.36	672.03	634.70
Coarse Aggregate (kg)	1165.00	1165.00	1165.00	1165.00
Rubber (kg)	Nil	37.34	74.67	112.00

The test specimens were stored at a place free from vibration for 24 hours, from the time of adding the water to the ingredients at room temperature. Thereafter, they were removed from the moulds, marked for later identification and stored in clean water till a little before testing.

The specimens stored in water, were tested in saturated surface dry condition after removing them from water. 150 mm cube specimens were placed in machine in such a manner that the trowel finished surface of the cube was in vertical orientation. The load on cubes was applied without shock and increased continuously at a rate of about 140 kg/cm^2/minute until the resistance of the specimen to the increasing load broke down and no greater load could be sustained. The maximum load applied to the specimen was recorded and appearance of the concrete along with any unusual features in the type of failure, were recorded. The compressive strength of each specimen was calculated (in N/mm^2 or MPa) by dividing the maximum load applied to the specimen during the test by the cross sectional area. Average of three specimen strength values was taken as the representative of the batch strength.

Disc shape specimens for impact test as per ACI-544 [18] report were prepared in the circular disc mould moulds having 152 mm diameter and 63.5 mm thickness and tested at 28 days. These specimens were also compacted and cured in the similar manner as the cubes for compressive strength. A specimen was placed in the positioning bracket, thereafter position lugs and the hardened ball was placed on the top of specimen within the bracket. The drop hammer was placed with its base upon the steel ball and held there with just enough down pressure to keep it from bouncing off the ball during test. The base plate was bolted into the concrete floor. The hammer was dropped repeatedly, and the number of blows required to cause the first visible crack on the top and to cause ultimate failure are both recorded. Ultimate

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failure is defined as the opening of cracks in the specimen sufficiently so that the pieces of concrete are touching three of the four positioning lugs on the base plate.

Test Results

Compressive strength and weight

In first phase of testing, the effect of fineness of rubber particles was determined. Concrete cubes of 150mm size were cast for M25 concrete with 15% replacement of fine aggregate by 30 mesh, 60 mesh and 80 mesh crumb rubber dust respectively. Table 7 shows average compressive strength of 3 cubes at 7 days and 28 days for these mixes along with control mix.

Table 7 Average compressive strength for different gradation of rubber dust

Sample No.	% rub ber	Type of rubber	Compressive strength (MPa)	
			7days	28 days
T-1	0	N.A.	29.57	39.04
T-2	15	30 mesh	21.88	26.67
T-3	15	60 mesh	19.65	26.09
T-4	15	80 mesh	18.34	22.74

In the second phase of testing, testing was done on M20, M25, M30 and M35 mixes, having a control mix and three mixes with 5%, 10% and 15% replacement of fine aggregate by rubber dust in each case. The compressive strength test results and unit weight of these mixes are given in Table 8.

The ultimate failure in impact test is defined as the opening of cracks in the specimen such that the pieces of concrete are touching three of four positioning lugs on the base plate. Number of blows required for ultimate failures were recorded and impact energy delivered to the failed specimens has been calculated as given below:

$E = N\, m\, g\, h$

Where, E is the impact energy (Nm), N is the number of blows, m is the mass of drop hammer (kg), g is acceleration due to gravity (m/s^2) and h is the height of the drop hammer (m). A view of impact testing equipment and failed specimens are shown in Fig. 1 and 2 respectively. Average number of blows and energy absorbed by a specimen up to failure under impact test are also shown in Table -8.

Fig 1 Impact testing equipment

Fig. 2 Failed specimens under impact test

Discussion

From Table 7 it is clear that a significant decrease in compressive is observed, i.e. up to 42% on addition of rubber dust in concrete. It is also observed that as the size of rubber particles decrease, the concrete mix becomes less workable and also the compressive strength reduces further.

Unit weight of 150 mm concrete cubes were recorded after 28 days of curing, the results are shown in Table 8. On comparison, 6 – 9 % reduction in unit weight of concrete has been found when 15% of fine aggregate is replaced with the rubber dust. This reduction in weight is expected because of low specific gravity of rubber dust as compared to fine aggregate which reduces the mass density of the mix. Maximum reduction in unit weight of concrete was found for M20 concrete and minimum in M35 concrete.

As observed in first phase of testing that the compressive strength of concrete reduces significantly on addition of rubber dust. 5% replacement reduces 28 days compressive strength by 13 – 23%, 10% replacement causes reduction by 26-39% and 15% replacement reduces compressive strength by over 45%. The reduction in compressive strength of a concrete, increases with the increase in percentage of rubber replacement.

Conclusions

1. A reduction in unit' weight up to 9% was observed when fine aggregate was replaced by crumb rubber dust. Further reduction in weight can be achieved by increased percentage of replacement of fine aggregate by the rubber dust, if lightweight concrete is required for non structural applications.
2. Increase in rubber dust content decreases compressive strength of concrete significantly. The pattern of strength reduction is similar for different grades of concretes. After 28 days of curing, compressive strength reduction was up to 54% with 15 % replacement for M20 grade concrete. This reduction in compressive strength can be attributed due to less stiff (i.e. flexible) rubber material used as replacement and poor bonding of rubber particles in concrete matrix, which makes rubber particles to behave as voids, resulting in a reduction of compressive strength.
3. The visual observation revealed that the control concrete shows a failure with clear distinct cracks. Whereas, in rubber concrete, the failure behaviour was not well defined, it was gradual as compared to brittle failure of control concrete, which shows more ductility in rubber concrete than the normal concrete.
4. Impact resistance capacity of concrete increases significantly as the percentage of rubber particles increases in concrete. The results also show that for lower grade of concrete, the increase in impact resistance capacity is higher in percentage than for higher grade of concrete. The increase in absorbed energy is 133% forM20 grade concrete against 68% for M35 grade concrete for 15% replacement of fine aggregate with rubber dust.
5. On addition of rubber dust to the concrete, the workability of concrete reduces and more water is required for the mix to maintain workability. Addition of super-plasticizer can be an alternative to maintain low water/cement ratio of the mix.
6. Use of rubber in concrete reduces environmental threat, caused by the waste tyres and also introduces as an alternative source of aggregate for concrete.

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Table 8 Average compressive strength for different grade of concrete and replacements

Sample No.	Grade of concrete	% rubber	Weight (kg/m^3)	Compressive strength (MPa)		No. of blows	Absorbed energy (Nm)
				7 days	28 days		
Set-1	M20	0	2459.26	20.12	27.87	180	3660
Set-2	M20	5	2370.37	18.19	21.60	276	5612
Set-3	M20	10	2281.48	15.00	17.13	320	6507
Set-4	M20	15	2234.90	10.13	12.79	419	8519
Set-5	M25	0	2510.78	28.67	40.62	351	7137
Set-6	M25	5	2419.33	24.67	33.41	486	9882
Set-7	M25	10	2385.21	22.82	28.56	517	10512
Set-8	M25	15	2340.74	18.83	21.08	673	13684
Set-9	M30	0	2548.15	35.78	47.62	621	12627
Set-10	M30	5	2459.26	31.32	39.50	799	16246
Set-11	M30	10	2429.63	24.30	33.56	930	18910
Set-12	M30	15	2379.16	19.92	24.59	1080	21959
Set-13	M35	0	2573.41	37.17	51.81	750	15250
Set-14	M35	5	2518.52	32.52	45.13	876	17812
Set-15	M35	10	2488.89	25.05	38.33	1047	21288
Set-16	M35	15	2414.80	21.12	28.09	1260	25619

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