MECHANICAL PERFORMANCE OF RUBBER CONCRETE: EXPERIMENTAL INVESTIGATION

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ABSTRACT

Conventional building materials are facing some challenges due to their high demand and durability. Alternative materials or partial replacement of the traditional ones by abundant waste is now focused on overcoming any undue environmental impact. The used rubber tyre is generally dumped and considered as non-decaying materials, which contaminate the surrounding environment. This rubber has high elastic property when force is applied to it and undergoes significant deformation, and can store energy. This research aims to represent the mechanical properties of rubberized concrete and compare them to control concrete. In this study, inert materials (fine and coarse aggregate) of concrete were replaced with rubber crumbs by volume of these aggregates: 0%,2.5%,5%,7.5%10,12.5%,15%. A series of specimens were cast with partial replacement (0%,2.5%,5%,7.5%10,12.5%,15%) of aggregate by crumped rubber in volumetric measure. After testing, it was observed that the workability was increased with an increasing percentage of rubber crumbs linearly. The compressive strength decreases with increasing rubber crumb amount when compared to normal concrete (0% replacement level). However, an opposing result was found in the case of splitting tensile strength up to 5 % replacement level. At this level, compressive strength was reduced by 7.08%, and splitting tensile strength was increased by 13.45%, compared to the zero percent replacement level. Based on these results, it may be concluded that a five percent aggregate replacement level could be considered for rubber concrete.

Keywords: *Rubber Crumb, Compressive Strength, Splitting tensile strength, workability*

1. INTRODUCTION

Waste tyre rubber is a highly elastic material. When a force is applied to rubber, it can deform significantly, but it will return to its original shape once the force is removed. This property is known as elasticity or elastic behaviour. So, waste tyre rubber in concrete improves the ductility and energy absorption capacity of concrete to maintain other mechanical properties of concrete. Improper disposal of used tires through dumping or burning can have severe consequences for human health and the environment, such as air and water pollution, soil contamination, fire hazards, increased pest breeding, and a negatively impacting the aesthetics of the surrounding areas. The European Waste Catalogue classifies used tires as non-hazardous waste. It contains a mixture of synthetic and natural rubber, Sulphur and Sulphur compounds, silica, phenolic resin, oil, polyester and nylon fabric, petroleum waxes, pigments, carbon black, fatty acids, inert materials, and steel wires (The European Waste Catalogue,2002; Siddique & Naik,2004). While burning waste tires remain a popular and economical method for disposal, the associated release of greenhouse gases and hazardous air pollutants has prompted many countries to ban this practice. As an alternative, researchers have explored the possibility of partially substituting natural aggregates with rubber aggregates from used tires in concrete to reduce waste and potentially improve performance. Tyre rubber is generally non-biodegradable and difficult to reprocess, which creates a severe problem (Pacheco et al., 2012). Each year, approximately one billion unused or discarded tires are generated globally, representing a significant portion of 65% of rubberized waste, as reported by the European Tyre and Rubber Manufacturers' Association (ETRMA ,2023). In a research was investigated various properties of rubberized concrete, in which the fine aggregate was partially replaced with 0%, 5%, 10%, and 15% rubber crumb, while 5% fly ash was added to replace cement. The mix proportion for normal concrete (0% rubber crumb) was M25 with a w/c ratio of 0.4 and mix proportions of cement: aggregate: sand was 1:2.11:3.17, respectively. The results revealed a decrease in compressive and tensile strength with an increase in the percentage of rubber crumb used in the concrete mix. However, at a 5% replacement of rubber crumb, the compressive strength, tensile strength, and flexure strength were found to be higher than those of normal concrete (Jamdar &Ansari,2018).

The experimental study of different properties of rubberized concrete was showed that the sample were prepared with replacement of fine aggregate by 0%, 2.5%, 5%, 7% & 10% rubber crumb. For compression strength test, 150 x 150 x 150 mm sizes of cubes and Flexural Strength Test, 500 x 100 x 100 mm sizes of beam were cast. The compressive strength decreased with an increasing percentage of rubber crumb. Flexural strength increases with increasing rubber crumb up to 5%, however, addition of rubber crumb beyond this percentage exhibits decreasing in flexural strength (Bhavik Bhatt et al., 2017).

The superior impact resistance of rubberized concrete makes it a suitable choice for applications where impact load is applied. Moreover, future research should focus on a dedicated study of the incorporation of waste rubber particles of varying sizes and dosages in concrete mixes to explore the potential for significant improvements in durability performance (Fatima et al.,2022). Investigation into the fresh, mechanical, and impact resistance characteristics of rubberized concrete and revealed that higher proportions of rubber crumb in the mix lead to a reduction in both fresh and mechanical characteristics. On the other hand, the energy absorption capacity of rubberized concrete was found to increase with increasing rubber crumb in the mix. The findings are very amazing, as a replacement level up to 15% rubber crumb was found to be acceptable (Kumar et al.,2022). Waste truck tyre rubber crumb in concrete used as a replacement of coarse aggregate. Two types of control strength concrete (M25 and M35) were used to replaced 0%, 10%, 20% & 30% coarse aggregate by tyre rubber crumb. To compare with the control strength, concrete decreased in strength maximum of about 18%, 39% and 26% was found for M25 grade of concrete concerned with compressive strength, splitting tensile strength and flexural strengths respectively, and that for M35 grade of concrete was found to be at 20%, 47% and 33%. As the result was found that the optimal value of 20% addition is suggested which will increase the strength values considerable (Prasad et al., 2021). An experiment was conducted to produce early-age concrete by replacing coarse aggregate with rubber waste (tire rubber) and compare its strength as a filler in concrete with crushed stone as coarse aggregate and sand fine aggregate. Two types of concrete, rubberized concrete and concrete with rubber filler, were used in the study. The rubberized concrete included rubber in place of river sand for both fine and coarse aggregates. The crushing strength of the concrete is mainly influenced by the water-cement (w/c) ratio, where a lower w/c ratio results in higher crushing strength. The water-cement ratios of 0.4, 0.5, and 0.7 were used to prepare the rubber filler concrete and rubberized concrete, and two sizes of rubber crumb, type-I (7mmX20mm) and type II (mmX25mm), were used. The coarse aggregate was completely replaced with waste tyre rubber crumb for Mix I and Mix II. The compressive strength of rubber filler concrete was 2.77 times higher than the rubberized concrete of Identity mix-I and mix-II, influenced by the size and surface condition of rubber particles, mix proportions, and type of cement used. Mix II had an approximately 64% reduction in strength, and Mix I had an approximately 66% reduction in strength. The relationship between compressive strength and water/cement ratio was studied for rubber filler concrete and rubberized concrete (Al Bakari et al.,2007). when fine aggregates are replaced with tyre shreds, a high tensile (flexural) strength is achieved. Only 5.8% and 7.30% strength are lost with a replacement of fine aggregate volume 50 and 75 percent respectively. However, a 28.2% drop in strength would occur if coarse aggregates were replaced with the same ratios. The parameters of the rubber aggregate have an impact on the tensile strength of crumb rubber concrete. While some researchers conclude a decrease in tensile strength, others have focused on gaining tensile strength. Thus, future research should focus on the rubber aggregate properties especially on the tensile strength (Aiello & Leuzzi, 2010).

The most common and cost-effective method of decomposing waste tyres is burning them. However, because this method produces such unacceptable levels of air pollution due to releasing significant amounts of greenhouse gases during combustion, it has also been made illegal in many countries.

It has been reported that crumbed tyre rubber concrete was performed better against spalling due to fire (Herman & Barluenga , 2004). Some researchers explored that rubber crumb concrete performed better than normal concrete in freeze-thaw resistance (Marzouk et al.,2007; Stubblefield et al.,2004; Paine etal.,2002)

This concrete can be used in structural components especially in culverts, crash barriers, side walk, running tracks, sound absorbers (Yang et al.,2001). In addition of that, rubber aggregate used in rigid pavement, runway pavement, railway sleeper, asphalt pavement etc. because of rubber had high elasticity properties that improved the properties of concrete, including its high energy absorption capacity and ductility. Waste tyre rubber crumb was recommended as an additive in asphalt mixture, as all results were within standard requirements. Strength increased with increase rubber aggregate in asphalt mixture and it showed a rise tend for stability and a decreased tend for flow (Wulandari & Tjandra,2007). Rubber crumbs concrete used in rigid pavement. Waste tyre in the form of crumb rubber and rice husk ash was added to the concrete mixes to investigate their mechanical properties. It was found that crumb rubber-rice husk ash contributed to improving the mechanical properties of concrete as a rigid pavement material (Abdurrahman et al.,2019). The workability of rubberized concrete increased with increasing rubber content in concrete, and the mechanical properties of like compressive and tensile strength decreased with increasing percentage of rubber aggregate in concrete (Charankumar & Siddi 2015). The compressive, tensile and flexural strengths reduced with increased rubber chip aggregate replacements, but the 5% replacement results are acceptable (Muyen et al.,2019).

To reduce the use of natural coarse aggregates and fine aggregate, researchers replaced a portion of the conventional coarse aggregates and fine aggregate with waste tyre rubber aggregates. These rubber aggregates are produced by cutting worn tires into small pieces and also rubber power. Most of the previous research was performed analytically and experimental work in the laboratory. The significant finding was that rubber concrete had a decrease in compressive strength even though it increased ductility. This study aims to determine the mechanical behaviour of concrete with locally available crumb rubber as a partial replacing material for coarse and fine aggregates.

2. METHODOLOGY

There are different methods of incorporating rubber particles into concrete, such as the dry mix method, the wet mix method, and the pre-coating method. The amount of rubber added to the mixture can vary depending on the desired properties of the final product and the availability of rubber waste.

In this study, conventional concrete compound prepared with binder and inert materials (fine aggregate and coarse aggregate). Different properties of materials were performed in laboratory and details description of different materials was given below.

2.1 Cement

As described in BS EN 197-1; 2003, the Premier Cement Portland Cement CEM II had used to mix concrete that obtained from local supplier. The specific gravity of cement was 3.15. The cement is carefully stored in an airtight environment to prevent moisture from entering and to avoid the formation of lumps.

2.2 Inert Materials

Concrete is an artificial stone manufactured from a mixture of binding materials (cement, Lime) and inert materials (coarse aggregate, fine aggregate) with water. Details description of inert materials in concrete was given below:

2.2.1 Coarse aggregate

In this study, two types of crushed stone aggregate have been used in mixed in concrete. The maximum size of crushed stone was 19mm down. The different test results of crushed stone are given below.
According to ASTM C702, the test of combine gradation (20mm down stone and 12mm down stone) of crushed stone had been performed. Table 1 and Figure. 1 showed the gradation of crushed stone.

Table 1: Combine graduation of crushed stone

Sieve Size (mm)	Weight Retained (gm)	Cumulative Weight Retained (gm)	Cumulative Percent Retained (%)	Specified Limit (%Passing)	
				Lower Limit	Upper Limit
25	0	0	0.0	100	100
19	936	936	9.4	90	100
9.5	4970	5906	59.1	20	55
4.75	3752	9658	96.6	0	15
2.36	306	9964	99.6	0	5
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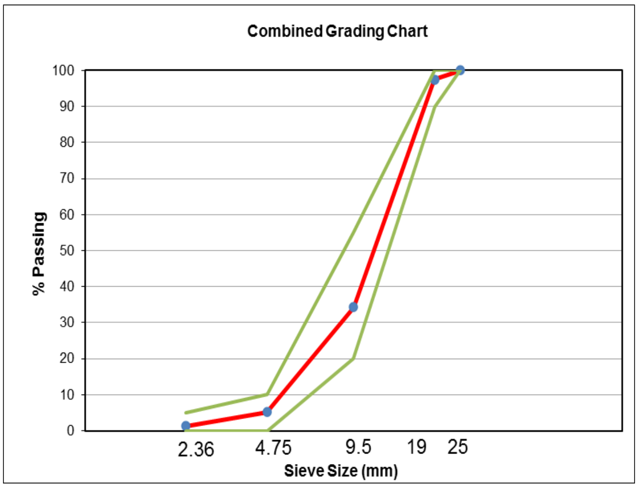

Figure 1: Gradation of coarse aggregate

In above Table 1 and Figure. 2, it was found well-graded stone was used in this research. The other properties of coarse aggregate (20mm down stone and 12mm down stone) are shown in Table 2

Table 2: Properties of coarse aggregate

Test name	Specification	Unit	Result
Los Angeles Abrasion (LAA)	ASTM C131-81	%	16.5%
Specific gravity (SSD)	ASTM C127	-	2.94
Bulk Unit weight 20mm down	ASTM C29	Kg/m^3	1610
Bulk Unit weight 12mm down	ASTM C29	Kg/m^3	1580
Aggregate Crushing value (ACV)	BS 812-110	%	17.28%
Elongation Index	ASTM D4791	%	17.02%

2.2.2 Fine aggregate

In this study, fine aggregate obtained from nearby sources and it's collected from a clean river. The properties of sand are given below in Table 3.

Table 3: Properties of fine aggregate

Test name	Specification	unit	Result
Fineness Modulus	ASTM C136-84a	-	2.71
Specific gravity (SSD)	ASTM C128	-	2.49
Bulk Unit weight	ASTM C29	Kg/m^3	1600
Adsorption	ASTM C128	%	2.9%

2.2.3 Rubber aggregate

The properties of rubber crumb were given below Table 4 and gradation in Table 5. Here, l is length is thickness

Table 4: Properties of rubber crumb aggregate

Test name	Specification	unit	Result
Fineness Modulus	ASTM C136-84a	-	4.115
Bulk Unit weight	ASTM C29	Kg/m3	453
Size and shape	-	mm	l=2 to 20 t= 0.5 to 2

Table 5. Gradation of rubber crumb aggregate

Sieve size (mm)	Weight Retained (gm)	Cumulative Wt Retained (gm)	Cumulative Retained (%)	Percent Passing (%)
9.5	145	145	3.0	100.0
4.75	622.0	622.0	12.8	87.2
2.36	1576.0	2198	45.4	54.6
1.18	1213.0	3411.0	70.4	29.6
0.60	894.0	4305	88.8	11.2
0.30	333.0	4638	95.7	4.3
0.15	171.0	4809	99.2	0.8
0.075	32.0	4841	99.9	0.1
Pan	5.0	4846.0	512.3	

The rubber crumb was done gradation in lab according to ASTM C136-84a that shown in Figure.2.

Figure 2 : Waste tyre and Rubber crumb gradation

2.2.4 Mix Proportion

The mix proportion of concrete refers to the ratio of the materials used to make the concrete mix. The four main components of concrete are cement, water, aggregate (usually sand and gravel or crushed stone), and admixtures (such as chemical additives to enhance specific properties of the concrete). The mix proportion of concrete is usually specified by weight or volume. The most common method for specifying mix proportions by weight is the "absolute volume" method, which involves calculating the volume of each component based on its weight and density according ACI 211.

The volume of inert material (fine aggregate and coarse aggregate) in concrete was replaced by the volume of rubber crumb. In mixture 0%, 2.5%, 5%, 7.5, 10%, 12.5%, 15% of volume of inert materials in concrete were replaced by the volume of 0%, 2.5%, 5%, 7.5%, 10%, 12.5% and 15% of rubber crumb. The mix proportion of normal concrete and rubberized concrete was given in Table 6.

Table 6: Mix proportion of concrete

Mix Proportions (By volume)					
Sample ID	Ingredient of concrete				
	Cement	Replacement of aggregate		Rubber crumb	Replaced inert Agg by rubber crumb (%)
		Sand	Stone		

NC	1	2.55	3.02	0.0	0%
RC-2.5%	1	2.49	2.94	0.14	2.5%
RC-5%	1	2.44	2.86	0.27	5%
RC-7.5%	1	2.375	2.785	0.41	7.5%
RC-10%	1	2.31	2.71	0.55	10%
RC-12.5%	1	2.24	2.63	0.70	12.5%
RC-15%	1	2.17	2.56	0.84	15%

Water cement ratio was 0.37 and admixture (basf master polyheed) was used 0.6% of cement weight in concrete.

2.3 Experimental procedure

The Specimen of standard cylinders of (100mm X 200mm) were used to determine the compressive strength test of concrete. Three specimens were tested for 14 days and 28 Days. Forty-two specimens were cast to conduct compressive and tensile strength tests.

The volume of inert material (fine aggregate and coarse aggregate) in concrete was replaced by the volume of rubber crumb. 0%,2.5%,5%,7.5%,10%,12.5%,15% of the volume of inert materials in concrete were replaced by the volume of 0%,2.5%,5%,7.5%,10%,12.5%,15% of rubber crumb.

The workability of concrete refers to its ability to be mixed, placed, compacted, and finished without any segregation or bleeding. To determine the workability of concrete, various tests can be conducted such as slump test, flow table test, and Vebe test. In this study, workability was measured by slump test according ASTM C143. Slump value is a measure of the workability of freshly mixed concrete, indicating the concrete's consistency and plasticity. It is determined by conducting a slump test, which involves filling a standard cone-shaped mould with the concrete mix, compacting it with several layers, and then lifting the mould vertically to allow the concrete to settle and spread out. The slump value test is shown in Figure.3.

Figure.3: Measure workability of concrete according ASTM C143

In mechanics, compressive strength of a concrete is the capacity of a material or structure to withstand loads tending to reduce. The compressive strengths of normal concrete and rubberized concrete of specimens were determined 28 days of standard curing.

Compressive strength test conducted according to ASTM C39 shown in Figure 4.

The tensile strength of concrete is typically estimated using an indirect tension test, such as the splitting tensile test. According to ASTM C496 test was performed. In this test, a standard cylindrical specimen of concrete is placed horizontally and compressed diametrically, creating a tensile stress on the vertical plane perpendicular to the applied load. The magnitude of the tensile stress can be calculated using the following equation 1:

$$\text{Tensile strength } = \frac{2P}{\pi LD} \qquad (1)$$

Where P is the compressive load applied to the specimen, D is the diameter of the specimen, and L is the length of the specimen.

The tensile splitting test was conducted according to ASTM C496 was shown in Figure.5.

Figure 4: Compressive strength test according ASTM C39

Figure 5: Split tensile strength test according ASTM C496

3. RESULTS AND DISCUSSION

Workability of a concrete mix depends on many factors like w/c ratio, size and shape of aggregate, temperature and humidity, mixing method, admixture, and types of cement. In this experiment, there different percentages of inert materials were replaced by rubber crumb. According to Neville 1995, if the slum of a concrete ≥ 0 then this can be applied to measure the workability of a concrete mix.
The test was performed according to ASTM C143 used to measure the workability of concrete. The obtained result from different samples is provided in Table 7.

Table 7: Workability of normal and rubberized concrete

Sample ID	% rubber	W/C ratio	Slump (mm)
NC	0	0.37	45±2
RC-2.5%	2.5	0.37	45±3
RC-5%	5	0.37	50±2
RC-7.5%	7.5	0.37	50±2
RC-10%	10	0.37	56±2
RC-12.5%	12.5	0.37	56±3
RC-15%	15	0.37	67±3

It is clear from Table 7 that the workability of concrete increases with the increasing percentage of rubber crumb in concrete. The slump value of NC was 44 to 47 mm, and for 2.5% rubber addition, this result has no remarkable variation. Besides this, replacement level 5.0% and 7.5% exhibits much closer workability; no variation is observed for 10 to 15 percent addition of rubber crumb when compared. However, when all these replacement levels 2.5% ,5%, 7.5%, 10%, 12.5% and 15%, are compared with the Normal Concrete (NC) the workability of concrete increased by 2.22%, 11.1%, 15.55%, 26.66%, 31.11% and 42.22% respectively. Increase of workability with a constant w/c ratio, may be happened due to the low particle density, negligible water absorption, and low thermal conductivity of the crumbed rubber compared to the coarse and fine aggregates (Al-Sakini JS1998). The introduction of waste rubber tires into concrete significantly increased the slump and workability. It was noted that the slump has increased as the percentage of rubber was increased (Charankumar & Raju 2015). When the proportion of crumb rubber in the concrete increases, its workability increases as well. The workability of this modified concrete increases from 4% to 44% compared to regular concrete (Murugan & Natarajan 2015).

The trend of this research is similar to the above researcher's study. The workability of concrete is reduced with increasing rubber aggregate in concrete.

The compressive strength of rubberized concrete depends on various factors such as the type, size, and amount of rubber particles, the water-cement ratio, and the curing conditions. In general, adding rubber particles to concrete tends to decrease its compressive strength, but the extent of reduction depends on the rubber content and other factors. The normal and crumb rubber concrete are tested for their performance by determining their compressive strength development at different ages of 14th and 28th days. The obtained result is illustrated in Figure 6 for 28 days' specimen.

In Below result shows the compressive strength decreases 6.04%, 7.08%, 9.90%, 11.63%, 22.89%, & 34.16% with increasing percentage of rubber crumb by 2.5%, 5%, 7.5%, 10%, 12.5%, & 15% respectively.

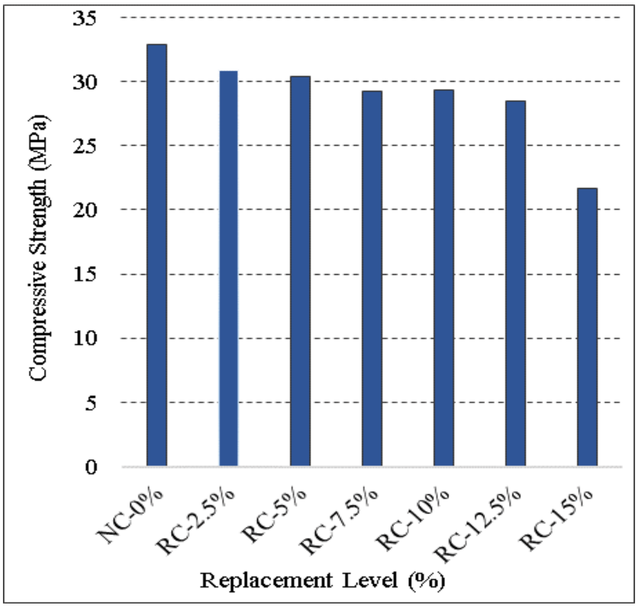

Figure. 6: Compressive strength for 28 days of concrete

The compressive strength of rubberized concrete was decreased linearly with increasing percentage of rubber crumb in concrete. Strength of different mix of rubberized concrete with compared to Normal concrete is shown in Table 8.

Table 8: Variation of compressive strength for 28 days

Sample ID	Avg strength (28 days)	Strength compares with respect to NC (%)	% of strength Decreases with respect to NC
NC	32.85	100%	0%
RC-2.5%	30.87	93.96%	6.04%
RC-5%	30.53	92.92%	7.08%
RC-7.5%	29.60	90.10%	9.90%
RC-10%	29.03	88.37%	11.63%
RC-12.5%	25.33	77.11%	22.89%
RC-15%	21.63	65.84%	34.16%

Several researchers reported a decrease in the compressive strength of concrete due to the incorporation of rubber crumb. compressive strength deceased with increasing percentage of rubber crumb that was replaced with fine aggregate (0%,10%,20%,30%,) (Prasad et al.2021). Fine aggregate replaced with 0 %, 10%, 20%, 30% & 40% rubber power in concrete and found compressive strength decreased with increasing percentage of rubber power in concrete (Khalil et al.,2015). Another studied that coarse aggregate was replaced by rubber crumb (0%, 10%, 25% & 50%) in concrete. The compressive strength decreased with increasing percentage of rubber crumb in concrete (Charankumar & Raju, 2015). Both fine and coarse aggregate were replaced by volume (0%, 10%, 20%, 30%) with the volume of rubber crumb and found the compressive strength reduced with increasing rubber aggregate in concrete (Aly et al.,2019). Mechanical properties like compressive strength reduce with an increment of rubber aggregate in concrete (Jokar et al.,2019; Bhavik et al.,2018). An investigation to use rubber crumb as a partial replacement of fine aggregate. As compared with normal concrete and 10%, 20%, 30%, replacement of fine aggregate with rubber powder. The compressive strength is reduced with increment of percentage of rubber crumb (Verma et al.,2022). Fine aggregate replaced by rubber crumb was affected compressive strength. In every 20% rubber crumb added in concrete, the compressive strength decreased by 26% (Irmawaty et al., 2020).

The trend of this research is similar to the above researcher’s study. The compressive strength is reduced with increasing rubber aggregate in concrete.

Several factors, such as the type and size of rubber particles, the ratio of rubber particles to cement, the water-cement ratio, and the curing conditions can influence the tensile strength of rubberized concrete. Splitting tensile test was performed according to ASTM C496. The test result is shown in Figure 7 for 28 days.

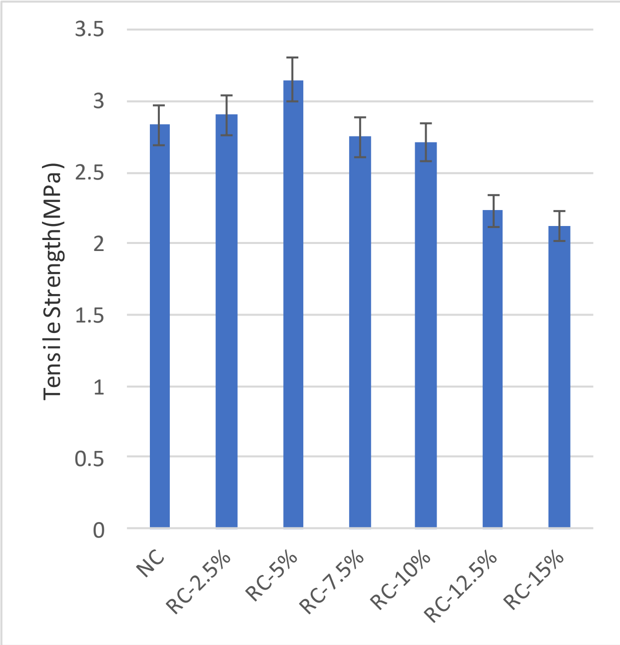

Figure 7: Splitting tensile strength for 28 days

In above result showed that the Splitting tensile strength of different sample normal and rubberized concrete for 28 days were varied +2.45%, +13.64%, - 1.75%, -5.24%, -20.03 & -25.87% with increasing percentage of waste tyre rubber crumb respectively 2.5%,5%,7.5%,10%,12.5%, & 15% in concrete was replaced by volume of the inert materials (coarse aggregate and fine aggregate).
The tensile strength increases with percentage of rubber crumb up to 5% replacement of inert aggregate and more increase up to 5 % of rubber crumb the tensile strength decreased significantly. 5% is the optimum for the replacement of inert material of concrete by rubber crumb. The tensile strength depends on size and shape of inert materials. The Shape of rubber crumb like fibre (length ranging 2 to 20mm and thickness 0.5 to 2mm) provided additional cohesion and distribute forces more evenly, which can result in improved tensile strength. Here replacement materials rubber crumb has elastic properties and fibre shape of rubber crumb effected to gain tensile strength up to 5% mix of rubber crumbs.

4. CONCLUSIONS

From the experimental studies in Civil Engineering Laboratory, KUET, it is clear that rubberized concrete can be used in the construction industry. Significant findings regarding the strength and workability of concrete with rubber are summarized below:
The compressive strength has decreased with increasing rubber crumb when compared to normal concrete in a linear nature. This may occur due to the weak interfacial locking between crumbed rubber and cement paste, along with the total amount of aggregate replaced by the crumbed rubber.

Splitting tensile strength of different specimens for 28 days were varied with increasing rubber content crumb in concrete. The results of split tensile strength show that there is a decrease in strength with an increase in rubber aggregate in concrete. But, at 2.5% and 5% replacement of rubber, the split tensile strength increases with comparison of normal concrete. The splitting tensile strength becomes optimum when 5% inert aggregate is replaced by rubber crumb.

Workability of concrete increases as the crumb rubber amount increases. When compared to the normal concrete, its workability increased from 2.22 to 42.22%. These higher values may be happened due to the negligible water absorption by the crumbed rubber in concrete.

It can be concluded that the rubber incorporated in concrete is more effective to use when improving Tensile strength, ductile properties and impact loading capacity is necessary for concrete.

REFERENCES

European Waste Catalogue (2002), Section 16, part 16 01 03, http://www.environment-agency.gov.uk/commondata/acrobat/ewc.pdf.

Siddique R. and Naik R.T. (2004), "Properties of concrete containing scrap-tire rubber – an overview", Waste Management, 24, 563–569.

Pacheco-Torgal F., Y.N. Ding, S. Jalali, (2012), "Properties and durability of concrete containing polymeric wastes (type rubber and polyethylene terephthalate bottles): an overview, Construct. Build. Mater. 30 (2012) 714e724, https://doi.org/10.1016/j.conbuildmat.2011.11.047.

ETRMA, https://www.etrma.org/rubber-goods/. (Accessed 9th January 2023)

S.D.Jamdar and U.S.Ansari,"Experimental Study of Rubberized concrete Abstract," vol.4, no. 1, pp. 166-169, 2018.

Bhavik Bhatt, Parth Khandla, Tausif Kauswala 2017 "Experimental Study of Crumb Rubber in Concrete" GRD Journal for Engineering | Volume 2 | Issue 6 | May 2017

Abbas, S., Fatima, A., Kazmi, S. M. S., Munir, M. J., Ali, S., & Rizvi, M. A. (2022). Effect of Particle Sizes and Dosages of Rubber Waste on the Mechanical Properties of Rubberized Concrete Composite. Applied Sciences, 12(17), 8460.

Kumar, R., Verma, M., & Dev, N. (2022). Investigation of fresh, mechanical, and impact resistance properties of rubberized concrete. In International e-Conference on Sustainable Development & Recent Trends in Civil Engineering (pp. 88-94).

Mustafa Al Bakri, S. A. Syed Nuzul Fadli, M. D. Abu Bakar and K. W Leong 2007. Comparison of rubber as aggregate and rubber as filler in concrete. International Conference on Sustainable Materials 2007_ICoMS 2007.

Aiello M, Leuzzi F. "Waste tyre rubberized concrete: properties at fresh and hardened state". Waste Manage 2010;30:1696–1704.

Prasad, M. G., Golla, S. Y., Prabhanjan, N., Krishna, A. S., & Alok, G. (2021). Mechanical properties of rubberized concrete using truck scrap rubber. Materials Today: Proceedings, 39, 849-854.

Khalil, E., Abd-Elmohsen, M., & Anwar, A. M. (2015). Impact resistance of rubberized self-compacting concrete. Water Science, 29(1), 45-53.

Charankumar, K., & Siddi, R. (2015). Re-use of waste tire rubber pieces in the production of light weight concrete. International Journal of Science and Research (IJSR), 4(5), 1720-1724.

Aly, A. M., El-Feky, M. S., Kohail, M., & Nasr, E. S. A. (2019). Performance of geopolymer concrete containing recycled rubber. Construction and Building Materials, 207, 136-144.

Jokar, F., Khorram, M., Karimi, G., & Hataf, N. (2019). Experimental investigation of mechanical properties of crumbed rubber concrete containing natural zeolite. Construction and Building Materials, 208, 651-658.

Verma, M., Juneja, A., & Saini, D. (2022). Effect of waste tyre rubber in the concrete. In International E-Conference on Sustainable Development & Recent Trends in Civil Engineering (pp. 99-103).

Irmawaty, R., Noor, N. M., & Muhaimin, A. A. (2020). Feasibility of crumb rubber as fine aggregate in concrete. In IOP Conference Series: Earth and Environmental Science (Vol. 419, No. 1, p. 012054). IOP Publishing.

Hernandez-Olivares, F., Barluenga, G., 2004. Fire performance of recycled rubber-filled high-strength concrete. Elsevier Cent and Concrete Research 34 (1), 109–117.

Marzouk, O.Y., Dheilly, R.M., Queneudec, M., 2007. Valorization of post-consumer waste plastic in cementitious concrete composites. Waste Management 27, 310–318.

Li, G., Stubblefield, M.A., Garrick, G., Eggers, J., Abadie, C., Huang, B., 2004. Development of waste tire modified concrete. Cement Concrete Research 34, 2283–2289.

Paine, K.A., Dhir, R.K., Moroney, R., Kopasakis, K., 2002. Use of crumb rubber to achieve freeze thaw resisting concrete. In: Dhir, R.K. et al. (Eds.), Proceedings of the International Conference on Concrete for Extreme Conditions. University of Dundee, Scotland, UK, pp. 486–498.

Yang, S., Kjartanson, B., Lohnes, R., 2001. Structural performance of scrap tire culverts. Canadian Journal of Civil Engineering 28 (2), 179– 189.

Wulandari, P. S., & Tjandra, D. (2017). Use of crumb rubber as an additive in asphalt concrete mixture. Procedia engineering, 171, 1384-1389.

Abdurrahman, H., Wibisono, G., Qoryati, M., Sitompul, I. R., & Olivia, M. (2019, October). Mechanical properties of crumb rubber-rice husk ash concrete as a rigid pavement material. In IOP conference series: materials science and engineering (Vol. 615, No. 1, p. 012112). IOP Publishing.

Muyen, Z., Mahmud, F., & Hoque, M. N. (2019). Application of waste tyre rubber chips as coarse aggregate in concrete. Progressive Agriculture, 30(3), 328-334.

Neville AM (1995) Properties of Concrete. Longman, London, UK

Al-Sakini JS (1998) Behaviour and Characteristics of Chopped Worn-Out Tires Lightweight Concrete. MSc thesis. University of Technology, Baghdad, Iraq.

R.Bharathi Murugan, and Dr. C. Natarajan (2015) , Experimental Study on Rubberized Concrete. International Journal of Scientific & Engineering Research, Volume 6, Issue 5, May-2015.