Mechanical properties of rubber aggregates based geopolymer concrete- A review

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Abstract. Aggregates are the furthermost vital components of concrete, but there is a need for replacement of these natural resources due to the insufficient availability of the materials. To overcome the difficulty of materials and to develop sustainable concrete, much research has been conducting to date. The replacement of aggregates wholly or partially is one of the best alternatives to this problem. To develop sustainability in concrete waste materials that are causing depletion to the environment are used as alternative materials. Rubber tire waste is one such material which is causing a lot of greenhouse gas emission. This paper reviews the use of rubber tire waste as aggregates in geopolymer concrete which shows the effect of various sizes of rubber, untreated and treated rubber aggregate on various properties such as Fresh Properties where flow values of mortar reduced with escalation in the rubber and workability of the mortar and concrete increased. Nevertheless, the Mechanical Properties shows a decrement in compressive strength, and tension properties show an increment. There is a significant amount of increment in the possessions of mortar and concrete after the crumbed rubber treated. The loss of strength for the small amount of replacement of rubber, which is 5-10% shows the strength higher than the standard concrete. The outcomes show that the custom of the rubber in concrete primes to a substantial amount of strength loss, but the addition of mineral admixture and superplasticiser helps us to achieve the geopolymer mortar and concrete applications in the field of construction.

1. Introduction
Sustainability means assembly the requirements of the current without conceding the ability of the forthcoming generation for their use [1]. Sustainability can be obtained by recycled and reuse of waste material as the replacements of natural resources. The automobile industry is a rapidly growing industry, which results in an abundance of tire production, and, subsequently, wastes tire is generated [2]. Annually more than 500 million tonnes of tires disposed of [3]. Its believed that around 30 million cars are produced alone in India by 2019. Rubber tires of 24 million tonnes weight of the rubber used on average. Millions of rubber tires are dumped illegally without secondary usage. This waste tire disposal requires a massive amount of landfills which amasses the risk of combustion which results in pollution due to high toxin emissions and are non-biodegradable, which leads to poses deadly diseases and a threat to surrounding environment [4]. Degradation of rubber is a prolonged process. It almost takes 50-80 years for itself. Mostly tires are dumped in the typical dump yard and are lit with other waste, which leads to black pollution. Therefore, recycled and reuse of this rubber tire waste in other forms can reduce the adverse effect on the environment.
Rubber tire waste incorporated in concrete by shredding the waste tire into desirable sizes of natural aggregates and is replaced partially or entirely as aggregates in conventional concrete. Rubber addition in concrete shall enhance the Impact resistance, Abrasion resistance, Freeze-thaw cycles, Durability performance of concrete [4]. The rubber-based concrete used in places where the impact resistance, vibrational damping, heat isolation is required such as the Building bunkers, Jersey barriers, Foundation for machinery, Railway stations, Lightweight concrete blocks, Tiles, sea dense, Armor units, floor screeds, trench filling and pile heads end to end with paving slabs and pipes bedding [2]. Rubber-based concrete also helps in reducing the noise, which is caused by various sources such as vehicles, aircraft, power plants, and machinery. The sound caused by sources not only causes health problems but also leads to serious health issues [5]. The sound waves impeded materials with notable porosity, which results in sound waves into solid and energy transforms into a form of heat and shall be dissipated [5]. Nevertheless, the usage of the crumb rubber still used as both coarse and fine aggregates incorporated in Ordinary Portland Cement-based concrete, which results in a large amount of CO₂.

Concrete is a significant material in the field of construction, which consists of components such as cement, aggregates, water. The demand for the components of concrete can never be satisfied and expected to increase in the coming future. However, there is a various environmental issue associated with the components—for instance, the cement industry-acclaimed to be the second-largest contributor to greenhouse gas emission [6]. Moreover, cement production expected to reach 4380 million tons by 2050 [7]. One ton of cement production leads to 0.85-1 tons of CO2 [8]. With the urgency to calm down the global crisis due to the greenhouse gas emission, there is a need for replacing these environment unfriendly materials and consider some other replacement materials in place of cement, which is the motive of this research to present a supplementary cementitious material.

Geopolymer concrete is the alkali-activated aluminosilicate material wherein alkaline chemicals used as binding material. Depending on material castoff in curing conditions for preparing the geopolymer concrete, the geo-polymerisation is different for those produced in hydration of OPC [9]. For this, the calcium content should also be shallow to qualify the construction of the three-dimensional polymeric chain, and the ring construction consists of a Si-O-Al-O bond [10]. The geopolymer concrete consists of the SiO₄ and AlO₄, which has a tetrahedral bond interchangeably sharing all the oxygen with a monovalent alkali metal. The principal empirical of the geopolymer shown in equation (1).

\[ M_n[-(\text{SiO}_2)]_z-\text{AlO}_2]_w \cdot \text{wH}_2\text{O} \]  

Where M is a monovalent alkali metal, n is the degree of the polycondensation of polymerisation, and z is the variable, which is 1,2,3 or higher.

2. Materials

The material component constitutes of binder materials such as aluminosilicate material such as the Fly ash, GGBS, burnt Rice husk ash, various quarry slag which forms geo-polymeric reaction when combined with alkali activator solution such as the sodium silicate and sodium hydroxide, potassium silicate and potassium hydroxide. Along with natural aggregates such as coarse aggregates and fine aggregate.

2.1 Production of pozzolanic materials

The explosive volcanic eruption is the primary source for the natural pozzolans in the pyroclastic rocks. This explosion results in small atoms of melted magma to expose to an atmosphere where the rapid compression decreases results in the microporous structures by the emission of the gases and quenching lead to their glassy state. This deposits of volcanic tuff by further exposed to the
weathering leads to zeolitisation results in zeolitic materials or clay minerals [11]. The artificial pozzolans such as fly ash, GGBS are the industrial produced during their production. This aluminosilicate material used for the geopolymer formation having a size of 20-40 µm.

2.2 Reactivity of pozzolanic material
Alkali activator solution (AAS) helps us to achieve the reactivity of the geopolymer binder. Reactivity mostly depends on the chemical composition, specific surface area, and mineralogical composition of materials. The chemical composition of fly ash used for geopolymer formation shown in Table 1. The significant portion of silica and alumina presence in the materials helps us to achieve the geopolymer blend. The sophisticated quantity of the loss of ignition in materials shows the presence of the CO₂ and water in the glassy form. It is difficult to differentiate between the high and low reactivity of material based on the chemical and mineral composition because only the glassy phase of mineral chemical composition used to determine the reactivity [12].

2.3 Production of the rubber aggregates
The production of the rubber aggregates starts with collecting rubber tire from the local sources. First, the tires inserted to cut the thickness of the tire in a circle, and then it sent into a strip cutter. The strip cutter helps us to obtain the rubber in strip form and then send it to the slice cutter. The slice cutter helps us to obtain the rubber blocks, and then rubber is crushed in the rubber crusher. The fiber obtained by crushing the rubber separated by using the fiber separator and remaining rubber waste sent for magnetic separator. The magnetic separator bifurcates the rubber powder and steel wires.

Treatment of the crumb rubber: The pre-treatment of the rubber helps us to obtained better results compared to untreated. The treatment of rubber is achieved by oxidation followed by sulphonation. In this treatment process, the rubber is immersed in the desired chemical, as mentioned for a stipulated amount of time, then cleaned and sundried. For the simple and cost efficiency purpose, the hydroxide treatment used. [13]

| Sources      | SiO₂ | Al₂O₃ | Fe₂O₃ | K₂O  | CaO  | MgO  | TiO₂ | SO₃ | Mn O | Na₂O | P₂O₅ | LOI |
|--------------|------|-------|-------|------|------|------|------|-----|------|------|------|-----|
| Fly ash      |      |       |       |      |      |      |      |     |      |      |      |     |
| Zhang et.al  | 50.3 | 22.9  | 8.17  | 3.55 | 3.38 | 2    | 1.15 | 0.58| 0.58 |       |      |
| Wongsa et.al | 39.4 | 20.8  | 11.5  | 2.4  | 14.5 | 2.2  | 0.5  | 4.2 | 1.4  | 0.2  | 1.5  |     |
| Mucsi et.al  | 45.85| 16.8  | 12.05 | 1.83 | 13   | 2.9  | 0.48 | 3.76| 0.18 | 0.5  |      |     |
| Azmi et.al   | 50   | 23.4  | 17.29 | 1.41 | 5.06 | 1.6  | 0.08 | 0.22|     |      |      |     |
| Iuhan et.al  | 58.88| 20.6  | 12.78 | 1.64 | 0.74 | 0.5  | 0.94 |     |      |      |      |     |
| Iuhan et.al  | 58.88| 20.6  | 12.78 | 1.64 | 0.74 | 0.5  | 0.94 |     |      |      |      |     |
| Azrem et.al  | 50   | 23.4  | 16.92 | 1.41 | 5.06 | 1.6  | 0.08 | 0.22|     |      |      |     |
| Aly et.al    | 39.79| 11.2  | 1.2   | 34.4 | 7.61 | 0.46 |     |     |      |      |      |     |
| Yuwadee et.al| 39.4 | 20.8  | 11.5  | 2.4  | 14.5 | 2.2  | 0.5  | 4.2 | 1.4  | 0.2  | 1.5  |     |
| Rahendran et.al | 61.75| 24.6  | 6.47  | 0.55 | 3.45 | 1.53 | 0.91 |     |      |      |      |     |
| GGBS         |      |       |       |      |      |      |      |     |      |      |      |     |
| Zhang et.al  | 34.1 | 12.3  | 0.41  | 0.56 | 44.2 | 8.12 | 0.96 | 2.59| 0.25 |      |      |     |
| Rahendran et.al | 37.73| 14.4  | 1.11  | 37.3 | 8.71 | 0.39 | 0.02 | 1.41|     |      |      |     |
| Kaolin       |      |       |       |      |      |      |      |     |      |      |      |     |
| Gandoman et.al | 63.63| 24.4  | 0.539 | 0.25 | 1.25 | 0.25 | 0.06 | 0.08| 9.71 |      |      |     |
| Metakaolin   |      |       |       |      |      |      |      |     |      |      |      |     |
| Gandoman et.al | 69.3 | 26.9  | 1.471 | 0.71 | 1.47 | 0.31 | 0.06 | 0.09| 0.55 |      |      |     |
| OPC          |      |       |       |      |      |      |      |     |      |      |      |     |
| Yuwadee et.al | 18.1 | 4.2   | 3     | 0.6  | 61.1 | 1.1  | 0.2  | 3.9 | 0.2  | 0.1  | 5.9  |     |
3. Properties of rubber-based geopolymer concrete

3.1 Mechanical properties

The mechanical properties of the rubber-based geopolymer mortar and concrete, such as compressive strength, split tensile strength, and flexural strength, is the most vital features of the geopolymer mortar and concrete for its application.

3.1.1 Compressive strength

The superiority of the concrete determined by conducting a compressive strength test plays a dynamic role. Factors affecting incorporation of the crumb rubber in concrete are % off replacement for both fine aggregate and coarse aggregates, and both combine, the addition of steel fiber along with crumb rubber, various size of aggregate, NaOH molarity, SS/SH ratio, AAS/Binder ratio, Elevated temperature. The Compressive strength test is conducted according to the certain standards by various codes BS EN:12390-3(2009)[4], ASTM C109/C109-16a (2016)[2], [14]–[16], MSZ EN 196-1:2005[17], IS:516-1959[18], ASTM C39[19]

Effect of the replacement of Fine Aggregate with the crumb rubber on OPC & GPC: The compressive strength of OPC and GPC for replacement of the fine aggregate by 0%, 10%, 20%, and 30% are studied [18]. Results show that the normal GPC shows similar strength than the OPC, which are 53.1 N/mm² and 54 N/mm² for the 28 days, 55.32 N/mm² and 56.23 N/mm² for 90 days and 56.9 N/mm² and 61.55 N/mm² for 365 days. For rubberised geopolymer concrete replacement of fine aggregate by 10% crumb rubber decreased the strength by 10-12% for curing period of 3, 7, 28, 90,365 days, 20% replacement of fine aggregate by crumb rubber the strength of concrete decreased by 25-28 % for the curing period of 3, 7, 28, 90 days and 30% replacement of fine aggregate by crumb rubber the strength of concrete decreased by 40-46 % for the curing period of 3, 7, 28, 90 days.

Effect of replacement of Coarse aggregate and fine aggregates with crumb rubber: The compressive strength of rubberised GPC when replaced with both coarse aggregate and fine aggregates by 2%, 6%, 10%, 14% are studied[5]. It shows that the replacement of coarse and fine aggregates by 2% of crumb rubber leads to increment in strength by 6% whereas further increment 6%, 10%, 14% leads to reduce the strength by 20 %, 45% and 60%[5]. The use of crumb rubber by minimal amount may show better results compared to standard concrete. Fig 1 shows the effect of replacement of aggregates with crumb rubber[5]

![Figure 1. Effect of replacement of coarse and fine aggregates with crumbed rubber on compressive strength.](image-url)

Effect of replacement of Fine aggregates with crumb rubber & steel fiber: The addition of steel fiber in GPC increases the compressive strength of concrete by a significant amount[4]. The study conducted on the rubberised geopolymer concrete replacement of fine aggregate by 5%, 10%, and 15 % along with the addition of 0.5% and 1% steel fiber. The results suggest that the compressive strength is obtained maximum for 28 days in the 5% replacement of crumb rubber along with 0.5%
steel fiber in geopolymer concrete. It also shows that the loss of strength for 15% replacement of crumb rubber and 1% steel fiber for 28 days is 35%. But remaining mixes show the loss is very less[4]. Fig 2 shows that the compressive strength of rubberised geopolymer concrete with crumb rubber and steel fiber.

![Figure 2. Effect of replacement of fine aggregate with crumb rubber along with steel fiber on compressive strength.](image)

Effect of various sizes of crumb rubber: The compressive strength of rubberised geopolymer mortar for various sizes of aggregates conducted by Mucsi (2018)[17] explained here. It's evident from the Fig 3 that if the size of the aggregate decrease for the same proportion of replacement of rubber in GPC leads to increment in compressive strength of geopolymer mortar by 10-25 %. But the addition of crumb rubber by 5 % leads to the same strength for both size aggregates[17].

![Figure 3. Effect of various size of aggregates on compressive strength.](image)

Effect of elevated temperature on GPC: The compressive strength of rubberised GPC for elevated temperatures studied by Luhar (2018)[20] shows that the increase in temperature results in loss of strength in concrete by a significant amount. Fig 4 shows that the 5 % replacement of fine aggregate by crumb rubber leads to lower the compressive strength by 50% for 800°C. But it shows that the 600°C temperature shows the least compressive strength on geopolymer specimen.[20]
Effect of Sodium Silicate/Sodium Hydroxide (SS/SH) ratio: The effect of various SS/SH ratio on the compressive strength of rubberised GPC is studied[2]. The compressive strength of mortar declines with the increase in the SS/SH ratio. It shows little increase for early days curing period such as 3 days is 2.08 N/mm², 2.69 N/mm² and 2.65 N/mm² for 0.5, 1 and 1.5 SS/SH ratio and for 14 days is 2.53 N/mm², 2.69 N/mm², 2.86 N/mm² for 0.5, 1 and 1.5 SS/SH ratio. But for a curing period of 28, 90, 180 days, the decrement in compressive strength of mortar by 10-15%[2]. Fig 5 shows the compressive strength of the GP mortar effect with the SS/SH ratio.

Effect of NaOH molarity: The effect of various molarity of NaOH on the compressive strength of rubberised GPC is studied[2]. The compressive strength of mortar increases with an increment in molarity of NaOH from 10 to 15, whereas further increment shows the decrement in strength for 20M. It shows the compressive strength of rubberized GPM for curing period of 3 days is 2.69 N/mm², 2.69 N/mm² and 2.44 N/mm² for 10, 15, 20 M of NaOH and for 14 days is 2.69 N/mm², 2.95 N/mm², 2.56 N/mm² for 10, 15, 20 M of NaOH. Compressive strength of rubber-based GPC increases 8% with molarity increment from 10-15 M. However, increment from 15 -20 M strength reduced to 5%[2]. Fig 6 shows the effect of various molarity of NaOH on the compressive strength of rubber-based geopolymer concrete.
3.1.2 Flexural strength

To determine the maximum stress of the concrete flexural strength test plays a vital role. Factors affecting the incorporation of crumb rubber in concrete are % off replacement for fine aggregate, the addition of steel fiber along with crumb rubber, various size of aggregate, NaOH molarity, SS/SH ratio, AAS/ Binder ratio, Elevated temperature. The flexural test is conducted according to the certain standards by various codes ASTMC1609[4], ASTM C78/C78-16 (2016)[2], [14]–[16], MSZ EN 196-1:2005[17], IS:516-1959[18], ASTM C78[19]

Effect of replacement of Fine Aggregate with crumb rubber on OPC & GPC: The addition of rubber in GPC increases the flexural strength of concrete both in OPC and GPC. The results show that the flexural strength of GPC is 6.45 N/mm² which is greater than OPC is 5.35 N/mm². The addition of rubber shows the increment of flexural strength by 6% for 28 days and 90 days curing period and 8% for 365 days curing period. The flexural strength of rubberised GPC shows for 10%, 20%, and 30% replacement of fine aggregate with crumb rubber is 2%, 3.8%, and 6% when compared with nominal GPC.

Effect of replacement of Fine aggregates with crumb rubber & steel fiber: The addition of steel fiber in GPC increases the flexural strength of concrete by a significant amount. [4]. The study conducted on the rubberised geopolymer concrete replacement of fine aggregate by 5%, 10%, and 15% along with the addition of 0.5% and 1% steel fiber. The results suggest that the flexural strength is obtained maximum for 28 days in the 5% replacement of crumb rubber along with 1% steel fiber in geopolymer concrete, which is 6.29 N/mm². It shows that the 5% replacement of crumb rubber shows an increment in flexural strength compared to nominal GPC, whereas further replacement results in the decrement of strength. But the addition of fiber to the rubber-based concrete shows better flexural strength[4]. Fig 7 shows the effect of replacement of fine aggregate with crumb rubber along with steel fiber on flexural strength.
Figure 7. Effect of replacement of fine aggregate with crumb rubber along with steel fiber on flexural strength.

Effect of various sizes of crumb rubber: The flexural strength of rubberised geopolymer concrete for various sizes of crumb rubber is studied[17]. The results show that the increase in flexural strength with an increase in steel fiber until 3% steel fiber for 4-8 mm size of aggregate. Further increment of steel fiber for 4-8 mm leads to a decrease in flexural strength, whereas for < 4 mm size aggregates, the increment in steel fiber leads to increment in flexural strength. The addition of rubber reduced the flexural strength compared to steel fiber-based concrete. Flexural strength of rubber-based geopolymer increases with an increase in rubber content, whereas if the size of the aggregates decreases leads to further increment in strength. Fig 8 shows the compressive strength of rubberised geopolymer concrete with crumb rubber and steel fiber.[17]

Figure 8. Effect of various size of aggregates on flexural strength.

Effect of various curing temperature on GPC: The flexural strength of rubberised GPC aimed at elevated temperatures are studied. It shows that the increase in temperature results in an increment
of strength in concrete by a significant amount. Fig 9 shows that the for 100% spare of the fine aggregate by crumb rubber on 25°C temperature shows Flexural strength of rubber-based geopolymer as 0.96 N/mm² whereas, for 60°C and 90°C, the flexural strength of mortar is 0.98 N/mm² and 1.89 N/mm² respectively. Various curing temperature displays that the surge in temperature primes to rise in flexural strength.[2]

![Figure 9. Effect of elevated curing temperature on flexural strength.](image)

Effect of SS/SH: The Fig 10 displays that the surge in SS/SH leads to decline in flexural strength for SS/SH ratio of 1 which is 0.98 N/mm² when compared with SS/SH ratio of 0.5 which is 1.46 N/mm² and SS/SH of 1.5 leads to increase when compared with SS/SH ratio of 0.5 and 1 which is 1.29 N/mm² [2].

![Figure 10. Effect of SS/SH on flexural strength.](image)

Effect of NaOH molarity: The Fig 11 shows that the flexural strength of rubber-based geopolymer concrete is maximum 1.85 N/mm² when the molarity of NaOH is 15 whereas for 10 M and 20M is 0.98 N/mm² and 1.28 N/mm² correspondingly.[2]

![Figure 11. Effect of various molarity of NaOH on flexural strength.](image)
3.1.3 Split tensile strength
The ductility of concrete can be attained by decisive the split tensile strength test. Factors affecting the incorporation of crumb rubber in concrete are % off replacement for both fine aggregate, size of aggregate.

Effect of replacement of Fine Aggregate with crumb rubber on OPC & GPC: The effect of replacement of fine aggregate by crumb rubber in proportions of 0%, 10%, 20%, 30%. The accumulation of crumbed rubber in OPC and GPC shows similar split tensile strength, but the GPC has split tensile strength advanced than OPC. The addition of rubber by 30% leads to obtained 5% increment in tensile strength compared to 0% replaced GPC[18]. This show that the tensile strength shows improvement by addition of rubber in GPC.

Effect of various sizes of crumb rubber: The scope of the various size crumb rubber affects the properties of rubberised GPC by means of a significant amount. Fig 12 shows that the tensile strength for 0% replacement shows that if the size of aggregates 1-4 mm, then the split tensile strength of rubberised GPC is 5.08, whereas, for size 2-4, the split tensile strength is 3.6 N/mm². Further addition of rubber by 10% shows the tensile strength of concrete as 5.13 for 1-4 mm size of aggregates whereas for size 2-4 mm is 2.355 N/mm². Results show if the size of the aggregate finer gives better split tensile strength[17].

![Figure 12. Effect of various size of aggregates on split tensile strength.](image)

4. Conclusion
- Workability of the concrete increases with an surge in the rubber concrete but the steel fibre addition leads to decrement.
- Flow value decreases with an advance in rubber content in the geopolymer concrete.
- Compressive strength shows decreased with an surge in rubber concrete by whereas steel fibre addition leads to increment.
- The compressive strength of mortar reduced with the rise in crumbed rubber, but adding the steel fibre shows a noteworthy increment.
- Compressive strength of geopolymer concrete declined by 60% for 15% spare of the crumb rubber in concrete and 10% spare of the crumb rubber in mortar.
- 95 % of geopolymer concrete total compressive strength achieved for 7 days curing period, which shows the accumulation of rubber principals to accelerate the strength.
- An intensification in temperature shows similar properties for both GPC and rubberised geopolymer concrete.
- Thermal exposure primes to decrement in compressive strength up and around 600°C, but then the further increment in temperature 800°C shows an increment in compressive strength, but the hairline crack observed.
• Tensile strength for rubberised geopolymerized concrete increases with the rise in the rubber content.
• Flexural strength for rubberised geopolymer mortar and concrete surges with the rise in the rubber content.
• Flexural strength is observed extreme for 30% standby of the Fine aggregate by the crumb rubber.
• Pre-treatment of the crumb rubber by NaOH leads to improve the compressive strength in geopolymer concrete.

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