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Experimental Study on Strength behavior of Concrete with partial replacement of Cement with Silica fume and Coarse aggregate with waste Tire Rubber: A Review

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Abstract

A very large amount of waste rubber tire are being generated each year all around the world. Being non-biodegradable in nature their recycling is not easy. On burning they produce very toxic and harmful smoke. So the only option is to dump them to landfills. It is also not a proper solution as it takes a lot of space and stockpiles of waste rubber leads to soil pollution and contaminate water bodies along with ground water. Statistics show that every year more than 500 million tires are discarded to landfills, and the estimation is about 5000 million tires would be discarded by 2030. Many research studies has shown that the waste rubber tires could be used in concrete. Concrete with rubber tire has shown reduction in compressive and flexural tensile strength but they do possess some positive aspects as they have better toughness, impact resistance, thermal and sound properties. This paper presents a literature review on using waste rubber tire in concrete as a partial replacement of cement, coarse or fine aggregates.

Keywords : Crumb rubber, chipped rubber, ground rubber, cement, silica fume, rubberized concrete

1. Introduction

The recent growth of automobile industry and use of vehicles has increased the production of tires all through the world. This has lead to large accumulation of used tires. The major problem of these tires is their disposal. Million of tires are discarded each year causing environmental risk to pollution.

It is estimated that each year about 1000 million tires end their service life and more than 500 million among them are discarded to landfills [30]. A future estimation is that the number of waste tire discarded yearly would reach 1200 million. And there could be as many as 5000 million of stockpiled discarded tire throughout the world. In 2008, the global production of waste tire was about one billion and production of new tires was about 1.5 billion. Rubber Manufacturer's Association [31] in one of their statement say that every year about 75 million of waste tires are stockpiled in US itself and more than 230 million are produced. In India also there would be about 112 million of discarded tire per year after retreading twice [13].

These waste tires are non-biodegradable in nature and on burning produces very harmful and toxic gases dangerous to health. So, a maximum amount of these waste tires are thrown to landfills causing very adverse effect on environment. A very small amount of rubber from the tire gets abraded after its whole service life, this means that a whole of rubber is discarded. Their disposal in landfill also has some adverse effect on nature. Along with occupying a very large space in a landfill their decomposition also creates a variety of issues making it unfeasible to decompose. Waste tire rubber own shape allows it to store water for a long period causing a breeding place for mosquitoes and other insects. It also causes contamination of underground water and above ground water and also spoils the fertility of soil by destroying many beneficial bacteria present in soil. [Wikipedia]

Research in the past has shown that these waste tire rubbers could be used in concrete. In literatures, the term "Rubberized Concrete" or "Rubber Modified Concrete" is used for concrete made with mixing waste tire rubber particles into plain concrete. A lot of properties gets enhanced by replacing some components of concrete with waste tire rubber particles making it suitable for use in a particular work. Many countries have made it compulsory to use waste tire rubber in their construction work. In this way it could be proved to be a means of sustainable development.

Waste tire rubber particles have been used in concrete in three different forms: (1) Shredded or Chipped rubber- It's size vary from 2- 20 mm. It is used to partially replace coarse aggregates. (2) Crumb rubber- It's size vary from 4.75- 0.425 mm. It is generally used to partially replace fine aggregates. (3) Ground rubber- It is in the powder form. It's size is less than 0.425 mm. It is used to partially replace cement content.

2. Properties of concrete

2.1 Fresh concrete properties

2.1.1 Workability

Aiello and Leuzzi [1] use rubber shreds and reports that the workability of concrete is slightly improved with the addition of rubber shreds. Elchalakani [2] used rubber powder and reports that the concrete exhibits good workability when admixtures is added in proper amount. Guneyisi [3] used crumb rubber in self-compacting concrete to replace sand and observed that the mix does not showed the required slump flow. Freitas et al. [4] have reported a decrease in slump. Huang et al. [5] says that workability reduces with an increase in the amount of rubber content. Su et al. [6] also reported a reduction in the slump of rubberized concrete and explains that rubber contents absorbs higher amount of water. cairns et al. [7] replaces coarse aggregates with rubber having maximum size of 20 mm and noticed a reduction in the workability. Holmes et al. [8] replaces fine aggregates with crumb rubber grades and explained that workability decreases with increase in crumb rubber content.

2.1.2 Density

Holmes et al. [8] uses crumb rubber of 10- 19 mm sizes for the replacement of fine aggregates with 7.5% and 15% and reports a decrease in the density in comparison with control mix. They explain that it could be due to the lower relative density of crumb rubber concrete than plain concrete with natural aggregates. Crumb rubber concrete also has a higher air contents than plain concrete. Sukontasukkul and Tiamlom [9] reported a reduction in the density for higher amount of crumb rubber. They also noticed that the density of mix was more effected by the use of crumb rubber of smaller size. Pelisser et al. [10] also noticed a reduction in density of rubberized concrete. Gesoglu et al. [11] uses tire chips, crumb rubber and fine crumb rubber as a replacement for both coarse and fine aggregates to prepare a rubberized pervious concrete having densities lesser than that of the control mix by about 2- 11%.

2.2 Hardened concrete properties

2.2.1 Compressive strength

Gupta et al. [12] uses rubber ash and rubber fibers to partially replace fine aggregates and observed that the compressive strength of rubber ash is decreased with increase in percentage of rubber ash. Also, the compressive strength increases marginally for w/c ratio of 0.55. At w/c ratio 0.55, homogeneous and improved packing of rubber particles due to higher workability of the mix is the reason explained for better compressive strength. Thomas et al. [13] uses three different sizes of crumb rubber mixed in definite proportions to replace fine aggregates, observed that the compressive strength showed a decreasing trend for the increased percentage of crumb rubber. Ganjian et al. [14] used chipped rubber to replace coarse aggregate, and ground rubber to replace cement and explained a reduction in the compressive strength. Guneyisi et al. [15] also mentioned that the strength of concrete containing crumb rubber and tire chips decreases with rubber content. Holmes et al. [8] also showed that there was a decrease in the compressive strengths of all crumb rubber concrete samples. And also mentioned that the significant reduction in the compressive strength could be avoided when the crumb rubber replacement level does not exceed 20 percentage of the total aggregate content.

Al- Akhras and Smadi [16] used tire rubber ash (obtained by incineration of bulk quantities of tire rubber chips in an oven at a temperature of 850o C for 72h) to replace sand partially at different levels to prepare mortar. They observed that the compressive strength of mortar sample increases with an increase in tire rubber ash content. At 28 days period, the compressive strength of mortar sample were increased by 12%, 14%, 23% and 40% for tire rubber ash content of 2.5%, 5%, 7.5% and 10% respectively. Gesoglu et al. [11] also reported a reduction in compressive strength of pervious concrete and the rate of reduction in strength increases with increasing rubber content.

Huang et al. [5] has used waste rubber in two ways: uncoated rubber and coated rubber with silane coupling agent and observed that the coated rubber has more compressive strength than uncoated rubber. This is due to the better chemical bonding and the interface around the rubber particles are improved. Some studies have shown that, zinc stearate is present in rubber particle which prevents the formation of strong bond between rubber particles and cement paste. Pre-treatment of rubber particles in NaOH solution removes the zinc stearate and improves the adhesion between rubber and cement. ElGawady et al. [17] applies this pre-treatment method and observed that the compressive strength of concrete specimens treated with NaOH increased by 15 percentage at 28 days in comparison to the non-treated specimen.

2.2.2 Flexural tensile strength

Al- Akhras and Smadi [16] in their study on tire rubber ash mortar observed that the flexural tensile strength was enhanced when fine aggregate is replaced upto 10 percentage with tire rubber ash. Segre and Joekes [18] also reports the enhancement of flexural tensile strength of concrete with rubber particles. The strength increases further if the rubber particles are pre-treated with NaOH solution. Ganjian et al. [14] replaces coarse aggregate with chipped rubber and cement with ground rubber and observed a reduction in flexural tensile strength by 37 percentage, if only coarse aggregate is partially replaced with chipped rubber. And a reduction of 29 percentage is observed if both coarse aggregate and cement is partially replaced for chipped rubber and ground rubber. This is due to the lack of good bonding between rubber particles and cement paste. Su et al. [6] also reports a reduction in flexural tensile strength by 12.8% for 20 percent replacement of fine aggregates with rubber contents. The reduction in strength was more for smaller sized rubber particles. Aiello and Leuzzi [1] also observed loss in flexural tensile strength. The loss was more when coarse aggregates was replaced with tire rubber in respect of fine aggregates replacement. Gupta et al. [12] also observed that the flexural tensile strength of concrete containing rubber ash decreased with increasing percentage of rubber ash.

2.2.3 Toughness and Impact resistance

Balaha et al. [19] studied the effect of using ground waste tire rubber as fine aggregates on the behaviour of concrete mixes and reported that the damping ratio of concrete containing 20 percent rubber particles gets enhanced by 63.2%. Similarly, Zheng et al. [20] also reported a 75.3% increase in damping ratio of concrete containing rubber. Ruiz et al. [21] explained that the replacement of 15 percent of cement with epoxy resin and tire rubber had slightly higher toughness than traditional concrete. Taha et al. [22] also explains that significant enhancements in the impact resistance and fracture toughness of rubber concrete is observed. Rao and Mujeeb [23] observed an increase in impact strength as the percentage of crumb rubber increases upto 15 percent. Also, the toughness is enhanced by about 14 times in concrete containing 15 percent of crumb rubber than control mix. Khatib and Bayomy [24] reports a gradual failure of specimens containing rubber particles is seen whereas a sudden failure in control specimen. Also, the failure mode shape of the test specimen is either a conical or columnar. Biel and Lee [25] also reported the failure of concrete containing 30- 60% of rubber particles replaced for fine aggregates to be gradual shear that resulted in diagonal failure, while the failure of control concrete specimen was explosive.

2.2.4 Water absorption and permeability

Gupta et al. [12] have replaced fine aggregates partially with rubber ash and observed that the percentage of water absorption of rubber ash concrete increases with the increase in rubber ash content. Water absorption of rubber ash concrete at 28 days is 1.26 for 20 percent replacement while for 0% replacement it is 1.08. This is due to improper compaction of rubberized concrete that leads to lower density of rubber. Thomas et al. [13] used crumb rubber in three different sizes mixed together to replace fine aggregates upto 20%. They observed that the permeability decreased for 5% replacement and there after it started to increase gradually upto 20%. Mohammed et al. [25] on their study on crumb rubber hollow concrete block observed that the water absorption increases with the increase in the percentage of crumb rubber replaced for fine aggregates. Onuaguluchi and Panesar [26] reported increase in porosity and water absorption with an increase in the percentage of crumb rubber in concrete. Brito and Bravo [27] has used tire rubber aggregates to replace both coarse and fine aggregates with replacement of 5%, 10% and 15% by total volume of aggregates. They observed that the water absorption increased by immersion of the concrete mixes. Azevedo et al. [28] also reported an increase in capillary water absorption with increasing crumb rubber content partially replacing fine aggregates. Gesoglu et al. [11] in their study on pervious concrete containing waste tire rubbers, explained that the permeability coefficient of the rubberized pervious concrete fell between 0.025 and 0.61 cm/s making it suitable to use in pavements. Sukontasukkul and Tiamlom [9] explained that when crumb rubber passing sieve no. 6 is used to prepare concrete, it shows better water absorption than control concrete.

2.2.5 Thermal and Acoustic properties

Thermal conductivity is the property of a material to conduct heat. Plain concrete as we know that is not that much good in thermal properties or sound insulation properties. Some research papers shows it that the rubberized concrete is much better in these properties. Mohammed et al. [25] in their study on properties of crumb rubber hollow concrete block have explained that the thermal conductivity decreases with an increase in the percentage of crumb rubber. When Silica fume and Fly ash is used to partially replace cement, then this leads to further reduction in the thermal conductivity. This is due to the lower thermal conductivity of Silica fume and fly ash in comparison to the cement.

Sukontasukkul [29] studied on pre-cast concrete panel using crumb rubber. Crumb rubber were used in two different sizes: No. 6 (passing ASTM sieve no. 6) and No. 26 (passing ASTM sieve no. 26) to replace fine aggregates. The conductivity of crumb rubber concrete was found to be lower than 20- 50% than that of the control specimen.

Ability of concrete to reduce the transmission of sound through it is termed as the acoustic properties of concrete. Plain concrete is a poor sound absorber and it leads to echoes within enclosed spaces [8]. Holmes et al. [8] studied on the acoustic properties of concrete panel in which they have used crumb rubber of 10- 19 mm sizes that has been used to replace fine aggregates. They explained that the absorption coefficient of crumb rubber concrete is 0.013 for 7.5% replacement of fine aggregate while that of control specimen is 0.018. Also, the sound absorption increases with an increase in size and volume of rubber particles. Crumb rubber concrete also exhibited better performance as an insulator. Mohammed et al. [25] have also explained that crumb rubber concrete has better sound absorption in comparison to the conventional concrete. Noise reduction coefficient increases with an increase in the percentage replacement of crumb rubber contents.

Sukontasukkul [29] studied on sound absorption of the crumb rubber concrete under two frequency ranges: (1) low-mid-frequency (125, 250 and 500 Hz) and (2) high-frequency (1000, 2000 and 4000 Hz). He explains that, at the low frequency range of 125 and 250 Hz both- control mix and crumb rubber concrete have similar sound absorption coefficient. But at the mid frequency (500 Hz), the crumb rubber started showing better results. And at higher frequency more than 1000 Hz , the sound absorption coefficient of crumb rubber concrete was much better than control specimen. This shows that crumb rubber concrete has superior sound absorption properties than plain concrete.

3. Conclusion

3.1 Workability reduces with an increase in the amount of rubber content. On reviewing literature, we conclude that workable concrete can be made with waste tire rubber if proper admixtures are used in required proportions. Density of rubberized concrete is lower than that of plain concrete. This is due to the lower density of rubber in comparison to the densities of natural aggregates. So, it is also possible to make lightweight concrete and pervious concrete with waste tire rubbers.

3.2 A very large reduction in compressive and flexural tensile strengths of tire rubber concrete can be seen. With an increase in rubber content, the compressive strength of concrete sample reduces but in cement mortar it is enhanced significantly. Strength in concrete specimens could be slightly improved by method of pre-treatment of tire rubbers with NaOH or other chemical solutions. This leads to an increment in the adhesion of cement-rubber particles and hence stronger bonding is achieved. So, rubberized concrete is not suitable for use in heavy structural components but it could be used in non-structural components such as Crash barriers, Pavement blocks, Sidewalks, Road culvert, precast roof, Roofing tiles, partion walls etc.

3.3 The toughness of concrete is much improved with the inclusion of rubber content. Damping ratio for rubberized concrete also gets enhanced. Also, with the inclusion of tire rubber in concrete it leads in the formation of a concrete having enhanced energy absorption and better failure criteria i.e. chance for sudden failure is reduced. This make rubberized concrete suitable for use in: foundation of heavy machinery, Dampers to be used in earthquake resistant structures, skid resistant ramps.

3.4 Water absorption of tire rubber concrete is more than that of plain concrete and it increases with increasing rubber content. Porosity is also better in tire rubber concrete.

3.5 Tire rubber concrete has better thermal and acoustic properties over plain concrete. It has low conductivity and also it gets reduces with increase in rubber concrete. Sound absorption of tire rubber concrete is better than plain concrete and it also gets better with increase in size and volume of rubber particle. This make it suitable for use as barrier or insulator for heat and sound transmission.

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