Experimental investigation on the strength of chipped rubber-based concrete

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Abstract. In this research work, the strength and microstructure of chipped rubber-based compressed concrete have been investigated. Chipped rubber has been utilized as an option over coarse aggregate. Chipped rubber at normal instance decreases the durable properties of concrete but the combination of compression testing as well as chipped rubber replacement can significantly affect the strength of the material. During the study, coarse aggregate has been replaced at 0-50% with chipped rubber. The freshly prepared concrete has been condensed in a specially designed mould and after that compression casting technique has been applied. Samples of both compressed chipped rubber as well as uncompressed chipped rubber have been prepared and then examined further for compressive strength, split tensile strength, and abrasion resistance. Microstructures of conventional concrete, compressed rubber concrete, and uncompressed rubber concrete, has also been analyzed. The results show that the concrete with replacement by 20% of chipped rubber gives the significant results for compressive strength and split tensile strength. This proposed method should be implemented by the concrete industry from an environmental point of view.

1. Introduction
In the whole world, approximately 1 billion tires are put in the waste category and this number is increasing day by day [1]. During the recent two to three decades, the automobile industry in the entire world is growing very rapidly due to which the availability of waste tire rubber is also increased. This waste is very much harmful from the environmental point of concern, so strict actions should be taken to dump it off safely and effectively [2]. From the total tire waste, approximately half is burnt which releases harmful gases that further lead harm to the natural parameters of the earth. The rest of this tire waste is dumped into the soil which can further result in drastic environmental issues [3]. Therefore, it’s a time clicking for the researchers to find alternative use of this kind of waste in this modern period. Nowadays, some of this waste is also used for various engineering projects but it should be increased as it has very much good effect in the civil industry. This increase will decrease the load of dumping of this waste and will decrease the environmental loss [4,5].

Waste rubber is used in the form of chipped rubber in the construction works [6]. Chipped rubber has some vulnerable properties which can be harnessed to produce concrete structures including beams, columns, sections such as I sections, h section, channel section. Chipped rubber is mainly used as a substituent of natural coarse aggregate and then it is compressed to produce compressed rubber concrete. Chipped rubber is generally replaced from 0 to 50% for both compressed as well as
uncompressed members. The effects of chipped tire rubber on the properties of concrete by replacing the fine as well as coarse aggregate with waste rubber has been reported in the literature. The fine aggregate particles were replaced partially with waste rubber and the results were quite satisfactory as the strength was enhanced at the lower replacement concentrations, but at higher concentration, the strength parameters were adversely affected [7]. Reduction in compressive strength is generally unavoidable when various forms of rubber particles are used for replacing the aggregates partially, irrespective of the particle size, the degree of rubber substitution, or the form of aggregate substituted. In general, a reduced compressive strength was indicated in many cases and a decrease in compressive strength was more conspicuous with an increased substitution level of rubber. This lessening effect is due to poor interfacial interaction between rubber and binder particles and the presence of the entrapped air in the voids at higher replacement levels [8]. Likewise, an increase in water absorption by immersion has been observed on the replacement of natural aggregates by rubber waste. The results were attributed to the requirement of higher water content by concrete with added rubber as well as a higher amount of pores due to poor binding of the rubber and the cement particles [4]. This factor also reduces the density of rubber-based concrete significantly as compared to conventional concrete [9].

The abrasion resistance of rubber concrete has been examined by replacing the fine aggregates with crumb rubber at 0-20% of replacement rates. They noticed that the introduction of crumb rubber increased concrete resistance in an aggressive environment at all replacement rates [10]. The microstructure as well as the inner structure of natural aggregate concrete as well as the waste rubber-based concrete has been compared by SEM analysis. It has been observed that replacing natural aggregate by waste tire rubber results in a denser microstructure as compared to natural aggregate concrete. However, with the increase in the replacement percentage, the microstructure of the matrix gets less dense and thus, strength is affected adversely [11]. The declining compressive strength with the increasing content of embedded rubber can be lessened by replacing a proper amount of cement with strength-enhancing additives like silica fume or by treatment of rubber with sodium hydroxide [12]. The strength and durability aspects of concrete have also been investigated by replacing natural river sand by tire rubber waste with the addition of silica fume [13]. The results specified that although the compressive strength of concrete decreases with the introduction of rubber waste, yet the introduction of silica fume compensates for the degrees of compressive strength [14]. Similarly, the compressive strength of concrete with substitution of aggregate by crumbed rubber in the presence of steel fibers has also been investigated. It has been found that the presence of steel fibers maintains the compressive strength of the concrete that would have been lesser in absence of steel fibers along with the introduction of waste rubber [15].

This study has been aimed to evaluate the strength parameters of concrete by partially replacing coarse aggregate by Chipped Rubber under specially designed compression casting technique and to compare the abrasion resistance for conventional concrete, compressed chipped rubber concrete, and uncompressed chipped rubber concrete. The microstructure of conventional concrete, compressed rubber concrete, and uncompressed rubber concrete has been analyzed using SEM analysis and the results have been correlated with the strength analysis.

2. Materials and Methods
Chipped rubber was collected from the nearest tire recycling plant in Chandigarh (India). The size of the chipped rubber taken for the research work lied in between 10 mm to 20 mm. 43 grade OPC (Ordinary Portland cement) was used for the research work. Coarse aggregates with particle size ranging between 10-20 mm and natural river sand as the fine aggregate was used for the preparation of concrete mix. Table 1 shows the physical characteristics of the aggregates. Three types of mix proportions were prepared with coarse aggregate for conventional concrete (M 30 grade), chipped rubber-based aggregate for uncompressed concrete, and compressed concrete to obtain eleven mixes in total. In the case of rubber aggregate concrete, chipped rubber was used as a replacement of natural coarse aggregate from 0% to 50% by volume. All the Mix proportions have been listed in Table 2. Firstly, the materials were mixed using a mixer as per their quantities. The mixtures for conventional
Concrete were transferred into the normal mold while the mixes for compressed rubber concrete specimens were transferred into specially designed molds attached with a compressive load. When the load was applied over the molds, the specimens were compressed with the removal of moisture and pores. This kind of compression leads to the condensation of the specimens. The load was removed after 24 hrs. and the samples were subjected to curing for 28 days after demoulding. The compressive and split tensile strength of the specimens was tested as per IS 516 while the abrasion resistance was tested as per IS 1237 [16].

### Table 1. Physical Characteristics of Aggregates

| Aggregate Type            | Bulk Density (kg/m³) | Water absorption (%) | Specific gravity |
|---------------------------|----------------------|----------------------|------------------|
| Natural Coarse Aggregate  | 1510                 | 1.25                 | 2.60             |
| Chipped Rubber            | 695                  | 1.65                 | 1.05             |
| Natural fine aggregate    | 1615                 | 1.15                 | 2.55             |

### Table 2. Mix proportion of Specimens

| Type  | Cement (kg/m³) | Sand (g) | Coarse Aggregate (g) | Chipped Rubber (g) | Water (g) | Specific gravity |
|-------|----------------|----------|----------------------|---------------------|-----------|------------------|
| CC    | 433.3          | 701.2    | 1110.6               | -                   | 0.45      |                  |
| URC10 | 433.3          | 701.2    | 999.54               | 111.06              | 0.45      |                  |
| CRC10 | 433.3          | 701.2    | 999.54               | 111.06              | 0.45      |                  |
| URC20 | 433.3          | 701.2    | 888.48               | 222.33              | 0.45      |                  |
| CRC20 | 433.3          | 701.2    | 888.48               | 222.33              | 0.45      |                  |
| URC30 | 433.3          | 701.2    | 777.42               | 333.18              | 0.45      |                  |
| CRC30 | 433.3          | 701.2    | 777.42               | 333.18              | 0.45      |                  |
| URC40 | 433.3          | 701.2    | 666.36               | 444.24              | 0.45      |                  |
| CRC40 | 433.3          | 701.2    | 666.36               | 444.24              | 0.45      |                  |
| URC50 | 433.3          | 701.2    | 555.30               | 555.30              | 0.45      |                  |
| CRC50 | 433.3          | 701.2    | 555.30               | 555.30              | 0.45      |                  |

*Type CC denotes conventional concrete, URC denotes uncompressed rubber concrete and CRC denotes compressed concrete.

### 3. Results and Discussions

#### 3.1. Compressive Strength

Figure 1 illustrates the effect of the coarse aggregate replacement by rubber waste on the compressive strength of the compressed and uncompressed concrete at 28 days. The replacement by rubber waste in uncompressed concrete was found to result in a substantial strength reduction [17]. The compressive strength of the URC50 concrete was 50.0% lower compared to the CC concrete. For compressed concrete, the increase in strength was noticed up to a substituent dosage of 20% followed by a decrease in compressive strength, w.r.t. conventional concrete. The compressive strength of the CRC20 concrete was 24.0% higher than CC concrete while that of CRC40 concrete was 3.0% lesser than that of the CC concrete, at 28 days (Figure 2). Due to the compression casting mechanism, the pores inside the concrete microstructure get filled leading to the condensation of concrete specimens. This condensation as well as pore pressure densifies the microstructure of the concrete which further enhances the overall strength of the concrete. In general, the substitution by a higher amount of rubber waste (30%) decreased the compressive strength w.r.t. conventional concrete, regardless of the compression treatment performed on the mixes. Rubber is a soft and elastic material in contrast to the other binding materials present in concrete. Hence, there is poor bonding between chipped rubber waste and other binder particles in the concrete matrix. It results in the appearance of micro-cracks in the cement matrix leading to a lessening in compressive strength. The results are consistent with earlier studies reported in the literature [16,18]. The compressive strength of compressed rubber concrete was found better than uncompressed rubber concrete at all replacement amount. The
compressive strength of URC10 was noticed as similar to that of CRC50 indicating the positive impact of compression technique on the compressive strength [18].

![Figure 1. Compressive Strength vs % Rubber Replacement in Concrete Specimens](image1.png)

**Figure 1.** Compressive Strength vs % Rubber Replacement in Concrete Specimens

![Figure 2. % variation in Compressive Strength vs % Rubber Replacement in Concrete Specimens](image2.png)

**Figure 2.** % variation in Compressive Strength vs % Rubber Replacement in Concrete Specimens

3.2. **Split Tensile Strength**

Figure 3 displays the effect of the replacement by the rubber waste on the split tensile strength of the concretes at 28 days. The reduction of the split tensile strength is noticeable in uncompressed rubber concrete specimens as the rubber replacement percentage is increased [17]. For instance, the UCR50 has split tensile strength reduced by 28% as compared to CC. A reduction in the split tensile strength of uncompressed rubber concrete is exhibited when the rubber content is increased so that a reduction by 56% at a rubber replacement of 50% takes place (Figure 4). For compressed rubber concrete, split tensile strength increased for a rubber replacement up to 20%. For further rubber replacement, split
tensile strength has decreased in comparison with conventional concrete, irrespective of the compression technique used. Other researchers have also noticed a decrease in split tensile strength at higher rubber replacement dosage [18]. The reduction of tensile strength is caused by the same factors as affecting compressive strength that mainly includes an increase in porosity due to weak interaction between rubber and binder materials. The impact further intensifies with the increasing replacement dosage of rubber particles leading to the appearance of cracks on the application of load. The split tensile strength of CRC10, CRC20, and CRC30 increase by 13%, 22%, and 6% in comparison to CC. Since the maximum increase in split tensile strength is attained for CRC20, the optimum replacement percent of rubber is 20%. The split tensile strength of CRC40 is almost comparable to that of CC illustrating the reliability of the compression method to improve the rigidity of the rubber concrete.

![Figure 3. Split Tensile Strength vs % Rubber Replacement in Concrete Specimens](image)

**Figure 3.** Split Tensile Strength vs % Rubber Replacement in Concrete Specimens

![Figure 4. % variation in Split Tensile Strength vs % Rubber Replacement in Concrete Specimens](image)

**Figure 4.** % variation in Split Tensile Strength vs % Rubber Replacement in Concrete Specimens

3.3. Abrasion Resistance
Figure 5 illustrates the impact of rubber replacement on the abrasion resistance of concrete in terms of depth of wear at 28 days. A decrease in depth of wear was observed for the concrete as the percentage of rubber increases irrespective of the compression treatment. This observation can be attributed to the flexible nature of rubber particles that acts as a shield for wear due to abrasion [16]. The depth of wear for CC was observed as 1.1 mm while at the 30% replacement level of rubber, a decrease of 59%, and 31% was observed in the case of CRC30 and URC30 respectively. Further, the abrasion resistance was found to improve with increasing rubber replacement level from 0-50% [19]. Although, the auxiliary chipped rubber waste improved the abrasion resistance of uncompressed rubber concrete as compared to conventional concrete, yet the abrasion resistance of compressed rubber concrete was better as compared to uncompressed rubber concrete for the same level of rubber replacement (Figure 6). For instance, in comparison to CC, a decrease of 13% was observed for URC10, while a decrease of 41% for CRC10. In case of compressed rubber concrete, abrasion resistance of CRC10 was similar to that of URC50 indicating the positive impact of compression technique. Thus, the results signify the role of compression technique in enhancement of mechanical properties of rubber-based concrete. Further, the results are within permissible limits confirming to the suitability for use of chipped rubber waste in concrete [20].

![Figure 5. Depth of Wear vs % Rubber Replacement in Concrete Specimens](image-url)
Figure 6. % variation in Depth of Wear vs % Rubber Replacement in Concrete Specimens

3.4. SEM Analysis
The microstructures of conventional concrete CC, uncompressed rubber concrete URC10, and compressed rubber concrete CRC20 has been shown in Figure 7. In the case of compressed rubber concrete, fewer pores and microcracks are observed along with denser microstructure than CC and URC10. The denser microstructure of the compressed rubber concrete with reduced pores and microcracks results in an enhanced strength instigated by the compression pressure used during casting to the concrete. Other researchers have also related the pore structure and strength of concrete [12]. Due to poor binding interactions between rubber and binder components in the matrix, the interfacial transition zone is weak in the case of uncompressed rubber concrete [20]. The pre-compression of concrete leads not only to the void condensation but also increases the rigidity of materials in concrete. The weak interfacial transition zone suffices the origin of microcracks in the cement matrix. As the interaction between the binder and the other constituents in the case of compressed rubber concrete gets improved due to the reduced pores, it leads to a denser microstructure of the compressed concrete as compared to the uncompressed type of concrete [18].

Figure 7. Micrographs of (a) CC; (b) URC10; (c) CRC20 specimens

4. Conclusion
This study was mainly done to signify the usage of the waste chipped rubber in the concrete industry. For achieving this goal, the compression technique was used to increase the compactness of concrete.
Waste chipped rubber was used as a replacement of coarse aggregates at a replacement level from 0% to 50%. Depending upon the research work some conclusions and suggestions are drawn:

1. The compressive strength test as well as the split tensile strength test of the compressed rubber concrete gives excellent results as compared to conventional concrete up to a replacement of 30%. The maximum result was found at a lower replacement percentage that is at 20% replacement. This type of concrete gives satisfactory results up to 30% replacement but after this, the bond between the binder and the waste particles weakens which leads to the decrease in the strength so the recommendation from this research work is to use compressed rubber concrete up to a replacement of 30%.

2. Rubber replacement was found to improve abrasion resistance. The microstructure of the compressed concrete is far denser as compared to the conventional concrete and uncompressed rubber concrete. Compression casting densifies the concrete and leads to the condensation of the concrete.

3. The compressive strength and the split tensile strength of the uncompressed concrete were found to be poor as compared to compressed concrete and even with reference to the natural aggregate concrete. So it is advisable not to implement this type of concrete as its life as well as the strength aspects lead to the failure of the whole structure.

4. The compression technique should be implemented in the case of precast members where strength as well as the life of the structure is a major concern.

References

[1] Sofi A 2018 Effect of waste tyre rubber on mechanical and durability properties of concrete – A review Ain Shams Eng. J. 9 2691–700
[2] Aiello M A and Leuzzi F 2010 Waste tyre rubberized concrete: Properties at fresh and hardened state Waste Manag. 30 1696–704
[3] Thomas B S, Gupta R C and Panicker V J 2016 Recycling of waste tire rubber as aggregate in concrete: durability-related performance J. Clean. Prod. 112 504–13
[4] Bravo M and de Brito J 2012 Concrete made with used tyre aggregate: durability-related performance J. Clean. Prod. 25 42–50
[5] Senin M S, Shahidian S, Leman A S, Othman N, Shamsuddin S M, Ibrahim M H W and Mohd Zuki S S 2017 The durability of concrete containing recycled tyres as a partial replacement of fine aggregate IOP Conf. Ser. Mater. Sci. Eng. 271
[6] Turatsinze A and Garros M 2008 On the modulus of elasticity and strain capacity of Self-Compacting Concrete incorporating rubber aggregates Resour. Conserv. Recycl. 52 1209–15
[7] Huang W, Huang X, Xing Q and Zhou Z 2020 Strength reduction factor of crumb rubber as fine aggregate replacement in concrete J. Build. Eng. 101346
[8] AbdelAleem B H and Hassan A A 2018 Development of self-consolidating rubberized concrete incorporating silica fume Constr. Build. Mater. 161 389–97
[9] Roychand R, Gravina R J, Zhuge Y, Ma X, Youssf O and Mills J E 2020 A comprehensive review on the mechanical properties of waste tire rubber concrete Constr. Build. Mater. 237 117651
[10] Thomas B S, Gupta R C, Mehra P and Kumar S 2015 Performance of high strength rubberized concrete in aggressive environment Constr. Build. Mater. 83 320–6
[11] Arteaga-Arcos J C, Chimal-Valencia O A, Yee-Madeira H T and D??az De La Torre S 2013 The usage of ultra-fine cement as an admixture to increase the compressive strength of Portland cement mortars Constr. Build. Mater. 42 152–60
[12] Rashad A M 2016 A comprehensive overview about recycling rubber as fine aggregate replacement in traditional cementitious materials Int. J. Sustain. Built Environ. 5 46–82
[13] Onuaguluchi O and Panesar D K 2014 Hardened properties of concrete mixtures containing pre-coated crumb rubber and silica fume J. Clean. Prod. 82 125–31
[14] Copetti C M, Borges P M, Squaiavon J Z, da Silva S R and de Oliveira Andrade J J 2020
Evaluation of tire rubber surface pre-treatment and silica fume on physical-mechanical behavior and microstructural properties of concrete *J. Clean. Prod.* **256** 120670

[15] Eisa A S, Elshazli M T and Nawar M T 2020 Experimental investigation on the effect of using crumb rubber and steel fibers on the structural behavior of reinforced concrete beams *Constr. Build. Mater.* **252** 119078

[16] Choudhary S, Chaudhary S, Jain A and Gupta R 2020 Valorization of waste rubber tyre fiber in functionally graded concrete *Mater. Today Proc.* 3–8

[17] Ganjian E, Khorami M and Maghsoudi A A 2009 Scrap-tyre-rubber replacement for aggregate and filler in concrete *Constr. Build. Mater.* **23** 1828–36

[18] Wu Y, Kazmi S M S, Munir M J, Zhou Y and Xing F 2020 Effect of compression casting method on the compressive strength, elastic modulus and microstructure of rubber concrete *J. Clean. Prod.* **264** 121746

[19] Gesołu M, Güneyisi E, Khoshnaw G and Ipek S 2014 Abrasion and freezing-thawing resistance of pervious concretes containing waste rubbers *Constr. Build. Mater.* **73** 19–24

[20] Gupta T, Chaudhary S and Sharma R K 2014 Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate *Constr. Build. Mater.* **73** 562–74