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Potential Use of Rubber Powder as Cementitious Material

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Abstract

Tire production for vehicles is increasing exponentially given the rapidly growing population and transportation development. This study was conducted due to the lack of journals in determining the potential of rubber powder as a replacement material in mortar. The purpose of this study is to evaluate the potential use of rubber powder in mortar as a cementitious material and to determine the optimum amount of rubber powder to use as a cement replacement material in mortar. The testing included X-ray fluorescents test, moisture content, pozzolanic activity test, and strength activity index. A compressive strength test was used to determine the optimum amount to use as cement replacement. The data for the X-ray fluorescents test shows that rubber powder contains chemical elements in the range 0.49 %, 51%, and 35%. The strength activity index data was 73% and 39% for 7 days and 28 days. This finding shows that the strength activity index for mortar with 20% rubber powder for both days does not exceed the minimum requirement of 75% as stated in ASTM C618. The pozzolanic activity test shows the rubber powder does not react with saturated lime solutions. Rubber powder was melted before reaching 105°. The compressive strength test shows that the optimum use of rubber powder in mortar mix at 5% to 10% because it is still in an acceptable range. This study contribute to the next research on combining rubber powder with other addictives with high pozzolan for important.

1. Introduction

Waste tire disposal has become a significant environmental concern due to its non-biodegradable nature and the hazardous chemicals it contains. According to [13], an estimated 1.5 billion tires are produced worldwide each year, with developed countries generating waste tires at a rate of approximately one passenger tire per person per year, resulting in approximately 1 billion waste tires being produced annually. Despite efforts in recycling and regulation at various levels, improper disposal of tires is still prevalent, posing a major environmental threat.

With the growing environmental problems associated with the disposal of waste tires, there is a growing interest in exploring sustainable alternatives to using this material [14]. One approach is the incorporation of rubber powder from waste tires as a replacement material in cementitious products. This not only addresses the issue of waste management but also examines the potential benefits of improving concrete properties. Research into the possible use of rubber powder in concrete aims to develop innovative and environmentally friendly building materials, contributing to sustainable construction practices and a circular economy.

The first objective of this study is to evaluate the potential use of rubber powder in mortar as a cementitious material. Tests are conducted according to the ASTM C618 specification, which determines the potential of

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pozzolan as a cementitious material. This study's second objective is to determine the optimal amount of rubber powder to use as cement replacement material in mortar. Compressive strength tests are conducted to determine the optimal amount of rubber powder to be added.

Rubber can be applied to concrete and mortar by replacing fine aggregates (FA)and coarse aggregates (CA) or used as binders. The advantages of incorporating rubber powder (RP) into any engineering cementitious composite (ECC) include lowering CO_2 emissions and increasing the greenness of the environment [14]. The application of rubber waste in concrete is explored worldwide to reduce the number of waste tires produced annually.

2. Literature Review

The use of rubber powder as a substitute material will be the main topic of this study. Rubber waste tires are recycled and then cut into different sizes to create rubber powder. One kind of polymer material that is renowned for its remarkable toughness and resilience is rubber [1] in addition to its low density. It also has the appropriate levels of impact resistance and fatigue resistance. Construction materials with improved mechanical and physical qualities, like rubberized concrete or mortar, can be made by mixing rubber with cement-based alternatives. Additionally, this integration may help to enhance environmental sustainability. [9,10]. Researchers suggested grinding waste tires into various particle sizes of waste rubber powder (WRP) as a solution to mitigate the environmental risk caused by the buildup of waste tires. This method aims to substitute natural aggregates to produce concrete with enhanced toughness and damping capabilities.

In the construction sector, products like rubber powder are frequently utilized as substitutes for asphalt and other substitute materials. [7] conducted an investigation on the compatibility of rubber powder asphalt by experimenting with the chemical structure of the powder. The aim of that paper is to examine the effects of modified rubber powder on polymer compatibility using developed techniques for modification (physical, mechanical, and chemical surface etching methods). Three types of modified rubber powder with distinct chemical structures (sulfonic acid groups, thiol groups, and amide groups) are prepared in a laboratory. Rubber powder can be utilized in concrete in addition to asphalt.

The research by [2] states that the paper is based on the developed techniques for the modification of rubber powder (such as the physical method, mecha no chemical method, and chemical surface etching method) and the study of the effect of modified rubber powder on polymer compatibility, the three typesof modified rubber powder with different chemical structures (sulfonic acid groups thiol groups, amide groups) are prepared in the laboratory. [2] stated that the research aims to study the incorporation of rubber tire residues in mortars in two grades of granulometry for example spheroids (S) and fibers (F), replacing the conventional aggregate in 7.5%, 15%, and 30%. The results show that the rubber mortar exhibits a density reduction of up to 34.6% compared to conventional mortar,resulting in an approximately four-fold reduction in compressive strength.

3. Methodology

The rubber powder for this study that has been tested for its potential as a cement replacement material through chemical and physical tests. Then it will be incorporatedinto cement mortar and tested for its strength.

3.1 Material

Ordinary Portland Cement Type I was used in this study as it conforms to ASTM C150 and is suitable for use in concrete and used as the primary binder due to high strength, durability, and widespread availability. Fig. 1 shows the Ordinary Portland Cement follows ASTM C150 [6].

Fig. 1: Ordinary Portland Cement

The rubber powder used for this study was supplied by a local factory at Batu Pahat, Johor. The size of rubber powder used is 30 mesh. This rubber powder has been sieved according to several sizes. The results help in evaluating the fineness, which indicates the overall particle size and affects the design of the mortar mix, affecting properties such as workability and strength of the mortar. Proper grading ensures a well-balanced mortar mix with optimized durability performance.

Based on the ASTM C33 standard of grading fine aggregates, this table explains that fine aggregate should not be more than 45% passes any sieve and is retained on the next successive sieve shown in table 3.1, and its fineness modulus shall not be less than 2.3 or more than 3.1. The sieve size specified in the ASTM C33 specification is 9.5 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600 μm, 300 μm, and 150 μm. Table 1 shows the fine aggregate sieve results.

***Table 1*:** sieve results for the fine aggregate.

Sieve (Specification E11)	Percent Passing
9.5 mm (3/8 in)	100
4.75 mm (No.4)	95 to 100
2.36 mm (No. 8)	80 to 100
1.18 mm (No. 16)	50 to 85
600 – μm (No. 30)	25 to 60
300 – μm (No. 50)	5 to 30
150 – μm (No. 100)	0 to 10

Portable water free from contaminants was used for pouring and mixing cement mortar. The result is that the quality of the mortar that consistent, and there will be no additives that will lower its strength and durability.

3.2 Specification based on ASTM C618.

To evaluate the potential use of rubber powder, tests has been performed according to the ASTM C618 standard. In this process, it is important to comply with the chemical and physical requirements of ASTM C618.

3.2.1 Chemical Requirements

The rubber powder was tested with X-ray fluorescence to determine the chemical composition to compare with ASTM C618. An X-ray fluorescence test was conducted following ASTM C114. The procedure for performing this test has been followed [12] which states that rubber powder was sieved through a 63 µm sieve. The rubber powder was mixed with wax at a proportion of 2:8 (wax to ash). After that, the material was compacted to form a pallet by using the compacting machine. The specimens were kept in the vacuum desiccator. The XRF analyser was used to analyses the compound composition of the specimens[12].

The measurement of moisture content is an important step in determining the chemical properties of rubber powder, which can affect the performance and quality of the material. This process starts with taking a sample of rubber powder that is 45 μm in size. After that, the sample is placed in a drying oven set at a temperature between 105°C to 110°C for 24 hours.

3.2.2 Physical Requirements

Physical requirement tests done for rubber powder are fineness on a wet sieve and strength activity index. A total of 1 gram of sample is taken for this test. Next, a sieve with an opening size of 45 µm (No. 325 sieve). The rubber powder sample is poured onto the sieve, and clean water is passed through the sieve while shaking the sieve using a wet sieve for 10 to 15 minutes to ensure that all fine particles pass through the sieve. After the sieving process is completed, the rubber powder left on the sieve is collected and dried under sunlight for 5 hours. The weight of the rubber powder is then weighed, and the percentage of fineness is calculated by comparing the weight of the rubber powder with the initial weight of the sample. The results of this test are compared to the maximum requirement of 34%, as specified in ASTM C618, to assess whether the rubber powder meets the required fineness criteria.

The strength activity index evaluates the development of the compressive strength of mortar samples containing rubber powder and the strength of reference samples containing only cement. Based on Table 2, the design mix followed the ASTM C311 state in the test mixture, replacing 20 % of the mass of the cement used in the control mixture with the same mass as the test sample. The control mixture was 500g cement, 1375 g of fine aggregates, and 342 ml water, while the replacement 20% rubber powder mixture became 400 g cement, 100 g rubber powder, 1375 g of fine aggregates, and 342 ml of water.

Table 2: shows the design mix follows ASTM C311

Mix	**Cement (g)**	**Rubber Powder (g)**	**Fine Aggregate (g)**	**Water (ml)**
Control	500	0	1375	342
20% RP	400	100	1375	342
Total	900	100	2750	684

The mortar mixture was prepared and poured into 50 mm cube molds in two layers, each compacted 25 times to eliminate air voids. Figure 3.10 shows the mixing of mortar based on ASTM C311. The specimens were cured in a moist curing room at 23°C ± 2°C and 100% relative humidity for 24 hours, then de-molded and subsequently immersed in saturated calcium hydroxide solution until testing, as outlined in ASTM C311. The strength activity index with Portland cement was calculated as in Equation 1, which follows [3]. Where A is the average compressive strength of the test mortar, and B is the average compressive strength of the control mortar.

$$\text{SAI} = \left(\frac{A}{B}\right) \text{X } 100\% \qquad \text{Equation 1}$$

3.3 Pozzolanic Activity Test

A pozzolanic activity test was performed to evaluate the pozzolanic properties of rubber powder. This procedure follows the method by [11]. Figure 3.2 shows an unsaturated Ca $(OH)_2$ solution was prepared by dissolving 200 mg of analytical grade Ca $(OH)_2$ in 250 ml of deionized water. After the lime water system reached stable conductivity, 5 g of rubber powder was added to the solution as shown in Figure 3.2. This pozzolanic test was carried out for 180 minutes to obtain the conductivity loss of the rubber powder in the Ca $(OH)_2$ solution. A conductivity meter is used to take readings of conductivity loss and pH of the solution as shown in Fig. 2.

(a) **(b)** **(c)**

Fig. 2: Procedure for pozzolanic activity test (a) Saturated Ca $(OH)_2$ solution (b)Rubber powder added to saturated Ca $(OH)_2$ solution (c) Conductivity meter

3.4 Mortar Mix Design

The mix design relies on conventional quantities of the ingredients used in mortar making, incorporating rubber powder into the cement. The specific mix ratio chosen for this study is 3:2:1 (cement: sand: water) with a water-cement ration W/C 0.4 [8]. The rubber powder was set to replace cement with 5%, 10%,15% and 20% of the total weight of the cement. The mixed-design compressive strength test that has been conducted is shown in Table 3. A mixed design for the compressive represents twelve cubes, each four cubes will be tested on 3 days, 7 days, and 28 days.

Table 3: Mixed design for compressive strength test.

Mix	**Cement (g)**	**Rubber Powder (g)**	**Fine Aggregate (g)**	**Water (ml)**
Control	185	0	555	74
5RP	175	10	555	74

10RP	165	19	555	74
15RP	146	28	555	74
20 RP	118	37	555	74

3.5 Compressive Strength Test

According to ASTM C109, using a compression testing machine, the compressive strength test was carried out on the mortar at 7 and 28 days [5]. The sample sizes used are 50mm x 50mm x 50mm. These steps ensure a comprehensive evaluation of the pozzolanic activity of the material, confirming its suitability as an additional cementitious material in concrete. The mix design of the mortar, prepared according to standard guidelines, was developed to ensure both the consistency of the compressive strength test and the strength activity index test.

4. Results and Analysis

A dry sieve analysis was performed to determine the particle size of the rubber powder obtained. This process involves filtering the material through a set of sieves of different sizes to get distribution of particles based on size. Fig. 3 shows the results of the dry sieve for rubber powder showing that the majority of rubber powder particles are in the size range between 1.18 mm to 75 μm, with the highest percentage at 600 μm.

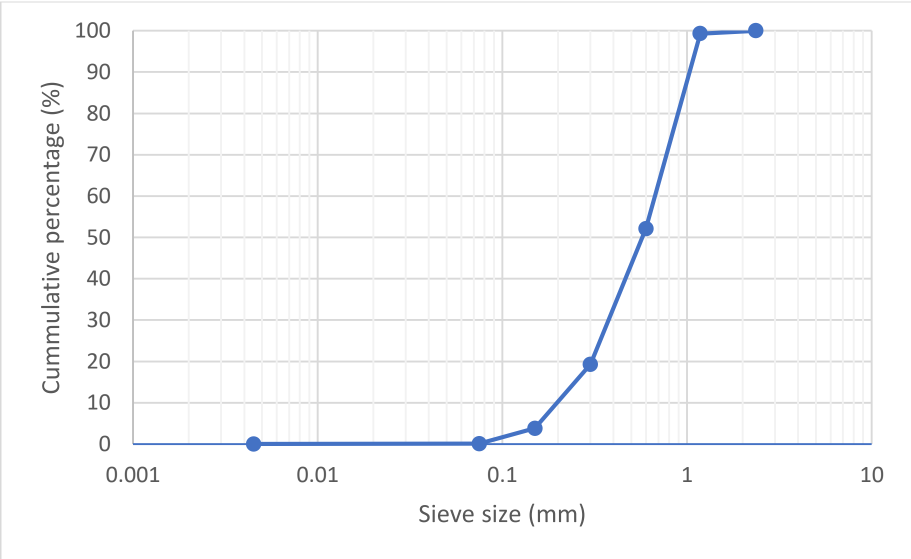

Fig. 3: Dry sieve fineness of rubber powder

As mentioned in Chapter 2, the XRF test was performed on the rubber powder to identify the composition of the elements and oxides found in the material. Table 4 shows XRF test data for rubber powder based on [15], [16], and [17]. Based on the results, it shows the presence of chemical elements in minimal amounts, which gives a clear picture of the nature of this material. According to [15] data, the content of silica (SiO_2) is as low as 0.49%, indicating that the rubber powder does not have a significant potential to act as a pozzolanic material since silica is the main component required to form the C-S-H (calcium silicate hydrate) gel in the reaction with calcium hydroxide. [15] data state alumina (Al_2O_3) is present at only 0.51%, insufficient to contribute to C-A-H gel formation, crucial for cement strength. Iron oxide (Fe_2O_3) at 0.01% does not affect the material's color or mechanical properties [15]. The low calcium oxide (CaO) content of 0.35% suggests minimal chemical reactivity, as CaO is vital in hydraulic reactions. Sulfur trioxide (SO_3) at 0.64% indicates minor gypsum presence, insufficient to significantly control cement hardening. Other elements are negligible, while a high carbon dioxide (CO_2) content of 94.03% reflects the dominance of organic matter from rubber decomposition or burning. .

Table 4: The data by the journal [15];[16] ; [17]

Elements	Results (%)
Silica (SiO_2)	0.49-72.17
Alumina (Al_2O_3)	0.51-12.51
Calcium Oxide (CaO)	0.35-3.66

Iron Oxide (Fe_2O_3)	0.01-3.43
Magnesium Oxide (MgO)	0.6-3.09
Sodium Oxide (Na_2O)	2.28
Potassium Oxide (K_2O)	0.36-2.11
Sulphur Trioxide (SO_3)	0.64-16.90
Titanium Dioxide (TiO_2	0.22
Zinc Oxide (ZnO)	0.001-14.60
Cuprum Oxide (CuO)	0.01-0.21
Phosphorus pentoxide (P_2O_5)	1.04
Carbon dioxide (CO_2)	94.03

The potential of rubber powder to be a replacement material in cement is determined according to ASTM C618 specification which has chemical requirements and physical requirements. For chemical requirements, Table 5 shows the requirement set by ASTM C618 for the classification of pozzolan or cement replacement materials. The summation of these three oxides to at least 50% [4]. This XRF data shows that rubber powder contains chemical elements in low amounts, especially elements essential for pozzolanic reactions such as SiO_2, Al_2O_3, and CaO [15], [16], [17]. In CO_2 indicates that rubber powder is an organic material rich in carbon and less chemically active. Therefore, rubber powder is more suitable for study as an additive with a specific function rather than as the main ingredient in a mortar or cement mixture. Fig. 4 shows during the moisture content test, the 45 µm rubber powder started to melt before the temperature reached 105°C. This shows the thermal properties of rubber powder, where the heat-sensitive rubber polymer structure causes it to melt quickly when exposed to high temperatures. The dry state of this powder also reduces uniform heat retention, causing the surface particles to reach their melting point earlier.

***Table 5*:** Requirement set by ASTM C618

Chemical Requirement based on ASTM C618		Findings
Silicon dioxide (SiO_2) plus aluminum oxide (Al_2O_3), plus iron oxide (Fe_2O_3), min, %	>50%	1.35% (min. range)
Sulfur trioxide (SO3), max, %	<5%	16.9% (max. range)
Moisture content, max, %	<3%	-

***Fig. 4*:** shows the melted rubber powder after being put in the oven

For physical tests, the fineness wet sieve and strength activity index were conducted to evaluate the potential of rubber powder. The results of the fineness test showed that 52% of the rubber powder remained on the 45 µm sieve, exceeding the maximum limit of 34% as specified in the ASTM C618 standard. These results show that rubber powder does not meet the fineness criteria for pozzolanic materials. This result shows that the rubber powder is not soluble in water, thereby reducing the pozzolanic reaction with calcium hydroxide (Ca $(OH)_2$) and causing lower strength. A strength activity index is done to test the strength of rubber powder in cement replacement. Data was collected over 7 and 28 days. Table 6 shows the results of the strength activity index test. The data with 20% rubber powder for mortar was 73 % and 39% for 7 days and 28 days, respectively. This shows that the SAI for mortar with 20% rubber powder for both testing days does not exceed the minimum requirement of 75% as stated in ASTM C618.

***Table 6*:** The results of the strength activity index

	Results (MPa)	Strength Activity Index (%)

Types of mixes	7 days	28 days	7 days	28 days
Control	4.1	13.2	-	-
20 % RP	3.0	5.1	73	39

In this pozzolanic activity test, rubber powder (RP) and palm oil fuel ash (POFA) have been tested for their conductivity with a mixture of calcium hydroxide which is carried out for 180 seconds. POFA has been used in this test to compare its performance with rubber powder as it is a well-established pozzolan. Based on the graph in Fig. 5, for rubber powder, the continuous graph shows a slow but consistent increase in conductivity, starting at around 1% at 0 seconds and increasing to nearly 2% at 180 seconds. This increase shows that RP does not react chemically with calcium hydroxide (Ca $(OH)_2$) solution but that there may be a release of specific ions, causing the conductivity to increase. In contrast, the dashed graph for POFA shows a sharp decrease in conductivity, starting at 6% at the beginning and decreasing to 2% after 180 seconds. This decrease occurs rapidly in the first 30 seconds, reflecting active chemical reactions between POFA and ions in the solution. After 90 seconds, the rate of decline becomes slower, indicating that most of the reaction has been completed or the POFA has been finished reacting with calcium hydroxide solution, and the remaining ions are minimally consumed.

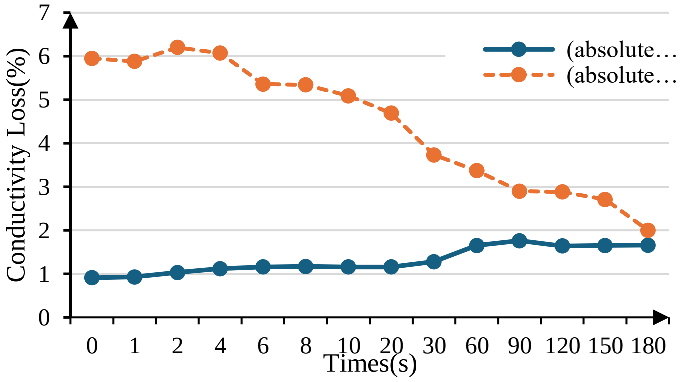

Fig. 5: Loss of conductivity of rubber powder in calcium hydroxide (Ca (OH)2) solution

The compressive strength test for mortar was conducted based on the ASTM C109/C109M-08 standard and the BS 4550-3.4 standard, which shows how the compressive strength test is performed by using the electromechanical table-top testing machine. Fig. 6 shows the graph data compressive strength test to determine the optimum amount of rubber powder to use as cement replacement material in mortar. This graph shows the data between the rubber powder content in the mortar mix with the average compressive strength (MPa) for a period. Data at 3 days, 7 days, and 28 days show a trend of decreasing compressive strength along with increasing rubber powder content, which indicates that the replacement of rubber powder has a negative effect on mortar strength.

The control mix recorded the highest compressive strength for all test periods, with strength increasing significantly from 3 days to 28 days. This shows that conventional mortar is more effective in increasing strength with time. Rubber powder is used as a replacement material at a ratio of 5%, 10%, 15%, and 20%, the compressive strength of the mortar experiences a gradual decrease. At a replacement rate of 20%, a compressive strength reading on day 3 could not be obtained because the specimen failed to reach the minimum strength required to be tested. This early failure may be due to the nature of the rubber powder which interferes with the binding and hardening process of the mortar, resulting in a strength that is too low to be registered by the testing machine. This situation shows that the replacement of rubber powder at a rate of 20% has a significant negative effect on the initial development of the mortar's compressive strength.

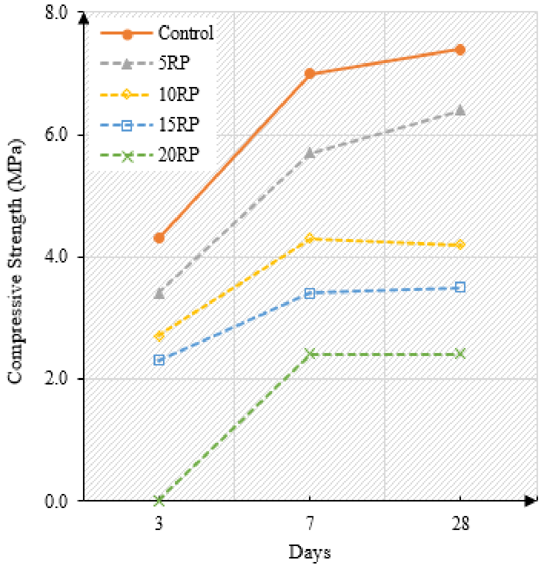

Fig. 6: Compressive strength results

5. Conclusion and Recommendations

In conclusion, the first objective, to evaluate the potential use of rubber powder in mortar as cementitious material, was achieved by doing the testing regarding ASTM C618. The summation of SiO_2, Al_2O_3, and CaO shows that rubber powder contains chemical elements in low amounts. For the moisture content, rubber powder was melted before reaching 105°. The strength activity index for the rubber powder shows that the strength activity index for mortar with 20% rubber powder did not exceed the minimum requirement of 75%, as stated in ASTM C618. The pozzolanic activity test showed rubber powder did not react with saturated lime. All these tests show that rubber powder has no potential to be used as a replacement material.

The second objective to determine the optimum amount of rubber powder to use as cement replacement material in the mortar was achieved by using a compressive strength test. This testing found that the optimum amount of rubber powder in the mortar mix is 5% to 10% because, at that rate, the compressive strength of the mortar is still in an acceptable range.

The future researcher is recommended to test the performance of rubber powder in non-structural applications, such as thermal and sound-insulating mortars, lightweight panels, and industrial floor covering materials that require resistance to shock or vibration. In addition, the future researcher can also focus on combining rubber powder with other additives with high pozzolan properties, such as fly ash, silica fume, or slag, to improve the mortar's chemical reaction and compressive strength test.

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