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Compressive Strength Behavior of Recycled Concrete with Fine Aggregate Replacement Using Rubber Crumb

Abhijit Nath Abhi*[,a], Md. Nafiuzzaman[b], Md Rafi Uzzaman[b], Abdul Awol Rabby[a], Md. Mosfiqur Rahman Rafid[b]

[a]Department of Civil Engineering, Dhaka International University, Satarkul, Badda, Dhaka-1212, Bangladesh

[b]Department of Civil Engineering, Ahsanullah University of Science and Technology, Dhaka-1208, Bangladesh

***Corresponding Author:** Abhijit Nath Abhi (abhijitnath.ce@gmail.com)

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ABSTRACT

The use of recycled materials in concrete has drawn considerable attention in recent years as it means to enhance sustainability, strength, minimize landfill waste, cut carbon emissions and diminish the environmental influence of construction methods. This study focuses on investigating the compressive strength behaviour and sustainability analysis of rubberized concrete incorporating recycled aggregates. In this study, compressive strength tests have been conducted following standardized procedures to assess the load bearing capacity of rubberized concrete at different curing periods. The results will provide valuable information for engineers, researchers, and policymakers engaged in the development and utilization of sustainable construction practices. Recycle aggregates size ranging from 4.75 mm to 25 mm collected from crushing pile head from various construction site are utilized in this experimental research and also rubber crumbs are used as a partial substitute of fine aggregate at percentages of 6%,12%,18% and 25%, while maintaining a constant ratio of cement to water 0.45. The study was conducted at three different curing days of 7 days, 14 days and 28 days. From the test result, it has been noticed that conventional concrete has achieved the most effective result compared to the other percentages of mixtures of rubber crumb. Additionally, the compressive strength has been gradually decreased up to 56.82% in tandem with the increasing percentage of rubber crumb replacement in the specimens.

Keywords: Recycled Aggregates, Rubberized Concrete, Compressive Strength, Rubber Crumb, Curing Periods

INTRODUCTION

Concrete is a stone-like substance created by allowing a precisely measured mixture of cement, fine aggregate, coarse aggregate, and water to solidify in molds that conform to the shape and size of the intended structure. Sand is commonly utilized as fine aggregate, whereas stone chips are commonly used as coarse aggregate. To improve the properties of concrete, other materials such as mineral additives and chemical are also mixed with it.

Concrete is a material that can be used for a variety of purposes because its properties can be changed in various ways by adding the right ingredients to the cement concrete mix. These changes allow concrete to be optimized for workability, strength, and durability, satisfying a range of building requirements. Because of this occurrence, concrete can be used for a variety of applications. The strength and durability of concrete manufactured using rubber crumb and recycled stone chips, which partially replace natural aggregates, can be on par with that of traditional concrete made with natural aggregates. This illustrates how these materials can support environmentally friendly cement concrete mixtures without sacrificing structural integrity [1]. The usage of natural aggregate is increasing in intensity due to the development of sophisticated infrastructure [2]. Rubber crumbs and recovered stone chips can be used as substitutes for natural aggregates in cement concrete mixtures to reduce their use [3]. Crushed and graded organic particles are used to make sustainable concrete, such as recovered stone chips from crushed pile heads and rubber crumbs from used tires [4]. The building industry has recently had to deal with the growing problems of waste management and environmental sustainability [5]. Natural resources have been heavily exploited and large amounts of waste materials have been produced as a result of the growing demand for concrete, one of the most important building materials.

Urbanization-related waste tires present serious environmental problems if improperly handled [6,7]. The two main ways of disposal that are currently used are burning them or depositing them on agricultural land, both of which cause environmental issues for the tire business [8]. The increasing amount of trash tires annually has made it crucial to develop efficient recycling methods in order to achieve social and environmental advantages [9]. One practical approach proposed by researchers is to mill tire waste into dust or shreds and then mix them with concrete [10]. Recycled concrete might potentially utilize a vast number of old tires by substituting broken or crumbled rubber for natural particles. This method further reduces reliance on river sand and gravel, reducing the negative ecological effects of the concrete industry and the risks associated with over-exploitation of natural resources [11].

Concrete is a remarkable material that is frequently utilized in structural applications and is thought to be necessary for contemporary civilization and society [12]. Utilizing scrap tires as a supplement to construction components, especially concrete, has been proposed as a remedy for the problem of type waste buildup. This approach not only offers economic advantages and helps in environmental cleanup but also brings beneficial modifications to the properties of concrete [13]. By substituting coarse or fine particles to some extent with the dimensions of particles, specific gravity and vibrations of rubber tires can be reduced, while attributes such as ductility, absorption of water, and abrasion resistance can be enhanced [14].

Every year the world produces more than 25 billion tons of concrete [15]. Matter of fact is, this rate of production is going to be double in next few years. The swift urbanization and expansion of population is creating huge demand of concrete which are producing more waste [16]. Concrete waste is a severe environmental hazard since it is neither biodegradable nor improper disposal practices. Discarded concrete materials, often sent to landfills, contribute to the depletion of valuable landfill space and can leach harmful chemicals into the soil and water systems [17]. Furthermore, the production of conventional concrete involves high energy consumption and releases substantial carbon dioxide emissions, exacerbating the issue of climate change. The dust and particulate matter created by the demolition process degrade the local air quality. Ultimately, inappropriate concrete debris disposal contaminates water, disrupts habitats, and harms ecosystems, highlighting the urgent need for sustainable alternatives and responsible waste management measures. Approximately 900 million tonnes of trash are produced annually by construction and demolition in the US, Japan, and Europe, with additional waste produced in other regions of the world [18]. Waste tires have a long lifespan that they can endure for decades due to their durability. [19]. Tires accumulation in landfills over time, reducing available space and providing habitat for disease-carrying organisms.

Tire fires pose a threat to public health and air quality because they are easily started and release harmful smoke and pollutants. Degrading tires release microplastics into waterways, polluting ecosystems and endangering aquatic life. Both ecology and aesthetics are impacted by abandoned tires, which deface landscapes, disturb habitats, and create a visual blight [20]. Effective recycling and disposal techniques are necessary to lessen the negative environmental effects of tires’ production, disposal, and burning, which all contribute to carbon emissions and worldwide pollution. Four billion end-of-life tires (ELTs) are thought to be in the global vault, according to the World Business Council for Sustainable Development’s (WBCSD) Tire Industry Project (TRP) [21]. In addition, 1.96 million new tires are produced annually, while around one billion tires, weighing up to 17 million tons, reach the end of their useful lives [22]. The utilization of ELTs in cement concrete mixes as recycled aggregates offers a sustainable solution to reduce waste while enhancing material properties. The requirement for tires is projected to rise to three billion units by 2019 with a 4% annual increase in demand globally [23]. So if the waste tire could use in construction as a recycle particles it would reduce a large amount of dump tire.

Objective of the Study

This study intention to inquire the compressive strength of rubberized concrete with recycled aggregates, focusing on its significance for sustainable construction. The objectives are:

- To explore existing research to understand the properties of both conventional concrete and rubber crumb mixed concrete.

- To investigate the compressive strength properties formed from recycled particles in concrete, sylhet sand, and rubber crumb, with replacement levels of 0%, 6%, 12%, 18%, and 25% for fine aggregates.
- To develop a suitable mix design that effectively incorporates rubber crumb, promoting a more sustainable approach to concrete production.

EXPERIMENTAL PROGRAMMES AND METHODOLOGY

MATERIAL PROPERTIES

Material used in this research are described below. In this research, recycled coarse aggregate sourced from pile head breaking were used as stone chips, as illustrated in Figure 1. The Sylhet Sand which is also locally known as "Red Sand" was used in this research which is shown in Figure 2. This Sylhet sand is collected from Durgapur, Mymensingh, a region renowned as the largest source of Sylhet sand. Ordinary Portland cement, named as "Crown Cement," was used as the binder material, as shown in Figure 3. Additionally, rubber crumbs of 6%, 12%, 18% and 25% were utilized to partially substitute fine aggregate to investigate its impact on the concrete properties which is illustrated in Figure 4 and the rubber crumbs that were used in this research were derived from the tire wastes with particle sizes ranging from 2.36 mm to 4.75 mm.

Figure 1. Recycled coarse aggregate

Figure 2. Fine aggregate

Figure 3. Cement

Figure 4. Rubber crumb

Process of Rubber Crumb

A sequence of procedures is shown in the Figure 5 to demonstrate how discarded tires can be recycled into crumb rubber. At first waste tires were cleaned and then they were processed in a preliminary shredder. After that, the shredded materials were sent through a granulator chamber to get rid of impurities like steel and fibre. A finer consistency was then attained by subjecting the material to fine grinding. The refined material then passes through a second preliminary shredder before being converted into crumb rubber at the last step. And finally the resulting rubber crumbs were sieved into the appropriate with particle sizes ranging from 2.36 mm to 4.75 mm.

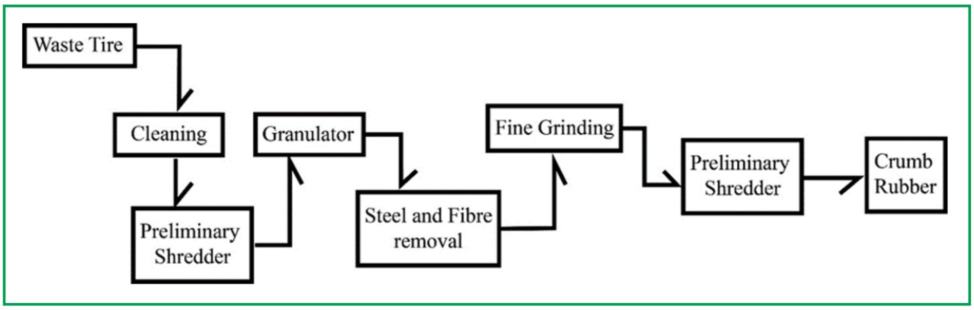

Figure 5. Process of Rubber Crumb from waste tire

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TEST SPECIMENS

In this research, 15 cylinders specimens were used which have a diameter of 4 inches (100 mm) and height of 8 inches (200 mm) which satisfies the ASTM C31 code is shown in Figure 6. And also 3 cylinders were created depending on the different percentages of rubber crumb at three different curing days [24]. All cylinders were utilized for compressive strength test.

Figure 6. Details of specimens

CONCRETE MIX DESIGN

The primary goal of designing a concrete mix is to gain the required intensity of the concrete blend. For the desired concrete strength, the concrete mix` design was used as 1:1.5:3, (C: FA: CA) which determines the strength, durability, and workability of the concrete mix. The design strength of concrete was taken to be 20 MPa at 28 days curing. And also the ratio of cement to water was taken 0.45. The weight of fine aggregate, coarse aggregate, cement and rubber crumbs were calculated according to the ratio for mix design and experimental set up. Table 1 lists the ingredients needed for both conventional concrete and concrete reinforced with rubber crumb.

Table 1. Mix proportion of the concrete used in the experimental works

Specimen Name	% of Rubber crumb	Weight of rubber crumb (kg)	Water (kg)	Cement (kg)	Fine Aggregate (kg)	Recycled Coarse Aggregate (kg)
RC0	0	0	0.297	0.661	1.100	2.062
RC6	6	0.066	0.297	0.661	1.034	2.062
RC12	12	0.132	0.297	0.661	0.968	2.062
RC18	18	0.198	0.297	0.661	0.902	2.062
RC25	25	0.275	0.297	0.661	0.825	2.062

C: Cement; CA: Coarse Aggregate; FA: Fine Aggregate; RC0: Recycled Concrete at 0% Rubber Crumb

CONCRETE MIXING AND CASTING OF SPECIMENS

The mixing process was done by using the mixer machine. At the beginning, Recycled Coarse Aggregate (RCA), Fine Aggregate (FA) and cement were dry mixed in the machine for conventional concrete. Then as per mix design, the required quantity of water was added in the machine and mixing was continued for four minutes. To ensure the rubber crumb was evenly distributed, it was manually mixed into the slurry. Once the mix was ready, it was poured into cylindrical molds that had been pre-lubricated to prevent sticking. The concrete was added in three layers, with each layer compacted using a tamping rod. Finally, the top surface was smoothed using a steel trowel. The process of preparing the cylindrical specimens is shown in Figure 7.

(a) (b)

(c)

Figure 7. (a) Concrete mixing; (b) Tamping; (c) Cylinder Specimens

Compressive Strength Test

According to ASTM C39/C39M, the evaluation for compressive strength was done by using Universal Testing Machine (UTM) [24]. The tests were conducted by applying a compressive load using UTM. Concrete cylinder was positioned in UTM, with the load being applied from the top by layer and bearing plates were positioned at both the top and bottom of the load distribution. Then applied the load continuously at a constant rate of 4mm/min until the specimen was crushed. And finally the maximum load that was implemented at the failure point was recorded and divided this load by the area of specimen, the compressive strength was evaluated. The test setup for compressive strength test is shown in Figure 8.

Result and Discussion

The Table 2 presents the outcomes of compressive capacity tests conducted on concrete specimens with varying percentages of rubber as a replacement material. The table categorizes the data into five specimens, each with a specific percentage of rubber replacement. It also showcases the compressive strength

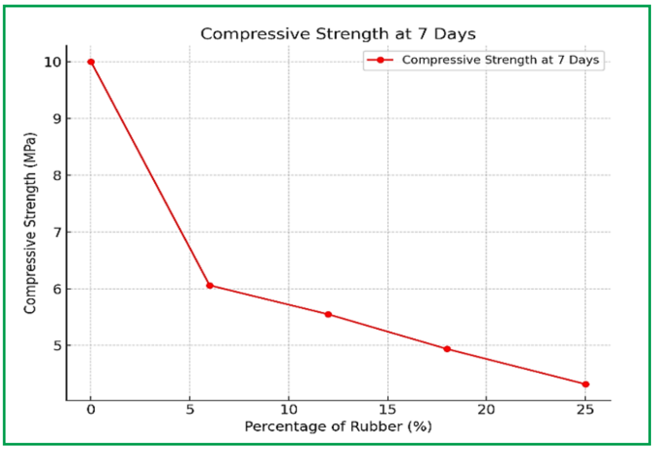
(a) (b)

Figure 8. (a) Universal Testing Machine; (b) Setup of cylinder for compressive strength test

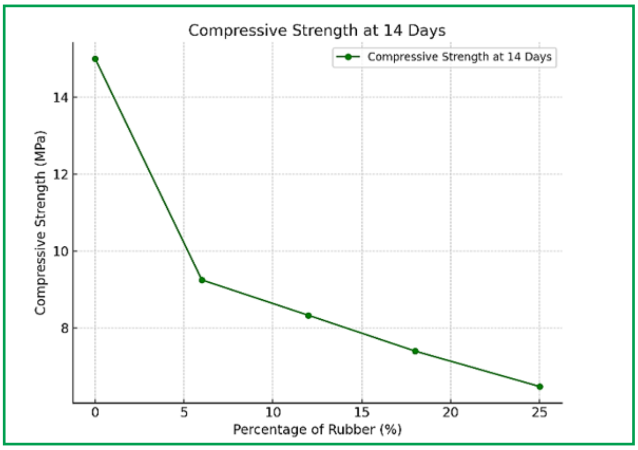
of the specimens at three different curing durations (7 days, 14 days, and 28 days). Table 2 and Figure 9 emphasizes the association between the proportions of rubber substitution along with compressive strength, providing insights into the material's performance over time under different curing periods. The results aim to evaluate the feasibility of using rubberized concrete in construction applications.

Table 2. Compressive strength test result

Specimen Name	Percentage of Rubber (%)	Compressive Strength (MPa)		
		7 days	14 days	28 days
RC0	0	10	15.0	17
RC6	6	6.06	9.25	10.29
RC12	12	5.55	8.33	9.44
RC18	18	4.94	7.40	8.39
RC25	25	4.32	6.48	7.34



(a)



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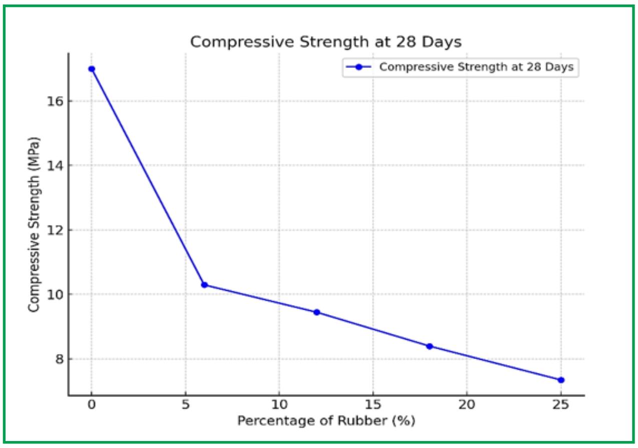

(c)

Figure 9. Compressive strength comparison graph of different rubber content: (a) at 7 days, (b) at 14 days, and (c) at 28 days

The three graphs in Figure 9 (a), (b), and (c) illustrate the correlation between the percentage of rubber crumb replacement in concrete and its compressive strength at curing periods of 7, 14, and 28 days, respectively. As the rubber content increases from 0% to 25%, a consistent decline in compressive strength is observed across all curing durations. At 7 days Figure 9 (a), the compressive strength drops significantly from 10 MPa at 0% rubber to 4.32 MPa at 25% rubber, indicating the detrimental effects of rubber crumbs on early concrete strength. At 14 days Figure 9 (b), the strength improves compared to 7 days but still decreases from 15 MPa at 0% rubber to 6.48 MPa at 25% rubber as rubber content increases. By 28 days Figure 9 (c), the concrete achieves its highest compressive strength values due to prolonged curing, but the same declining trend is evident, with strength reducing from 17 MPa at 0% rubber to 7.34 MPa at 25% rubber. The decreased stiffness and strength of rubber are the causes of this strength decline. compared to conventional aggregates, which compromises the concrete’s load-bearing capacity. Although extended curing enhances overall strength, higher rubber content consistently results in reduced compressive strength, highlighting the need to balance sustainability benefits with structural performance when incorporating rubber crumbs into concrete.

The comparison of reduced percentage of compressive strength by using different proportion of rubber crumbs is shown in Table 3.

Table 3. Reduced percentage of compressive strength

Specimen Name	Percentage of Rubber (%)	Reduced Percentage of Compressive Strength (%)		
		7 days	14 days	28 days
RC0	0	-	-	-
RC6	6	39.4	38.33	39.47
RC12	12	44.5	44.47	44.47
RC18	18	50.6	50.67	50.65
RC25	25	56.8	56.8	56.82

Table 3 demonstrates how the compressive strength of concrete specimens with varying percentages of rubber crumb decreased over the course of three curing times (7, 14, and 28 days). Using the rubber crumb-free control specimen (RC0) as a benchmark, it is seen that the compressive strength progressively declines across all curing durations as the rubber content rises from 6% (RC6) to 25% (RC25).The greatest decrease is seen in RC25, where at 28 days, the compressive strength drops by 56.82%. This pattern shows that adding more rubber weakens the concrete considerably, highlighting the necessity of mix designs that are optimised to strike a compromise between structural performance and sustainability.

CONCLUSION

Considering the results presented in the table, the study investigated the compressive capacity of concrete incorporating recycled stone chips and rubber crumbs.

- As the amount of rubber crumb in concrete increases, its compressive strength decreases across all curing conditions.
- The highest compressive strength is achieved with conventional concrete (0% rubber crumb) after 28 days of curing.
- The lowest compressive strength occurs in concrete with 25% rubber crumb at 28 days, showing a reduction of up to 56.82% compared to conventional concrete.
- Despite the reduction in strength, this type of concrete remains suitable for lightweight construction, such as low-rise buildings and structures with minimal load-bearing requirements.
- Using recycled stone chips and rubber crumb in place of natural sand and coarse aggregate helps reduce environmental impact by minimizing waste and promoting sustainable construction practices.

The study identifies a number of difficulties in creating rubberized concrete, such as the requirement to resize rubber crumb particles, which are usually obtained from used tires, and the time limits for evaluating strength at various curing phases. Additionally, because of specific collection regulations, getting recycled coarse materials presents challenges. Notwithstanding these drawbacks, the study aims to advance environmentally friendly building techniques while enhancing the structural soundness of rubberized concrete. To fully realize rubberized concrete's potential as an environmentally friendly building material, issues with material sourcing and optimization must be resolved.

RECOMMENDATION

- Conduct tests with additional specimens, including cube samples, to evaluate compressive strength comprehensively.
- Explore the use of rubber crumb in geopolymer and lightweight concrete, varying its percentage along with demolished waste, while addressing the impact of recycled stone chips' high water absorption on strength.
- Investigate the chemical interactions between rubber crumb and concrete ingredients, as well as its performance under impact loads in structural applications.
- The concrete mixes incorporating rubber crumb are particularly suitable for applications like rural road pavements and footpaths, providing a sustainable solution for construction while maintaining adequate performance for such uses.

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CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

AUTHOR CONTRIBUTIONS

Abhijit Nath Abhi: project administration, supervision, writing - original draft, investigation, visualization. **Md. Nafiuzzaman:** data curation, formal analysis. **Md Rafi Uzzaman:** methodology. **Abdul Awol Rabby:** conceptualization. **Md. Mosfiqur Rahman Rafid:** writing - review & editing.

DATA AVAILABILITY STATEMENT

The data used to support the findings of this study are included within the article.

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