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AN EXPERIMENTAL INVESTIGATION ON THE PERFORMANCE OF RUBBERIZED FLY ASH BRICKS MANUFACTURED USING WASTE RUBBER

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A B S T R A C T

Waste tyres have a substantial detrimental influence on the environment owing to their considerable volume, non-biodegradability, susceptibility to combustion, and function as a breeding habitat for mosquitoes and several other pests. The use of waste tyre rubber (WTR) for the production of environmentally-friendly rubberized fly ash bricks serves as a method for mitigating the issue of waste disposal, so contributing to the reduction of resource depletion and environmental deterioration. The aim of this study was to evaluate the practicality of using waste tyre rubber (WTR) as a partial replacement for sand in the manufacturing of rubberized fly ash bricks. The purpose was to provide evidence that WTR waste may be effectively used in the construction sector. Waste tyre rubber (WTR) was used as a substitute for sand, with proportions ranging from 10% to 30%. The effectiveness of the green rubberized fly ash bricks was evaluated by analyzing its compressive strength, water absorption, porosity, thermal conductivity, and microscopic properties. The results of this research suggest that the compressive strength of rubberized bricks decreased somewhat in proportion to the extent of replacement. At a sand replacement rate of 10% with waste tyre rubber (WTR), the bricks exhibited the greatest compressive strength of 10.73 MPa and water absorption rate of 16.68%. The findings indicate that WTR exhibits promise as a viable option for replacing up to 30% of sand in the production of environmentally sustainable construction bricks.

1. INTRODUCTION

Tyres that have worn down to the point that they pose a safety hazard on the road are considered waste, or scrap tyres. This term is synonymous with End-of-Life Tires (ELT). Some used tyres are repurposed for other uses, while others are thrown in landfills or incinerated to generate fuel or thermal energy. Tyres are non-biodegradable, easily combustible, and chemically composed in a way that causes poisonous compounds to leak into the earth when dumped and dangerous gases when burned, making them a major worldwide concern if they are not recycled (Shah & Makwana, 2019). The widespread negative effects of tyre disposal and have led to its recognition as one of the biggest environmental

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issues facing the world today. Tires do not biodegrade, even after being treated for a long period in a landfill (Güneyisi et al., 2004). In addition, they are bulky, with 75% of their volume being vacant, which fosters the perfect environment for the proliferation of mosquito and rodent populations (Aliabdo et al., 2015; Islam et al., 2016). A further problem associated with scrap tyre heaps is that, if they catch fire, it may be extremely challenging to put out the flames, and the thick smoke, carbon dioxide, and toxic substances that are released as a consequence may have a substantial negative effect on the environment (Jang et al., 1998). Nonetheless, these issues could be resolved by the use of natural aggregates. The expanding need for natural aggregates in the construction industry has led to a scarcity of these resources. The depletion of natural sources of aggregates has been exacerbated by this situation, increasing the use of synthetic aggregates. The fast pace of global growth has resulted in a rise in the demand for sand in recent decades. Construction of artificial islands, shoreline fortification, and other land- and water-based reclamation operations all rely on sand. The extraction of sand also has the potential to negatively impact the ecosystem. One of the tangible effects of sand mining is a decline in water quality and the unstable state of the stream bed (Asrah et al., 2020). Researchers are free to explore other materials, such as tyre rubber, since the rising cost of sand prompts them to look for cheaper alternatives. Hence, the production of artificial aggregates from various waste materials is a solution to two problems: pollution and the depletion of natural resources (Lamba et al., 2021; Sorout et al., 2023). This makes it possible to develop in a sustainable manner and also encourages the growth of environmentally friendly buildings (Colangelo et al., 2016). Furthermore, the compressive strengths of mixes including manufactured particles surpass those of combinations containing aggregates from natural sources (Colangelo & Cioffi, 2017).

As a consequence of this, a viable solution would be to recycle the components of used tyres that have been thrown away to produce new products or enhance the functionality of those that already exist. Crumb rubber particles, derived from recycled tyres, have been employed as a partial substitute for fine aggregate materials in the manufacturing of rubbercrete (Mohammed et al., 2016; Mohammed & Adamu, 2018). Rubbercrete offers several advantages, but the lack of mechanical properties and durability that it has prevents it from being used to a significant degree in the construction industry (Mohammed et al., 2011; Mohammed & Azmi, 2014). In order to increase qualities like heat conductance, resilience to electricity, and noise acceptance, CR has been employed in the construction of hollow building blocks (Mohammed et al., 2012). To establish the endurance and strength of this material on concrete, it would seem that the usage of tyre waste as an alternative in concrete still needs to be examined and further explored. Asrah et al. (Asrah et al., 2020) conducted a study to investigate the feasibility of using Waste Rubber Tyres (WRT) and Waste Tea Sludge (WTS) as alternative materials to clay soil and sand, respectively, in the production of Interlocking Compressed Earth Blocks (ICEB). The study aimed to demonstrate the potential use of these waste products in the building industry. The replacement percentages observed for WRT were 5%, 10%, and 15%, whereas for WTS they were 10%, 30%, and 50%. The assessment of the efficacy of green interlocking compressed earth blocks (ICEBs) was carried out by measuring two established parameters: compressive strength and water absorption.

In a research investigation carried out by Ling (2012)(Ling, 2012), the use of recycled waste tyre material, namely crumb rubber, was examined as a prospective substitute for sand in different ratios (0%, 10%, 20%, and 30%). The research aimed to investigate the behaviour of rubber particles under compaction circumstances during the production of rubberized pavement blocks. The research focused largely on studying the mechanical as well as physical features of RCPB while it is in its hardened state. The inspection specifically assessed factors like density, compressive toughness, bending capacity, and resistance to skid. In order to improve the flexural resistance and ductile behaviour, as well as address the environmental implications related to waste tyres, Mohammed and Adamu (2018) performed a research study in which they proposed a unique material known as roller compacted rubbercrete (RCR). This study included the crumb rubber (CR) as a partial substitute for the fine aggregate component in roller compacted concrete pavement (RCCP) (Mohammed & Adamu, 2018). Polydorou et al. (Polydorou et al., 2020) undertook a research to improve the mechanical characteristics of concrete by specifically targeting the reinforcement of the Interfacial Transition Zone, a recognized area of weakness. The hydrophobic nature of reused tyre rubber particles was reduced, and the issue of excessive liquid repulsion during the combining process was alleviated by subjecting the rubber particles to a pre-treatment using garbage Quarry Dust (WQD), a substance often regarded as garbage.

Based on the literature examined it can be deduced that waste tyre rubber has been largely used in various research to incorporate it into concrete production. Nevertheless, the use of this technique in brick manufacturing has been restricted to a limited number of research investigations. Furthermore, a comprehensive analysis of the current corpus of scholarly works has shown a significant scarcity of research investigating the production procedure of a conventional benchmark brick via the integration of fly ash, sand, and cement, while substituting sand with waste tyre rubber. This research investigates the mechanical characteristics of a material composed of fine powder obtained from the waste produced by the tyre production industry. The evaluation included the assessment of compressive strength, water absorption, porosity, thermal conductivity, efflorescence, and microscopic characteristics for both the control sample and samples including (WTR) as a substitute for cement.

2. MATERIALS AND METHOD

2.1 Materials

The primary materials used in the present study consisted of Ordinary Portland Cement (OPC), river sand, fly ash, and waste tyre rubber (WTR). The present study used OPC 43 grade cement in accordance with the standards specified in IS: 8112-1989. The present experimental investigation included the collection of fly ash from a nearby industrial facility specialising in the manufacturing of fly ash bricks. Fly ash is a leftover unwanted product generated from industrial operations, namely those conducted inside thermal power plants. The river sand was obtained from local vendors located in close proximity to the region. Sand is a plentiful natural resource that may be obtained from riverbeds and is extensively used for many applications, notably in the field of building. The Waste Tyre Rubber (WTR) was sourced from a facility involved in the production of tyres, and was then used as a substitute for sand at varying proportions of 10%, 20%, and 30% in the manufacturing process of rubberized bricks. Table 1 displays the proportions of the brick mix.

2.2 Mix proportion and sample preparation

The first step was the preparation of a control sample, referred to as sample C, which was produced by blending Portland cement powder, fly ash, and sand in a precise ratio of 20:40:40. The present study included the manufacturing of fly ash bricks in compliance with the standards established by the National Thermal Power Corporation (NTPC). The guidelines outline the necessary ratios of the constituent components as follows: The composition of the material consists of fly ash, which makes up 50-60% of the mixture, sand or stone dust, which accounts for 32-40%, and cement, which comprises 8-10% (IS 12894 (2002) NTPC, 2002). Various combinations of these materials were used in order to manufacture the bricks. Following that, the sand component (S) was replaced with WTR (waste tyre rubber) in different proportions, namely 10%, 20%, and 30%. Table 1 presents complete data on the constituent elements of the mixtures under investigation. The blends were produced manually by meticulously blending all essential components for 4-5 minutes until they attained a uniform texture. Brick specimens, measuring 228.6 × 101.6 × 76.2 mm (length × width × height), were manufactured for each composition, as seen in Figure 1. The specimens underwent a curing process inside a water-filled container at the 28-day mark to facilitate the conduction of compressive strength analysis and related examination

Table 1. The precise composition used for the preparation of bricks.

Sample name	Ingredients by wt.%			
	Fly ash	Sand	Waste Tyre Rubber	Cement
Control (C)	40	40	-	20
RUS-1	40	36	4	20
RUS-2	40	32	8	20
RUS-3	40	28	12	20

3. TESTING OF BRICKS AND TEST TECHNIQUES

3.1 Water absorption

The water absorption capacity of bricks was evaluated using a 24-hour submersion test. Pores may absorb water using this way. Before undergoing the testing, the brick samples were subjected to a drying process in an oven at a temperature of 150 degrees Celsius until a consistent mass was achieved. After bringing the specimen to room temperature, the initial weight (W1) was measured. After that, the samples underwent 24 hours entirely submerged in the liquid. Next, a damp towel was used to wipe the samples clean after they were taken out of the water. The samples were then weighed again, this time to record their wet weight (W2). The water absorption % may be calculated using the formula shown below.

Water absorption (%) = [(W2-W1)/W1] ×100, where W1=dry weight, W2 = wet weight

3.2 Compressive strength

The compressive strength of the specimens was assessed as per the IS-12894 using Ticom company's 100-ton compression testing equipment, after a curing of 28 days.

The Construction Services & Research Centre in Faridabad conducted compressive strength testing. The applied load on the sample was incrementally augmented until it reached a threshold beyond which it was unable to maintain structural integrity. Upon reaching that juncture, the burden was alleviated. Subsequently, this numerical value was used to assess the magnitude of their strength in order to make a comparison with the strength shown by the control sample.

3.3 Porosity

The proportion of voids in a material, or its porosity, may be determined by dividing the void volume by the total volume of the material. To find out how much air was trapped inside the samples, a simple porosity test was performed in line with Indian standards (IS 13030). In order to determine the volume of bricks, we multiplied their measurements (length x width x depth) and then soaked them for 24 hours. After that, samples were taken out, and the surface water was drained. These samples were put in a cylindrical container with a large opening and filled with water, leaving just a small amount of space at the top. I then gathered the water that had been forced out of the jar and calculated its total volume. Porosity was calculated in percentage form using the porosity formula. The details for same are as under in Table -3 keeping in view of Indian standard (IS 13030).

Porosity (%) = (Total volume – volume of brick / Total volume) x 100 or (volume of voids / Total volume) x 100.

3.4 Thermal conductivity

In order to ascertain the specimen's heat conduction efficiency, its thermal conductivity was measured. According to the 1980 publication IS-3346, the steady-state approach is used to measure thermal conductivity. In order to conduct the experiment, a heating coil was placed in the gap between two bricks, and the bricks were then tied together with a rope to prevent any heat escape. Except for two sides, the whole structure was encased in a highly insulating material. Glass wool serves this goal well since it restricts heat flow to one direction and so reduces heat loss. A thermocouple is attached to both of the open sides. The electric circuit that powers the heating coil includes a voltmeter, an ammeter, and a dimmer stat. The system was housed in an airtight chamber that kept the ambient temperature and humidity constant. So we began our experiment by turning on the power and regulating the power output using a dimmer stat. During time, both the heater coils and the surrounding air gradually heated up. After equilibrium was attained, two temperatures—T1 at the heater coil and T2 at the outside face were measured. Both the current flow (in amps) and the voltage drop (in volts) were measured using the ammeter and voltmeter, respectively. And calculated the thermal conductivity by using the formula given below.

Thermal Conductivity (k) = i x v x L /A x (T1 –T2) W/M˚C Where i =current in ampere, V = voltage drop in voltage, L = depth of specimen in m, A = area of sample in m, T1 = Temperature at heater coil, T2 = Temperature at outer surface

3.5 Scanning electron microscope (SEM)

The microscopic structures of the material were analyzed with the assistance of a scanning electron microscope made by ZEISS and model number EVO 40. Microscopic analysis was carried out on both the control brick sample, which was labeled with the letter C, and the rubber-mixed sample, which was marked with the letter RUS-1. Before submitting any of the specimens for evaluation, a coating of gold-platinum was first put on them all. An intense electron beam was directed toward the region that was being used as the test subject for the experiment. A scanning electron microscope was used to take photographs of each of the images displayed in Figures 5a, 5b, 5c, and 5d. The resolution of these photographs ranged between 2 and 20 micrometres. Based on the findings of the SEM tests, it was found that the samples included granules of a variety of sizes and configurations. The graphic shows a variety of various-sized spaces in addition to a variety of different-sized particles.

3.6 X-Ray Diffraction (XRD)

Utilizing the X-ray diffraction technique, the samples' mineral composition was examined. In the Central Research Facility (CRF) of IIT New Delhi, X-Ray Diffraction (XRD) testing was performed. The X-ray diffraction investigation was conducted using the PANalytical X pert PRO powder diffractometer. The diffraction experiment used X-rays with a wavelength of 1.54060 A˚, namely the K-Alpha wavelength. An X-ray detector needs an angle equal to two times the diffraction angle (2) to pick up the diffracted X-ray beam. X'Pert High Score Plus software was used to perform mineralogical analysis on the raw XRD data. Samples from both the Control and RUS-1 groups were analyzed by diffraction after 28 days of cure. An X-ray diffractometer was utilized to acquire the diffraction pattern using CuK radiation and a diffraction angle of 2θ varying from 10 degrees to 90 degrees. The major purpose of the X-ray diffraction investigation was to identify the different phases already present in the control sample and to evaluate whether the phases had experienced any qualitative changes owing to the partial substitution of rubber waste powder with natural sand.

3.7 Efflorescence

The term "efflorescence" is often used to describe the presence of a white powdery residue on the outside surface of bricks. The brick is composed of an alkaline salt with hygroscopic properties, which enables it to effectively absorb moisture from the surrounding environment. The desiccation process of the specified moisture leads to the accumulation of tiny particles of matter on the external surface of the brick.

4. RESULTS AND DISCUSSION

4.1 Water absorption

(Fig.1) displays the water absorption capability of the different samples. An observation was made about the correlation between the percentage rise in tyre rubber and the subsequent increase in water absorption percentage. The water absorption amount of the Control sample was found to be 16.68% by mass, whereas the samples containing 10%, 20%, and 30% tyre rubber waste exhibited water absorption percentages of 17.69%, 17.88%, and 17.95% respectively. The observed augmentation in water absorption might perhaps be attributed to the expansion of WTR, resulting in the formation of micro-cracks inside the samples. The potential cause of the expansion of WTR is hypothesized to be the absorption of water during the process of hydration. Fly ash increases the amount of water absorbed by the samples. This is due to the water-absorbent properties of fly ash, which enhance the capability to absorb water of the hardened material when incorporated into the mixture (Naganathan et al., 2015). There was no observed presence of efflorescence in either the control bricks or the bricks that received supplementation with (WTR).

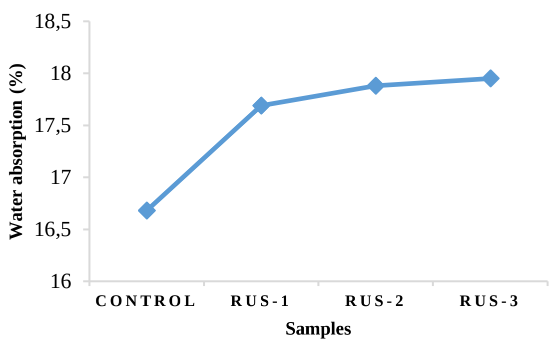

Figure 1. Variation of water absorption with different percentages of WTR.

4.2 Compressive strength

The study revealed that the compressive strength of the Control sample was measured at 10.75 MPa and exhibited a maintained strength as the proportion of tyre rubber increased. The measured values for the 28-day compressive strength of tyre rubber at 10%, 20%, and 30% concentrations were 10.73 MPa, 10.70 MPa, and 10.68 MPa, respectively (refer to Figure 2). The little reduction in compressive strength seen as the total rubber content rose in the samples may be due to the insufficient formation of bonds between the WTR particles and the cement. The aforementioned insufficiency results in the generation of micro fractures and diminished bonding within the matrix of the specimen. This phenomenon results in weakened adhesion between the WTR and cement, thus inducing increased porosity within the microstructure of the cement matrix, ultimately resulting in a decline in strength. The augmentation of the WTR content leads to a corresponding increase in the voids present within the samples. Furthermore, the increased elasticity of rubber particles is a crucial factor in the initiation of micro-fractures inside samples, since they expand when subjected to compressive pressure. Additionally, the specimen's compressive strength is reduced because of the low specific gravity and round form of rubber particles. A higher concentration of rubber might cause more empty spaces inside the material, resulting in a combination that has low density and weak strength. Moreover, the correlation between the rise in void percentage and the increase in the percentage of water absorption may be established. According to Benazzouk et al. (Benazzouk et al., 2007), the reduced compressive strength seen in specimens using crumb rubber tyres may be attributed to the same underlying cause. It is noteworthy to observe that the rate of spalling exhibited a progression in specimens containing WTR, in contrast to the control brick. This behaviour was seen in all specimens, except for the control specimen.

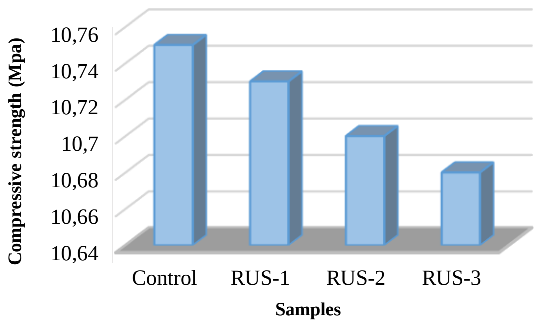

Figure 2. Variation of compressive strength with different percentages of WTR.

4.3 Porosity

According to the results shown in Figure 3, there is a direct relationship between the percentage of WTR replacement and the porosity of the rubberized samples. This means that as the proportion of WTR replacement rises, the porosity of the samples likewise increases. This observation aligns with the results reported in other studies conducted by (Thomas & Gupta, 2015). The reason for this phenomenon is attributed to the non-polarity of WTR, which causes it to reject water and trap air on its surface. As a consequence, the air spaces within the matrix are increased, as well as the pores within the interfacial transition zone. This increase in rubber content ultimately leads to porosity, hence reducing the material's ability to bear impact loads. It is possible to consider that an augmentation in the rubber composition may potentially result in an elevation of void formation within the matrix, thus yielding a composite material characterized by reduced density and inadequate mechanical strength (Thakur et al., 2020). The porosity of the control sample was determined to be 10.09%. In the case of rubberized bricks, the porosity values were found to be 11.69%, 11.88%, and 11.95% for sand replacement levels of 10%, 20%, and 30% with tyre rubber, respectively. These values indicate a rise of 15.8%, 17.7%, and 18.4% in porosity compared to the control sample. A higher proportion of voids may be substantiated by an increase in the percentage of water absorption.

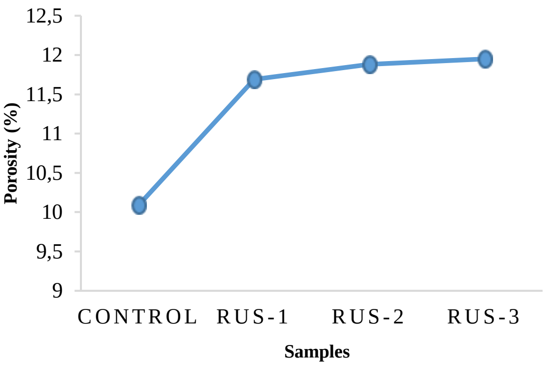

Figure 3. Variation of porosity with different percentages of WTR.

4.4 Thermal conductivity

Several building applications rely heavily on thermal characteristics. Energy is transferred from a hotter zone to a cooler one whenever a temperature difference occurs. The correlation discovered between the heat flow rate per unit area and the standard temperature variation suggests that conduction is the principal mechanism accountable for the transfer of energy (Aliabdo et al., 2015).

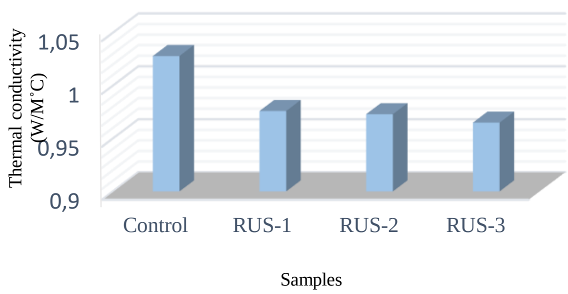

Figure 4. Variation of thermal conductivity with different percentages of WTR.

Fig.4 displays the thermal conductivity values of control bricks and rubberized bricks, with varying percentages of sand substitution by rubber particles. According to the provided data, the thermal conductivity of the control brick is measured to be 1.028 W/M °C. In contrast, the thermal conductivity values of rubberized bricks with rubber volume fractions of 10%, 20%, and 30% are found to be 0.976, 0.973, and 0.965 W/M °C, respectively. The conclusion that can be drawn from the test results is that the samples' thermal conductivity and rubber content are negatively correlated. This observation may be ascribed to two factors: the decrease in density of the samples and the insulating properties of the rubber particles that infiltrate the samples. Additionally, it can be observed that the k-values decrease by 5%, 5.4%, and 6.12% at rubber contents of 10%, 20%, and 30% respectively, in comparison to the thermal conductivity value of the control sample. Ghedan &Hamza (Ghedan & Hamza, 2011) documented a similar decrease in heat conductivity in the context of rubberized concrete. In a study conducted by Sukontasukkul (Sukontasukkul, 2009), an investigation was carried out to examine the thermal characteristics when varying percentages of sand were replaced with rubber particles. The hot plate technique was used for this purpose. Sukontasukkul's study determined that the heat conductivity of rubberized concrete decreases by about 20% and 50% when the fine aggregate is replaced by weight with rubber at levels of 10% and 30%, respectively.

4.5 Scanning electron microscope (SEM)

Following a 28-day curing period, SEM and energy-dispersive X-ray spectroscopy (EDX) analyses were performed on both the control samples and the samples having WTR. Fig.5 displays the microstructure images obtained using SEM as well as EDX data for two types of bricks: control bricks (C) and bricks including waste tyre rubber (RUS-1) at a concentration of 10%. Figure 5 (a-b) displays microscopic pictures of a control sample and an RUS-1 sample, captured at a magnification of 5.00 KX. Fig. 5a displays the SEM picture of the control sample. Fig.5b shows the SEM picture of the Rus-1 sample, revealing the presence of rubber ash particles characterized by an uneven form. At the present level, it can be seen that none of the pictures exhibit a uniform structure. Specifically, the image denoted as Control (Fig. 5a) has a somewhat more compact structure compared to the image representing the RUS-1 sample (Fig. 5b). It is evident that the particles of cement and rubber exhibit an irregular shape, whereas the particles of fly ash possess a spherical morphology (Fig.5 (a-d)). The spherical shape of fly ash is readily observable in the visual representation of the control sample, as seen in Fig.5a Pores are seen at the interface between the WTR and cement matrix, resulting in a decrease in the strength of the samples (see Fig.5b). Pores may also be seen in the control sample, as shown in Fig.5a. However, the percentage of porosity is higher in RUS-1 compared to the control sample. This disparity indicates a weaker binding between cement and waste tyre rubber, resulting in a decline in the strength of the rubber mixed sample(Gupta et al., 2014). Fig.5c and 5d show the SEM images captured at a magnification rate of 10.0 thousand times (10.0 KX). The presence of white patches indicated the production of C-S-H crystals(Praburanganathan & Chithra, 2020).

In some locations, the empty areas are visible. This phenomenon might perhaps arise from the inadequate adhesive properties shown by the rubberized particles when interacting with other constituents. The visibility of the CSH crystals is greater in the control sample (Fig. 5c) in comparison to the RUS-1 sample (Fig. 5d). The EDX images indicate the constituent elements of the control sample and RUS-1 sample samples in Fig. 5e and Fig.5f.

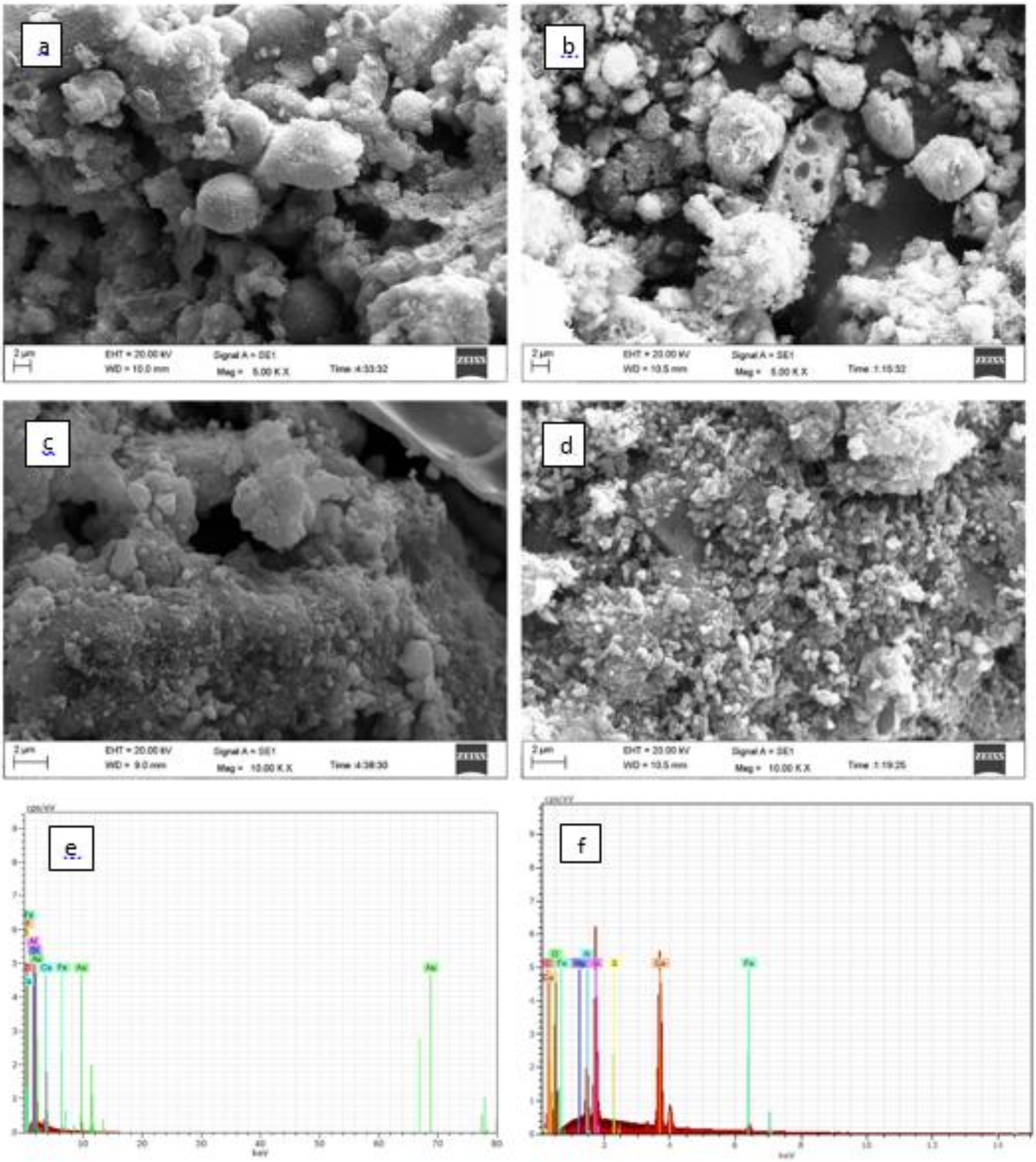

Figure 5. SEM and EDX images of control and RUS-1 samples

4.6 X-Ray diffraction

The X-ray diffraction (XRD) analysis reveals the crystalline phase, as seen in Fig.6. The objective of this test was to ascertain the effects of using rubber waste as a partial substitute for sand in the control mixture. Fig.6 shows the XRD pattern of a control sample and an RUS-1 sample, respectively. The graphs shown in the Figure provide evidence that both samples exhibit characteristics consistent with crystalline solids. The graphs demonstrate the presence of quartz (silicon oxide) with JCPDS Card (00-046-1045) and calcite ($CaCO_3$) with JCPDS Card (00-005-0586) crystals, suggesting that these minerals constitute the majority of the control sample. The dominant component of the intensity peaks is readily seen to be quartz (SiO_2), which is present in significant amounts. The predominant component of fly ash is quartz, which is responsible for the presence of SiO_2 in samples (Cabral et al., 2010). Based on the findings of the XRD analysis, it has been shown that the crystal structure of quartz exhibits a hexagonal arrangement. Furthermore, quartz is classified under the P3221 space group, specifically designated as number 154 within this particular space group. Furthermore, it has been shown that the density of quartz is 2.66 g/cm^3. The XRD pattern of the RUS-1 sample, as shown in Fig.6, reveals the presence of a crystalline phase consisting of quartz (SiO_2) that corresponds to the JCPDS Card (00-046-1045), as well as calcite ($CaCO_3$) that matches the JCPDS Card (00-005-0586). A comparison was made between the XRD patterns of the control (C) sample and the sample containing 10% waste tyre rubber. It was noted that the peak associated with calcite, which had the maximum intensity in the control sample, showed a reduction in intensity in the RUS-1 sample. The incorporation of rubber waste into the control mix might be attributed to the observed decrease because of the binding between cement and WTR.

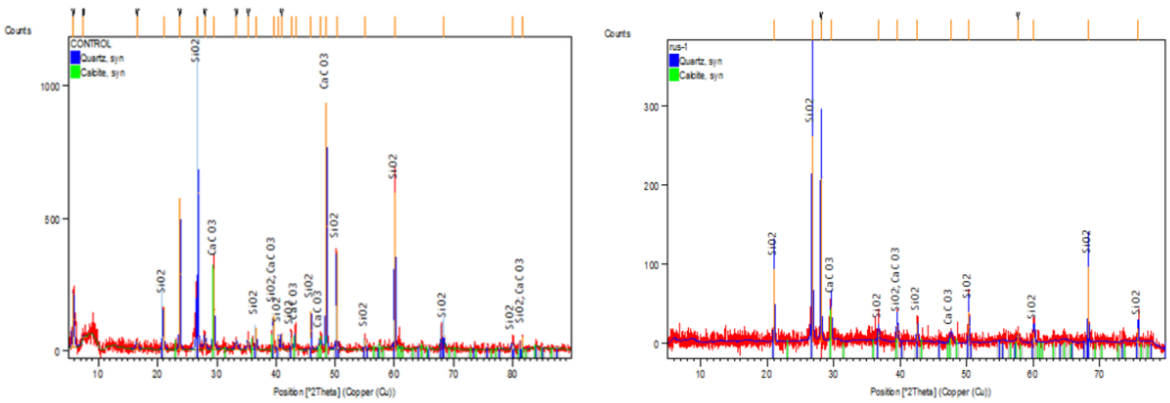

Figure 6. XRD graph of control and RUS-1 samples.

5. CONCLUSION

This research article examines the use of waste tyre rubber (WTR) in the brick manufacturing process as a viable and environmentally responsible approach to waste management. By implementing strategies to remove WTR from landfills or incineration and repurposing it as a valuable resource, we may effectively mitigate environmental degradation and promote the principles of waste reuse and recycling for waste management purposes. The empirical investigations have shown that bricks produced with WTR have favourable mechanical characteristics. The use of WTR in brick manufacturing has been identified as a promising option due to its capacity to have good compressive strength, durability, and thermal insulation characteristics of the resulting bricks. According to the results of the current investigation, the following conclusions may be drawn.

1. The bricks, which were produced by partially substituting sand with WTR after a period of 28 days of curing, exhibited a significant level of compressive strength that is suitable for use in building applications.
2. The incorporation of 10-30% of WTR as a substitution for sand has resulted in the manufacturing of bricks that exhibit satisfactory compressive strength, meeting the minimum criterion specified in IS 1077 (a minimum of 3.5 MPa).
3. The bricks containing WTR demonstrate a porosity ranging from 11.69% to 11.95% and a water absorption rate below 20%, all of which align with the permissible criteria outlined by the Indian standard for building bricks. Therefore, it is advisable to use them in areas characterized by mild to moderate weathering circumstances.
4. The use of WTR as a sand replacement in the manufacturing process of bricks resulted in a reduction in the thermal conductivity of the bricks.

However, it is necessary to conduct long-term research to examine the durability, performance, and life cycle of WTR bricks in different environmental situations to provide valuable insights for evaluating their suitability for commercial use.

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions.

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References:

Aliabdo, A. A., Abd Elmoaty, A. E. M., & AbdElbaset, M. M. (2015). Utilization of waste rubber in non-structural applications. *Construction and Building Materials*, *91*, 195–207. https://doi.org/10.1016/j.conbuildmat.2015.05.080

Asrah, H., Hamid, H. K. A., Khan, S., Karim, A., & Gungat, L. (2020). *Utilization of waste materials in the production of interlocking compressed earth brick*. International Journal Of Engineering Advanced Research, 1(4), 27-40.

Benazzouk, A., Douzane, O., Langlet, T., Mezreb, K., Roucoult, J. M., & Quéneudec, M. (2007). Physico-mechanical properties and water absorption of cement composite containing shredded rubber wastes. *Cement and Concrete Composites*, *29*(10), 732–740. https://doi.org/10.1016/j.cemconcomp.2007.07.001

Cabral, A. E. B., Schalch, V., Molin, D. C. C. D., & Ribeiro, J. L. D. (2010). Mechanical properties modeling of recycled aggregate concrete. *Construction and Building Materials*, *24*(4), 421–430. https://doi.org/10.1016/j.conbuildmat.2009.10.011

Colangelo, F., & Cioffi, R. (2017). Mechanical properties and durability of mortar containing fine fraction of demolition wastes produced by selective demolition in South Italy. *Composites Part B: Engineering*, *115*, 43–50. https://doi.org/10.1016/j.compositesb.2016.10.045

Colangelo, F., Cioffi, R., Liguori, B., & Iucolano, F. (2016). Recycled polyolefins waste as aggregates for lightweight concrete. *Composites Part B: Engineering*, *106*, 234–241. https://doi.org/10.1016/j.compositesb.2016.09.041

Ghedan, R. H., & Hamza, D. M. (2011). *Effect Of Rubber Treatment On Compressive Strength And Thermal Conductivity Of Modified Rubberized Concrete*. *15*.

Güneyisi, E., Gesoğlu, M., & Özturan, T. (2004). Properties of rubberized concretes containing silica fume. *Cement and Concrete Research*, *34*(12), 2309–2317.https:/doi.org/10.1016/j.cemconres.2004.04.005

Gupta, T., Chaudhary, S., & Sharma, R. K. (2014). Assessment of mechanical and durability properties of concrete containing waste rubber tire as fine aggregate. *Construction and Building Materials*, *73*, 562–574. https://doi.org/10.1016/j.conbuildmat.2014.09.102

IS 12894 (2002) NTPC. (2002). *IS 12894 (2002): Pulverized Fuel Ash-Lime Bricks -*.

Islam, M. M., Mohammed, E. Y., & Ali, L. (2016). Economic incentives for sustainable hilsa fishing in Bangladesh: An analysis of the legal and institutional framework. *Marine Policy*, *68*, 8–22. https://doi.org/10.1016/j.marpol.2016.02.005

Jang, J.-W., Yoo, T.-S., Oh, J.-H., & Iwasaki, I. (1998). Discarded tire recycling practices in the United States, Japan and Korea. *Resources, Conservation and Recycling*, *22*(1–2), 1–14. https://doi.org/10.1016/S0921-3449 (97)00041-4

Lamba, P., Kaur, D. P., Raj, S., & Sorout, J. (2021). Recycling/reuse of plastic waste as construction material for sustainable development: A review. *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-021-16980-y

Ling, T.-C. (2012). Effects of compaction method and rubber content on the properties of concrete paving blocks. *Construction and Building Materials*, *28*(1), 164–175.https:/doi.org/10.1016/j.conbuildmat.2011.08.069

Mohammed, B. S., & Adamu, M. (2018). Mechanical performance of roller compacted concrete pavement containing crumb rubber and nano silica. *Construction and Building Materials*, *159*, 234–251. https://doi.org/10.1016/j.conbuildmat.2017.10.098

Mohammed, B. S., Anwar Hossain, K. M., Eng Swee, J. T., Wong, G., & Abdullahi, M. (2012). Properties of crumb rubber hollow concrete block. *Journal of Cleaner Production*, *23*(1), 57–67. https://doi.org/10.1016/j.jclepro.2011.10.035

Mohammed, B. S., Awang, A. B., Wong, S. S., & Nhavene, C. P. (2016). Properties of nano silica modified rubbercrete. *Journal of Cleaner Production*, *119*, 66–75. https://doi.org/10.1016/j.jclepro.2016.02.007

Mohammed, B. S., & Azmi, N. J. (2014). Strength reduction factors for structural rubbercrete. *Frontiers of Structural and Civil Engineering*, *8*(3), 270–281.https:/doi.org/10.1007/s11709-014-0265-7

Mohammed, B. S., Azmi, N. J., & Abdullahi, M. (2011). Evaluation of rubbercrete based on ultrasonic pulse velocity and rebound hammer tests. *Construction and Building Materials*, *25*(3), 1388–1397. https://doi.org/10.1016/j.conbuildmat.2010.09.004

Naganathan, S., Mohamed, A. Y. O., & Mustapha, K. N. (2015). Performance of bricks made using fly ash and bottom ash. *Construction and Building Materials*, *96*, 576–580. https://doi.org/10.1016/j.conbuildmat.2015.08.068

Polydorou, T., Constantinides, G., Neocleous, K., Kyriakides, N., Koutsokeras, L., Chrysostomou, C., & Hadjimitsis, D. (2020). Effects of pre-treatment using waste quarry dust on the adherence of recycled tyre rubber particles to cementitious paste in rubberised concrete. *Construction and Building Materials*, *254*, 119325. https://doi.org/10.1016/j.conbuildmat.2020.119325

Praburanganathan, S., & Chithra, S. (2020). Synergy of waste glass powder and waste rubber: A research on loading, perseverance and morphological features of unburnt fly-ash-based masonry units. *Materiali in Tehnologije*, *54*(1), 99–106. https://doi.org/10.17222/mit.2019.142

Sam, M., Radhika, N., Sidvilash, V., & Mohanraj, T. (2022). Investigation on the mechanical and wear behaviour of Al-6082-BN-B4C-CorN COB ASH hybrid composites. *Tribology in Industry*, *44*(1), 294–309. https://doi.org/10.24874/ti.1165.08.21.11

Shah, S. S., & Makwana, M. M. (2019). *AN INVESTIGATIONAL STUDY ON USE OF WASTE MATERIALS IN ECO-FRIENDLY FLY ASH BRICKS*. *6*(3).

Sorout, J., Raj, S., Kaur, D. P., & Lamba, P. (2023). Waste-Based Bricks: Evaluation of Strength Behaviour of Bricks Containing Different Waste Materials as an Additive. *Water, Air, & Soil Pollution*, *234*(7), 424. https://doi.org/10.1007/s11270-023-06438-x

Sukontasukkul, P. (2009). Use of crumb rubber to improve thermal and sound properties of pre-cast concrete panel. *Construction and Building Materials*, *23*(2), 1084–1092. https://doi.org/10.1016/j.conbuildmat.2008.05.021

Thakur, A., Senthil, K., Sharma, R., & Singh, A. P. (2020). Employment of crumb rubber tyre in concrete masonry bricks. *Materials Today: Proceedings*, *32*, 553–559. https://doi.org/10.1016/j.matpr.2020.02.106

Thomas, B. S., & Gupta, R. C. (2015). Long term behaviour of cement concrete containing discarded tire rubber. *Journal of Cleaner Production*, *102*, 78–87. https://doi.org/10.1016/j.jclepro.2015.04.072

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