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A Study on Partial Replacement of Fine Aggregates with Crumb Rubber and Cement with Metakaolin

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Abstract

Concrete, often referred to as man-made rock, consists of cement, aggregates, and water. Recent experimental studies have explored the strength characteristics of concrete by partially replacing fine aggregate with crumb rubber and cement with metakaolin. Concrete cubes were tested for compressive strength at 7 and 28 days, using various percentages of crumb rubber and metakaolin as replacements for fine aggregate and cement, respectively. The aim of the study was to investigate the compressive strength of concrete when metakaolin and fine aggregate were partially replaced with crumb rubber. The findings revealed that the optimum mix included 10% crumb rubber and 10% metakaolin, resulting in the highest compressive strength. This study underscores the potential of incorporating rubber waste into concrete mixes as a partial replacement for fine aggregate, contributing to environmental sustainability by reducing waste and promoting resource efficiency. By optimizing the use of crumb rubber and metakaolin, the concrete industry can enhance the mechanical properties of concrete while addressing environmental concerns.

Keywords: Coarse aggregate, fine aggregate, crumb rubber, metakaolin, rubberized concrete, compressive strength.

INTRODUCTION

Concrete, a widely used material, is composed of aggregate, cement, and water. Aggregate, the weakest material in concrete, accounts for approximately 60% to 80% of its total volume. Proper aggregate selection is crucial for innovation in construction and controlling particle size distribution. With the increasing number of vehicles, waste tire production is also increasing, leading to environmental hazards such as 'black pollution ‘Burning tires is the simplest and least expensive way to dispose of tires, but it also creates dangerous fumes, major fire risks, and uncontrolled emissions of substances that could be toxic.

Rubberized concrete is a novel form of cement concrete that uses recycled tire rubber as aggregates. Its goal is to enhance the performance of the original multi-component concrete by adding flexible components.

The performance of crumb rubber concrete (CRC) is between regular concrete (NC) and asphalt concrete, and it is an inflexible material. The compressive strength of rubberized concrete is reduced by 90% compared to the control sample of non-rubberized concrete. Therefore, appropriate research should be conducted to optimize the rubber powder content in the concrete mix. The reduction in tensile strength of crumb rubber (CRC) will limit its use in concrete. [1]

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Rubberized concrete has been proposed as a partial replacement in aggregate to improve strength. Researchers have reported several advantages, including reduced specific gravity, improved non-structure crack resistance, acid resistance, lower heat conductivity, and noise level reduction when concrete is incorporated with rubber up to 30% of the cement weight. Rubberized concrete is lighter in weight and has several advantages over conventional concrete, such as lower unit weight, improved ductility, higher toughness, impact resistance, better resistance to chloride penetration, lower thermal conductivity, and increased noise reduction factor. Waste tire rubber in concrete is classified by size rather than composition. The mechanical grinding process typically takes place at room temperature or below cryogenic temperatures.

Mechanical grinding at room temperature is commonly used in industry to cracker mills and cut waste tire into small pieces. Steel wire and fiber parts are separated from rubber particles magnetically at various translation stages to classify rubber particles. The steel wire is magnetically removed by mechanical grinding to avoid surface oxidation. After grinding, rubber of various sizes is obtained, with different particle sizes having different effects on concrete. Most studies have identified three categories of used tire rubber. In concrete, crushed or fractured rubber is frequently used in place of coarse aggregate. [2]

Rubber crumb is obtained in a special mill that grinds tire rubber into granules of various sizes from 0.425mm to 4.75mm. Ground rubber can partially replace cement, depending on the grinding equipment.

Supplementary cementing materials (SCM) have become essential in high-strength concrete mix design, including naturally occurring materials, industrial wastes, by-products, and those requiring less energy. Fly ash, silica fume, rice husk ash, granulated blast furnace slag, and metakaolin are examples of common SCMs. Because of its pozzolanic qualities, metakaolin, which is created by carefully controlling the heat treatment of kaolin, can be a component of concrete.

Research on metakaolin focuses on the impact of kaolin structure on kaolinite conversion and the use of thermo-analytical methods for investigating kaolin thermal therapiesTo prepare high-performance concrete, replace the current concrete with Portland cement that contains metakaolin to boost its durability and strength. [3]

7.5% is the ideal amount of substitution for metakaolin. Concrete that is designed for high performance and contains 7.5% metakaolin will have a compressive strength that is 12% greater than that of regular concrete.

Metakaolin has been used to produce self-concrete with good results This research aims to provide information on the use of crumb rubber and metakaolin as alternatives to fine aggregates and cement in rubberized concrete. It integrates past and existing studies on rubberized concrete, focusing on the strength behavior changes with different percentages of crumb rubber and metakaolin as a partial replacement of cement. In order to comprehend the implications of using rubber as a low-stiffness material in the concrete matrix, the study also carries out theoretical investigations. Extensive investigation is carried out on the advantages of rubber treatment, which involves testing a novel technique of soaking in water.[4]

Material and Methodology

This chapter describes an experimental program involving the study of rubberized concrete and its constituents, as well as the testing methods used to evaluate its properties. The study used coarse, fine aggerates, crumb rubber and metakaolin.

Cement

Cement is an artificial building material that provides binding properties in construction work. It is manufactured by burning and crushing stone containing 20-40% clay and remaining lime carbonate. Artificial cement, made from a mixture of calcareous and argillaceous materials, is considered one of the leading engineering materials of modern times. The study used HK cement ordinary Portland cement of grade 43, which consists of lime, silica, alumina, calcium sulphate, iron oxide, magnesia, Sulphur trioxide, and alkalis. Cement consists of argillaceous and calcareous compounds that fuse when intergraded and burned, leading to the formation of bogues compounds.

Metakaolin

Metakaolin, a pozzolanic material derived from kaolinite calcination, is widely used in mortar and concrete for its mechanical and durability properties. It reduces cement content and effectively increases the use of industrial waste material in concrete mixes. Metakaolin was partially substituted for cement in a study. Table 1

Cao	*0.09*
SiO_2	53
Al_2O_3	45
Fe_2O_3	0.6–1.2
MgO	0.03
SO_3	–
K_2O	0.03
Na_2O	0.1
L.O. I	0.5–1.5

Table 1. Chemical Composition of Metakaolin

Water

The study utilized tap water, a drinkable, clear, and clean water, with a PH value between 6-9, as the mixing water for concrete, as it was not containing harmful substances, and was introduced for hydration.

Aggregates

Aggregates are inert granular materials used in concrete. They reduce cost and form approximately 75% of the concrete mass. Sand has the finest modulus ranging from a 2.0 to 4.0. Three categories of sand exist: fine, medium, and coarse sand.

Specific gravity of fine aggregates was calculated as per IS: 2386-1963 and it was having a value of 2.60. Therefore, in my study the sand that was used has a fineness modulus of 2.31. Hence it is a fine sand [5]

Crumb Rubber

It is used as a partial replacement for fine aggregate. This size was selected because, from an environmental perspective, it is more affordable and widely available than finer sizes, and the sieve study revealed that the rubber's gradation is nearly identical to the size of the natural aggregate fraction. As a result, crumb rubber's size falls between 1 and 1.18 mm in sieve diameters. Table 2

Characteristics	
Bulk Density	1.15
Sulphur content	1.74%
Polymer base	60/20/20
Composition (%)	

Rubber	65.82
Carbon black	28.77
Carbon black	5.41
Total%	100.00

Table 2. Characteristics and composition of crumb rubber

Rubberized Concrete Treatment

The use of crumb rubber in cementitious composites has been extensively researched, but few studies have focused on improving the mechanical behavior of crumb rubber concrete (CRC).

One such method is the water-soaking method, which involves evaluating the wet addition of crumb rubber into the concrete mix series. This method is cost-effective and practical, resulting in a homogenous mix with evenly distributed rubber particles and better bonding between rubber and cement paste in concrete. However, there are challenges when introducing rubber into the concrete mix due to the vastly different bulk properties of rubber particles and concrete aggregate. The specific gravity of rubber products is about 1, while the specific gravity of concrete aggregate and cement paste is 2.6 and 2.2 respectively. This makes it difficult to obtain a uniform and homogeneous mixture containing rubber. Additionally, rubber particles trap air bubbles in concrete, which is undesirable. This study presents a new and efficient way to incorporate rubber into concrete to alleviate these difficulties. Most previous studies on rubberized concrete included rubber in the concrete mix without special consideration. However, limited research has provided several commonly improved methods of mixing rubber and concrete, which are expensive to apply and inconsistent. Additionally, adding rubber directly to concrete can trap air bubbles attached to the rubber particles, leading to degradation of rubberizing compounds and segregation of the mixture. This behavior is primarily due to the water-repelling behavior of rubber particles, which is a hydrophobic characteristic of rubber. [610] Fig 1

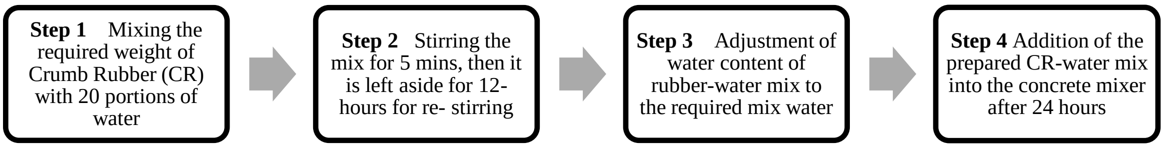

Fig 1. Wet procedure of introducing water-soaked rubber into concrete mix

Secondly the study introduces a wet procedure for introducing water-soaked rubber into concrete mix, addressing the issue of the specific gravity of rubber particles and the entrapped air bubbles. This method involves washing and cleaning the rubber surface with water and soaking it in water for 24 hours. This process can significantly resolve the hydrophobic behavior of rubber, as trapped air bubbles release gradually during the 24-hour soak. The procedure should be initiated 24 hours before mixing. After 24 hours, most rubber particles, around 50%, float on water, but eventually sink to the bottom of the container. This method is recommended for concrete mixtures.[10]

Experimental methods

The preparation of test specimens involves careful assembly of moulds. The moulds are pre-coated with mineral oil release agent to prevent adhering to the steel surface or damage to the concrete. Then the specimens were filled in three layers, each approximatively cast into two almost identical layers. The concrete was placed using a scoop and moved around the top edges of the moulds to ensure symmetrical distribution. Each layer was crushed for 30 seconds using a vibrating table to compact the concrete, preventing air entrapment. The top layer is leveled after the concrete overflows and cannot be filled in more. The moulds are stored in the laboratory for 24 ± 2 hours before demolding. After 24 hours, bolts are loosened, and samples are labeled and placed in curing water tanks until the test age of 7 and 28 days arrives. The process ensures accurate and reliable results in the testing of concrete specimens. The standards for concrete testing include weighing cement, aggregate, and water to an accuracy of 0.1 percent of the total weight of each batch. Materials must be prepared at room temperature, preferably 23°C, and moulds must be watertight and non-absorbent, coated with wax. Concrete must be compacted immediately after placing in moulds to produce full compaction without excessive segregation. Vibrating tables should be used to compact each layer, avoiding over-vibration to prevent air loss. Test specimens must be shielded from shock, vibration, and dehydration and kept in the mold for a full day at 20° ± 5°C. [1114]

Following removal, they need to be cured in water at 20° ± 2°C till testing. Applying load should be done gradually, building up to a point where no more can be maintained.

Physical test of Aggregates

Aggregates are crucial in concrete production, providing advantages such as strengthening structure and reducing cracking. Before using aggregates, they must be examined and evaluated for quality, including properties like strength, shape, hardness, toughness, water absorption, and specific gravity.

Various types of aggregate tests are conducted to determine the properties of aggregates, such as specific gravity and water absorption. Specific gravity tests measure the strength of aggregates, with low specific gravity resulting in weaker aggregates. Water absorption tests provide insight into the internal structure of aggregates, helping in general identification. Sieve analysis is a basic procedure in civil engineering that determines particle size distribution and fineness modulus of aggregates. In this study, manual sieving was used, with sizes for coarse aggregates being 25, 20, 16, 12.5, 10, 6.3, and 4.75mm. A popular method for figuring out particle size management for crumb rubber is sieve analysis, which entails shaking and tapping a given amount of the sample through a predetermined number of test sieves for a predetermined amount of time.

The experiment's crumb rubber had sieve widths that varied from 2.36 mm to 1.18 mm. Specific gravity and water absorption tests of crumb rubber verify suspected quantities of ingredients found in a compound by measuring the ratio of the mass of a crumb rubber to the mass of equal volume of water. The value of water absorption increased with the percentage of crumb rubber used in the study. Fresh concrete tests measure factors such as strength, consistency, specific gravity, and temperature to ensure consistent quality and strength. [15-9] Table 3

Description	**Value**	
Coarse aggregate size	10MM	20MM
Weight of saturated aggregate and basket in water W1(gram)	1802	1866
Weight of basket in water W2 (gram)	530	530
Weight of saturated surface Dry aggregate in air, W3 (gram)	1988	2092
Weight of oven dried aggregate in air W4 (gram)	1928	2020
Specific Gravity, W4/{W3_(W1-W2}	2.69	2.67
Apparent Specific Gravity, W4/ {W4	2.94	2.95
Water absorption (%) {W3-}	3.11	3.56

Table 3: Specific gravity and water absorption test of aggregates

Result and Discussion

This study uses an automatic universal testing machine (UTM) to test cubes. The specimen breaks at a specific point, and the load is noted. The compressive strength of the specimens is calculated using the compressive strength formula, resulting in the load/cross-sectional values of the specimens. Fig 2

Figure 2. Compressive strength testing setup.

Compressive strength decreases as the percentage of metakaolin and crumb rubber tires increases. At zero replacement, compressive strength is 39 N/mm2, but at 5% replacement of metakaolin and crumb rubber, the compressive strength decreases to 37.107 N/mm2, a decrease of 1.83. This is due to a volumetric replacement of sand by crumb waste tires and cement by metakaolin. The compressive strength is 35.51N/mm2 at 5% replacement of metakaolin and 10% replacement of crumb rubber, a 3.49 reduction from the initial value. [2021]

For the replacements of 5% metakaolin and 15% replacement of rubber the compressive strength drops to 33.12N/mm2 that is a decrease of 5.88 from the original value, at replacement, at replacement of 5% metakaolin and 20% crumb rubber the compressive strength decreases to 29.9N/mm2 that is a decrease of 9.1, at replacement of 5% metakaolin and 30% crumb rubber the compressive strength decreases to 23.35N/mm2 that is a decrease of 15.65, at replacement of 10% metakaolin and zero% crumb rubber the compressive strength increased to 45.22N/mm2 that is an increase of 6.22, at replacement of 10% metakaolin and 5% crumb rubber the compressive strength decreases to 41.6 N/mm2 that is an increase of 2.6, at replacement of 10% metakaolin and 10% crumb rubber the compressive strength decreases to 39.79N/mm2 that is an increase of 0.79, at replacement of 10% metakaolin and 15% crumb rubber the compressive strength decreases to 37.98N/mm2 that is a decrease of 1.02, at replacement of 10% metakaolin and 20% crumb rubber the compressive strength decreases to 33.46N/mm2 that is a decrease of 5.54, at replacement of 10% metakaolin and 30% crumb rubber the compressive strength decreases to 27.46N/mm2 that is a decrease of 11.54, at replacement of 15% metakaolin and zero% crumb rubber the compressive strength increased to 44.08N/mm2 that is an increase of 5.08, at replacement of 15% metakaolin and 5% crumb rubber the compressive strength decreases to 40.55N/mm2 that is an increase of 1.55, at replacement of 15% metakaolin and 10% crumb rubber the compressive strength decreases to 38.35 N/mm2 that is a decrease of 0.65, at replacement of

15% metakaolin and 15% crumb rubber the compressive strength decreases to 37.98N/mm2 that is a decrease of 1.08, at replacement of 15% metakaolin and 20% crumb rubber the compressive strength decreases to 33.5N/mm2 that is a decrease of 5.5, at replacement of 15% metakaolin and 30% crumb rubber the compressive strength decreases to 26.25N/mm2 that is a decrease of 12.75, at replacement of 20% metakaolin and zero % crumb rubber the compressive strength increased to 41.42N/mm2 that is an increase of 2.42, at replacement of 20% metakaolin and 5% crumb rubber the compressive strength decreases to 38.93N/mm2 that is a decrease of 0.07, at replacement of 20% metakaolin and 10% crumb

S.no	Sample	Replacement of fine aggregate with crumb rubber (%)	Replacement of Cement with metakaolin (%)	Compressive strength ($N/mm^{2)}$)	
				7 days	28 days
1(a)	MOR0	0	0	26.13	39
2(a)	M5R0	0	05	26.733	39.9
2(b)	M5R5	05	05	24.861	37.107
2(c)	M5R10	10	05	23.791	35.51
2(d)	M5R15	15	05	22.190	33.12
2(e)	M5R20	20	05	20.033	29.9
2(f)	M5R30	30	05	15.644	23.35
3(a)	M10R0	0	10	30.297	45.22
3(b)	M10R5	05	10	27.872	41.6
3(c)	M10R10	10	10	26.659	39.79
3(d)	M10R15	15	10	25.446	37.98
3(e)	M10R20	20	10	22.4182	33.46
3(f)	M10R30	30	10	18.3982	27.46
4(a)	M15R0	0	15	29.5335	44.08
4(b)	M15R5	05	15	27.1684	40.55
4(c)	M15R10	10	15	25.6945	38.35
4(d)	M15R15	15	15	25.446	37.98
4(e)	M15R20	20	15	22.445	33.5
4(f)	M15R30	30	15	17.587	26.25
5(a)	M20R0	0	20	27.751	41.42
5(b)	M20R5	05	20	26.083	38.93

5(c)	M20R10	10	20	24.146	36.04
5(d)	M20R15	15	20	24.220	36.15
5(e)	M20R20	20	20	20.535	30.65
5(f)	M20R30	30	20	20.535	30.65

Rubber the compressive strength decreases to 36.04N/mm2 that is a decrease of 2.96, at replacement of 20% metakaolin and 15% crumb rubber the compressive strength decreases to 36.15N/mm2 that is a decrease of 2.85, at replacement of 20% metakaolin and 20% crumb rubber the compressive strength decreases to 30.65N/mm2 that is a decrease of 8.35, at replacement of 20% metakaolin and 30% crumb rubber the compressive strength decreases to 30.65N/mm2 that is a decrease of 8.35[2227] TABLE 4
Table 4. Compressive strength values of specimens for 7 & 28 days

Modulus of Elasticity

The modulus of elasticity (Modulus of Elasticity) is a measure of a material's compressive strength. It is calculated as 5000 √fck. When replacing sand with crumb waste tires and cement with metakaolin, the compressive strength decreases as the percentage of these materials increases. At 5% replacement of metakaolin and the same amount of crumb rubber, the Modulus of Elasticity increases. However, at 5% and 5% replacement, Modulus of Elasticity decreases and continues to decrease until the replacement of 5% metakaolin and 30% crumb rubber. At 10% metakaolin and zero crumb rubber, the Modulus of Elasticity increases. Finally, at 20% metakaolin and 5% crumb rubber, the Modulus of Elasticity decreases and continues to decrease. Table 5

Cube Notion(%)	Modulus of elasticity (Mpa)	
SAMPLE	7 DAYS	28 DAYS
MORO	25,558	31,224
M5R0	25,851	31,583
M5R5	24,930	30,457
M5R10	24,388	29,795
M5R15	23,553	28,774
M5R20	22,379	27,340
M5R30	19,776	24,160
M10R0	27,518	33,622
M10R5	26,396	32,249
M10R10	25,816	31,539
M10R15	25,222	30,813
M10R20	23,673	28,922
M10R30	21,441	25,980
M15R0	27,170	33,196
M15R5	26,061	31,839
M15R10	25,344	30,963
M15R15	25,219	30,813
M15R20	23,688	28,939

M15R30	20,968	25,617
M20R0	26,339	32,179
M20R5	25,535	31,196
M20R10	24,569	30,016
M20R15	24,607	30,062
M20R20	22.658	27,681
M20R30	22,658	27,681

Table 5. Modulus of elasticity values of specimens for 7 & 28 days

Tensile Strength

As per IS:456, Tensile strength=0.7√fck.

As a result of a volumetric replacement of sand by crumb waste tires, and cement by metakaolin compressive strength decreases as percent of crumb waste tires and metakaolin increases, at 5% replacement of metakaolin and zero% of crumb rubber Modulus of elasticity is increased , at 5% replacement of metakaolin and 5% replacement of crumb rubber, Modulus of elasticity decrease from the original value and continues to decrease till the replacements of 5% metakaolin and 30% replacement of crumb rubber.[28-30] at replacement of 10% metakaolin and zero% crumb rubber the Modulus of elasticity increased, at replacement of 10% metakaolin and 5% crumb rubber the Modulus of elasticity starts to decreases and kept decreasing till the replacement of 10% metakaolin and 30% crumb rubber. At replacement of 15% metakaolin and zero% crumb rubber the compressive strength increased, at replacement of 15% metakaolin and 5% crumb rubber the compressive strength decreases and kept decreasing till the replacement of 15% metakaolin and 30% crumb rubber. At replacement of 20% metakaolin and zero % crumb rubber the Modulus of elasticity increased, at replacement of 20% metakaolin and 5% crumb rubber the compressive strength decreases and kept decreasing till the replacement of 20% metakaolin and 30% crumb rubber.[31-34] TABLE 6

Cube notion (%)	**Tensile strength (N/mmm2)**	
Sample	**7DAYS**	**28DAYS**
M0R0	3.57	4.37
M5R0	3.61	4.42
M5R5	3.49	4.26
M5R10	3.41	4.17
M5R15	3.29	4.02
M5R20	3.13	3.82
M5R30	2.76	3.38
M10R0	3.85	4.70
M10R5	3.69	4.51
M10R10	3.61	4.41
M10R15	3.53	4.31
M10R20	3.31	4.04
M10R30	3	3.66
M15R0	3.80	4.64
M15R5	3.64	4.45

M15R10	3.54	4.33
M15R15	3.53	4.31
M15R20	3.31	4.05
M15R30	2.93	3.58
M20R0	3.68	4.50
M20R5	3.57	4.36
M20R10	3.43	4.20
M20R15	3.44	4.20
M20R20	3.17	3.87
M20R30	3.17	3.87

Table 6: Tensile strength values of specimens for 7 and 28 days

Conclusion and Recommendations

This research thesis reveals that the optimal replacement level of cement and sand by MK and crumb rubber is 10%, providing the highest compressive strength. Rubber aggregate concrete can be used as lightweight concrete, but increasing the proportion of rubber particles in concrete reduces its workability. Metakaolin plays a crucial role in increasing compressive strength. The study evaluated the qualities of crumb rubber concrete using the water-soaking method, which is low-cost and produces homogeneous and evenly distributed rubber particles. Scrap tires are used to eliminate waste and are cost-effective, but there is a need to expand the tire recycling business to reduce land contamination and unlawful disposal. Concrete is lighter in weight, making it suitable for architectural purposes.

The use of waste tire crumb for non-structural Portland cement concrete in buildings is advised. Replacement percentages around (M10R5, M10R10, M10R20, and M10R30) in the PCC are also used. Replacements should be increased by 10% to improve the identification of behavioral changes in physical characteristics. The effects of larger tire shred sizes on PCC are also investigated. The physical characteristics of PCC are further tested through permeability and shrinkage limit, and the influence of additional raw materials in these mixes is explored.

In conclusion, using waste crumb tires in the production of concrete blocks, ribbed concrete blocks, and paving is strongly recommended.

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