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Sustainable Civil Engineering at the Beginning of Third Millennium

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Umut Türker · Özgür Eren · Eris Uygar
Editors

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Editors
Umut Türker
Department of Civil Engineering
Eastern Mediterranean University
North Cyprus, Türkiye

Özgür Eren
Department of Civil Engineering
Eastern Mediterranean University
North Cyprus, Türkiye

Eris Uygar
Department of Civil Engineering
Eastern Mediterranean University
North Cyprus, Türkiye

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Preface

The quality of civil engineering directly impacts people's lives and personal safety, and it also has a significant impact on the advancement of society. Civil engineering and human life are intimately intertwined. To address the issues pertaining to the current state of civil engineering development, it is imperative that the field's advancement and development status be thoroughly examined. Hence, the proceedings book shares current trends in civil engineering including new technologies, methods, theories, and practices in all branches of civil engineering by bringing together researchers and experts worldwide. As a result, we obtained fascinating papers detailing recent developments in the field of civil engineering. We are optimistic that the papers included in the proceedings book will spark fruitful debate among scholars and enable us to increase our level of understanding, opening new avenues for the civil engineering profession.

The popular research topics in the book comprises: investigation in the areas of innovative materials in concrete production, recycling of waste in the construction industry, fiber reinforced and high strength concrete, soil stabilization, problematic soils of semi-arid and arid regions, deep foundations, staged construction modeling, repair and maintenance of reinforced concrete, earthquake engineering and seismic retrofitting, coastal and harbor engineering, water resources management, hydrology and hydraulics engineering, traffic engineering and urban transport, life cycle cost analysis, and decision making strategies. All these topics have been in the general context of the rising trends recently, as we advance into the third Millennium, the current outlook is such that they will continue to be as important as ever. With sustainability in mind, research and practice in the field of civil engineering will also continue to deliver societies' demand effectively.

Getting together with researchers and practitioners to share ideas and create future research partnerships was very pleasant. As the hosting organization, Eastern Mediterranean University appreciates everyone who participated in the congress by submitting, reviewing, and delivering papers.

Umut Türker

Contents

Building Materials

Check for updates

Influence of Short Polyethylene Terephthalate Fibres on Mechanical and Physical Properties of Cementitious Mortars

Can Özgün Sayı(✉), Necat Özaşık, and Özgür Eren

Civil Engineering Department, Eastern Mediterranean University, Famagusta, North Cyprus, Turkey
can.sayi@gmail.com, ozgur.eren@emu.edu.tr

Abstract. Commodity plastics are being used in many applications due to their low density, high durability, and relatively low cost. Their wide usage and degradable nature create environmental problems. Polyethylene terephthalate (PET) is the one of most used plastics and the second largest contributor to the global plastic waste. The scientific literature suggests a global effort for utilizing PET waste in building materials including concrete, mortars, and cementitious composites, in the form of granules, powder or fibres. This study aims to contribute to the knowledge about the material behavior of Recycled PET Fibre Reinforced Mortars (RPFRMs) by investigating the influence of fibres on some physical and mechanical properties of a cementitious render mortar.

Recycled-PET monofilaments with 0.45 mm diameter were chopped into fibres with 6 mm length. RPFRM mixtures with varying fibre volume fractions (0.5, 1.0 and 1.5%) were prepared and tested. The fresh properties were assessed by measuring the fresh density, and mean flow diameter. The influence of recycled PET fibres on the mechanical properties of render mortars were investigated using flexural strength and compressive strength. Furthermore, water absorption coefficient of the specimens was also measured for briefly investigating the influence of recycled-PET fibre addition on durability properties.

Keywords: PET fibre · mortar · compressive strength · flexural strength · water absorption coefficient

1 Introduction

Their relatively low price, density, availability and easy production, make plastics useful in many products, and they are being used in great amounts for various industries [1]. The global plastics production is increasing at a concerning rate, reaching 390.7 million tonnes in 2021 [2]. The plastic waste generated are either sent to landfills, incinerated, or recycled, where recycling in considered to be a more environmentally responsible method for disposal [3]. The recycled plastic waste can either be used as raw materials for plastics production. Another approach is the utilization of plastic waste in construction industry, in which the plastic waste can be used in insulation materials, as fillers [4],

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concretes or cementitious mortars [5]. Polyethylene Terephthalate (PET) is a type of commodity plastic, which the usage amount is one of the highest [6] and constitutes the second largest fraction in plastic waste stream [5]. However, the recycling rate of PET waste is relatively lower than its production and the most of them end up in landfills or nature [4, 7]. Therefore, any effort for making use of PET waste contributes towards environmental sustainability. PET waste can be utilised as aggregate substitute, or as fibres in concretes and mortars [7]. In this study, mortars reinforced with recycled PET fibres will be focussed.

Depending on the dimensions, properties and the volume of fibres, the properties of matrix phase and the quality of bonding between fibre and the matrix phases, the fibres can affect the properties of cementitious materials [8]. For instance, a study by Oliveira et al. [5] reports significant increase (up to 33%) in the flexural strength of mortars when PET fibres were added at 1.5vol%, Francioso et al. [9] reports insignificant increase at same volume of PP fibres, and rather reduction at lower fibre volumes, probably due to poor adhesion which reduce the potential positive impact. In general, synthetic fibres with low elastic modulus such as PET fibres contribute to the control of shrinkage cracks via bridging mechanism [5]. Literature reports insignificant changes of compressive strength of cementitious mortars upon the addition of synthetic fibres made of PET and PP [5, 9, 10]. As the specific gravity of PET is lower than that of conventional aggregates used in cementitious mortars, the fresh and hardened density is expected to decrease slightly with PET fibre or PET granule addition, as reported in previous studies [5, 7]. There are conflicting views regarding the influence of PET fibres on the consistency and water absorption of cementitious mortars.

This study aims to contribute to the knowledge about the material behaviour of Recycled PET Fibre Reinforced Mortars (RPFRMs) by investigating the influence of fibres on some physical and mechanical properties of a cementitious render mortar. The physical properties of cementitious mortars were looked into, by measuring the fresh density, hardened density and consistency of render mortar samples with varying amounts of fibres, as well as non-fiberized mortar samples. Furthermore, the mechanical properties were also evaluated by investigating the compressive and flexural strength of the same set of mortar samples. Finally, the durability properties were also briefly discussed by investigating the water absorption.

2 Methodology

2.1 Materials

Type 1 (42.5) Ordinary Portland Cement complying with TS EN 197-1:2012 was used as the binder phase of the mortar mixes. The fine aggregate consisted of crushed limestone which was obtained from quarries in Beşparmak Mountains. The properties of fine aggregate and cement are presented in Table 1. Short fibres (Fig. 1) were produced by cutting monofilament threads made of recycled PET (Table 2).

Table 1. Chemical and physical properties of mortar constituents

Property	Cement	Fine Aggregate
SiO_2 (%)	19.17	1.67
Al_2O_3 (%)	4.51	0.53
Fe_2O_3 (%)	3.24	0.31
CaO (%)	63.29	84.51
MgO (%)	1.99	12.58
SO_3 (%)	3.21	0.06
Loss on Ignition	3.72	–
Insoluble Residue	0.66	–
Blaine Specific Area (cm^2/gr)	3700	–
Residue on 45μm sieve (%)	2.50	–
Specific Gravity (gr/cm^3)	3.15	2.71
Maximum Diameter (μm)	–	2000
Water Absorption (%)	–	2.55

Table 2. Physical properties of recycled PET fibres.

Diameter (mm)	Length (mm)	Aspect Ratio	Specific Gravity
0.45	30	67	1.61

Fig. 1. Short PET fibres with 0.45 mm diameter and 6 mm length.

2.2 Sample Preparation

The mix design for the non-fiberized cementitious mortar were adapted from the formulation of a commercial dry-mix render mortar, and the parameters were presented in Table 3. The constituents were weighed and mixed at room temperature. The recycled PET fibres were added at a volume of 0.5%, 1.0% and 1.5% of the non-fiberized mortar.

Table 3. Mix design of mortar

Constituent	Dosage (kg/m^3)
Cement	415
Fine Aggregate	1120
Water	335

2.3 Test Procedures

Fresh and hardened properties of cement-based mortars with and without fibers were briefly investigated. Related standards were followed to evaluate the behavior of mortar on specific properties of which the test procedures were explained below.

Density
Bulk density of samples was measured according to BS-EN 1015-6.

Mean Flow Diameter
Average mean flow diameter of cement-based mortar samples was investigated according to BS-EN 1015-3 standard. Freshly mixed mortar was filled into the cone placed on the flow table in two layers by stroking each layer at least ten times with tamper until the cone was completely full. The steel cone was later removed to leave samples free, and the handle was rotated fifteen times at approximately fifteen seconds to provide enough jolting of the flow table. Finally, the diameter of the fresh spread mortar was measured both in vertical and longitudinal dimensions to record the diameter in mm.

Mechanical Strength (Compressive and Flexural Strengths)
The specimens were prepared and tested according to BS EN 1015-11 standard in a hydraulic press with relevant test jigs (see Fig. 2). The test specimens were prisms with dimensions 160 × 40 × 40 mm. For the compressive strength test, three prism specimens were broken down into two halves to provide six test samples to be tested at an age of 28 days. The machine with two supporting rollers and span length of 100 mm was used for flexural strength tests.

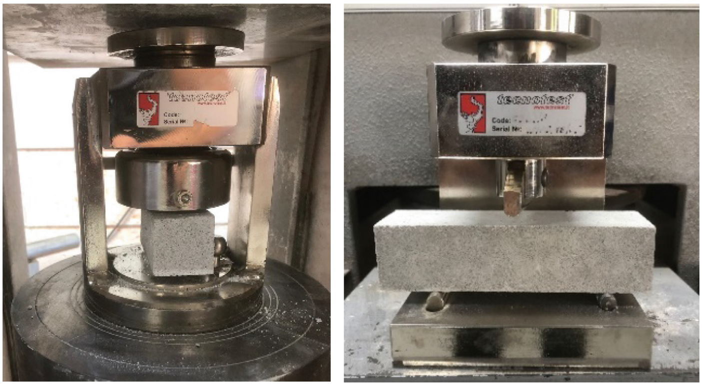

Fig. 2. RPFRM samples being tested for their compressive strength (left) and flexural strength (right)

Water Absorption Coefficient

The water absorption coefficient of control and fiber added cement-based mortar samples were measured according to BS EN 1015-18 standard. First of all, freshly prepared mortar was placed into molds covered with filter papers on both bottom and top surfaces. Then, cured for two days in the molds plus five days with the molds removed at 95% relative humidity, followed by 21 days at 65% relative humidity. After the curing period, four long sides of the specimens were sealed with wax material to prevent ingress of water from the sides and broken down into halves. On the day of testing, oven dried specimens were placed in the tray with broken surfaces downwards and immersed in water with a depth of 5 to 10 m. Weight of each specimen was recorded at 10 min and 90 min of immersion (Fig. 3).

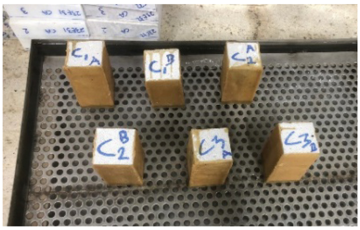

Fig. 3. Control mortar samples being tested for water absorption coefficient.

3 Results and Discussion

3.1 Density

Fresh and hardened density measurements of control and RPFRM samples were performed, and the results are presented in Fig. 4. It can be seen that in both fresh and hardened states the recycled PET fibre addition decreased the density of mortars. In literature, small decrease in mortar density with PET fibre addition was previously reported [5]. Maximum density reduction (8.4% for fresh density and 10.4% for hardened density) was observed at highest fibre content (1.5vol%). The relatively lower density of PET fibres in comparison to that of the control mortar mix, could be contributing to the density reductions. Furthermore, the formation of voids around the fibres due to potential entanglements, or other imperfections in fibre dispersion could be other reasons for the reductions in density.

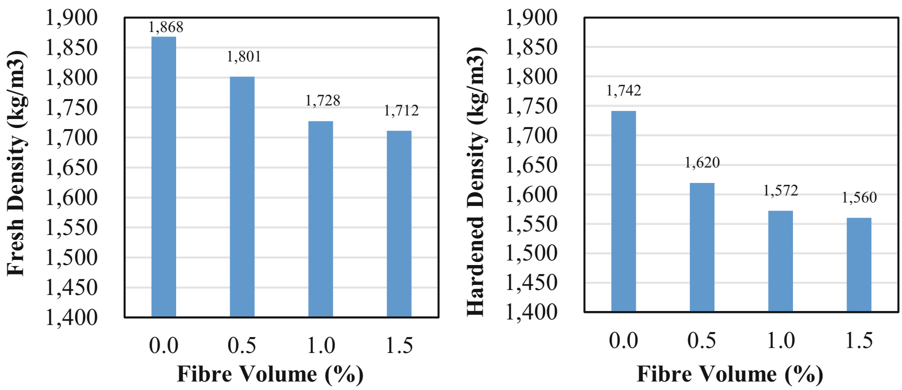

Fig. 4. Influence of PET fibres on the fresh (left) and hardened (right) density of mortars.

3.2 Mean Flow Diameter

Mean flow diameter measurements were performed for control and RPFRM samples and the results are presented in Fig. 5. It can be observed that fibre addition into mortar resulted in a steady decrease in the mean flow diameter of the mortars. The maximum reduction in the flow diameter was 3.4% and was observed at a fibre volume of 1.5%. Study of Bendjillali et al. [8] mentions that the mortar becomes less workable with the addition of synthetic fibres, due to higher surface area. However, Sposito et al. [7] reports increased workability with PET granule addition, due to lower absorption of PET surface, allowing free water which enhances the flow. This may suggest that the effect of PET fibre geometry could be dominating the effect of low absorption of PET.

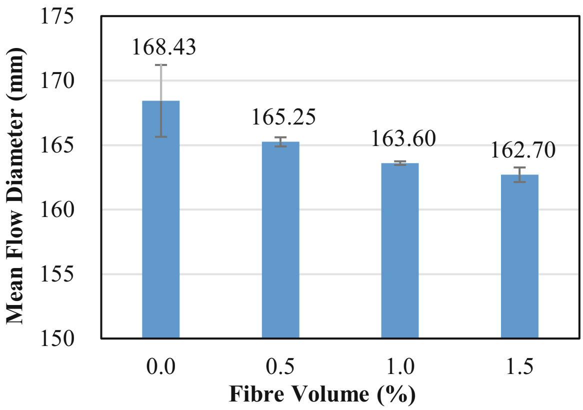

Fig. 5. Influence of PET fibres on the mean flow diameter of PFRMs.

3.3 Compressive Strength

Compressive strength tests were performed for control and RPFRM samples and the results are presented in Fig. 6. It can be observed that fibre addition into mortar resulted in insignificant variations in compressive strength, where the maximum increase compared to non-fiberized mortar was 2.2% and maximum reduction was 5.5%. Insignificant changes in compressive strength of cementitious mortars as a result of PET fibre addition was previously encountered in similar studies [5].

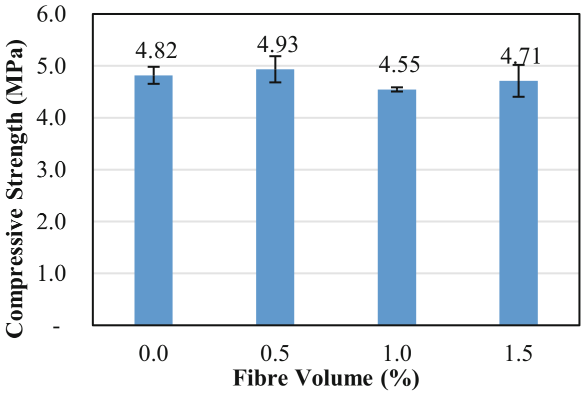

Fig. 6. Influence of PET fibres on the compressive strength of RPFRMs.

3.4 Flexural Strength

Flexural strength tests were performed for control and RPFRM samples and the results are presented in Fig. 7. It can be observed that recycled PET fibre addition resulted in a steady decrease in flexural strength of mortar. The maximum reduction was %22.6 and it was observed at a fibre content of 1.5 vol%.

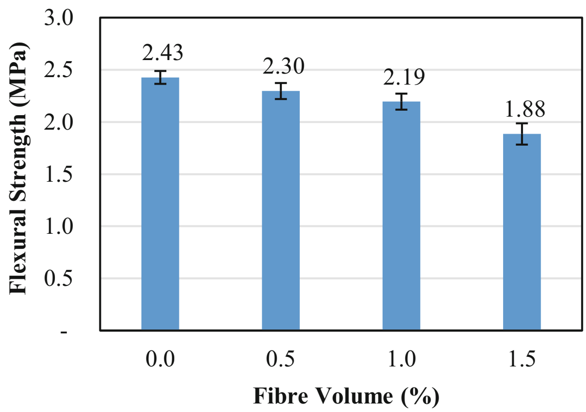

Fig. 7. Influence of PET fibres on the flexural strength of PFRMs.

3.5 Water Absorption Coefficient

Water absorption coefficient measurements were performed for control and RPFRM samples and the results are presented in Fig. 8. It can be observed that recycled PET fibre addition resulted in a slight increase in water absorption coefficient of mortar. The maximum increase was %5 at a fibre volume of 0.5 vol%. The increase in water absorption could be attributed to the potential void formations around the recycled PET fibres in the mortar specimens, which could increase the overall porosity which could allow water ingress. It was previously mentioned in the literature that the water resistance of PET could be deteriorating the adhesion and dispersion within cementitious materials, which could lead to receives that increase the water permeation at the interface between PET fibre and cement phases [11]. A non-linear increase of water absorption of mortars upon addition of PET granules was also observed in literature [7], which also supports such effect of PET. Further fibre addition resulted in water absorption coefficient values which were statistically the same as 0.5 vol%. In a similar study performed by Oliveira et al., the insignificant and irregular variations of water absorption at different fibre volumes were attributed to potential pullout of fibres at the fracture surface [5].

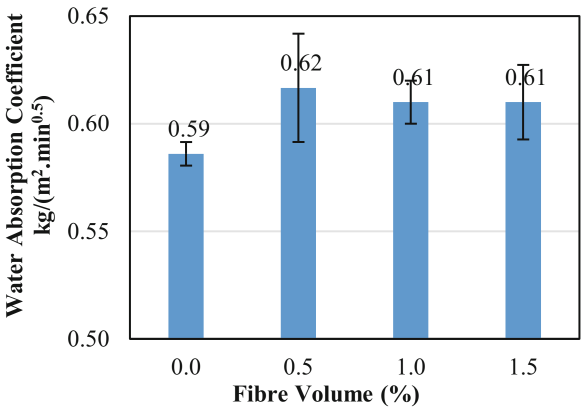

Fig. 8. Influence of PET fibres on the water absorption of PFRMs

4 Conclusions

Tests and measurements were performed in order to assess the mechanical and physical properties of recycled PET reinforced mortars. It was observed that:

- Density of mortars decreased with PET fibre volume, due to lower density of fibres and void formation,
- Mean flow diameter volume of RPFRMs decreased with addition of PET fibres. At 1.5% fibre volume, 3.4% reduction in the flow diameter was observed.
- The effect of PET fibres on compressive strength of mortar samples was insignificant. The maximum increase and decrease compared to control mortar were 2.2% and 5.5% respectively.
- A steady decrease was observed in flexural strength of mortar with PET fibre addition where maximum reduction was 22.6% with addition of 1.5% fibres.
- Water absorption coefficient of mortars were increased up to 5% when recycled PET fibres were added at a volume of 1.5%.

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Alkali Activation of Stabilized Rammed Earth Bricks: A State-of-the-Art Review

Maroan Elgallal(✉) and Ayse Pekrioglu Balkis

Civil Engineering Department, Cyprus International University, Nicosia, North Cyprus, Turkey
marwanelgallal@yahoo.com, apekrioglu@ciu.edu.tr

Abstract. The construction industry's increasing focus on sustainability has led to a growing interest in Stabilized Rammed Earth (SRE) as a low-carbon and affordable building material. However, SRE's widespread adoption has been hindered by its relatively low strength and durability. This review explores the potential of alkali activation to enhance the mechanical properties of SRE. Alkali activation involves using alkaline solutions to activate pozzolanic materials, such as fly ash, slag, or calcined clay, to form a hardened binder. The review compares the mechanical properties of traditional stabilized rammed earth with its alkali-activated counterparts, investigating the effects of alkali activation on structural integrity, durability, and overall performance. Various methodologies of alkali activation are discussed, along with an explanation of the underlying chemical reactions and mechanisms involved. Additionally, the review examines the use of lime-gypsum and cement additives to improve the compressive strength and durability of SRE. The incorporation of fibers, such as polypropylene, straw, plastic, and marble dust, is explored for further enhancing the mechanical properties. The findings highlight the potential of alkali activation in improving the mechanical properties of SRE. Optimal binder compositions, replacement percentages, and selection of alkali activators are crucial factors in achieving high-performance SRE structures. Further research is needed to fine-tune these parameters and fully unlock the potential of alkali-activated SRE for sustainable construction practices.

Keywords: Stabilized Rammed Earth · Alkali Activation · Mechanical Properties · Sustainable construction · environment

1 Introduction

The construction industry is facing increasing pressure to adopt sustainable practices in response to the growing concern about environmental degradation and the depletion of natural resources [1]. In this context, Stabilized Rammed Earth has emerged as a promising alternative to conventional building materials due to its low carbon footprint, abundance, and affordability [2]. SRE involves compacting a mixture of earth (containing a proportion of clay, aggregate such as gravel or sand), and a stabilizer such as cement or lime [3]. This mixture is rammed into place within temporary forms to create walls, and is often done in layers to create an aesthetically pleasing striped effect [3]. Although SRE has been used for centuries, its widespread adoption has been limited by its relatively

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low strength and durability [4]. Recently, Alkali Activation has been identified as a potential solution to improve the mechanical properties of SRE [5]. Alkali activation is a process that uses alkaline solutions to activate silica-rich materials, such as fly ash, slag, or calcined clay to form a hardened binder [6]. This review aims to explore and compare the mechanical properties of traditional stabilized rammed earth and its alkali-activated counterparts, in order to elucidate the effects of the alkali activation process on its structural integrity, durability, and overall performance [7]. Furthermore, it discusses the diverse methodologies of alkali activation used in the field, and it outline the fundamental understanding of the underlying chemical reactions and mechanisms involved in the activation process.

2 Traditional Stabilized Rammed Earth Bricks

Traditional Stabilized Rammed Earth (TSRE) bricks are an innovative and sustainable material designed for construction that optimally combines strength, and durability [8]. The typical composition of TSRE bricks is made up of a carefully balanced blend of earthen materials, water and stabilizing agents [9]. Approximately 60–75% of these bricks are constituted by earthen materials, a composite mixture of clay and sand [9]. These materials give the bricks their inherent strength and natural insulation properties, as well as allowing them to be sourced locally in many regions, reducing their overall carbon footprint [10]. The clay, with its cohesive properties, binds the sand particles together, providing the raw material for the brick [11]. The sand contributes to the brick's structural integrity, preventing excessive shrinkage and cracking that can occur if the clay content is too high [12]. The remaining 25–40% of the brick consists of stabilizing agents and water, which further enhance the brick's structural integrity and weather-resistance [13]. This typically includes a mixture of lime, gypsum, or cement [13]. Lime, a calcium-based binder, reacts with the clay to create a hydraulic set, improving the brick's durability and resistance to water damage [14]. Gypsum acts similarly, aiding in binding the components together while also making the bricks more workable [15]. Alternatively, cement provides high compressive strength and increased durability, particularly in exposed conditions [16]. The specific blend of materials can vary based on the desired characteristics of the bricks and the local availability of resources, making TSRE bricks a versatile and adaptable option for sustainable construction [17].

2.1 Lime-Gypsum Additives

The use of a mixture of lime and gypsum as stabilizing agents in the composition of traditional Stabilized Rammed Earth (SRE) bricks has garnered attention and has been the subject of numerous studies due to its potential to improve the material's overall properties [18]. Research has shown that incorporating a small percentage of lime, usually not more than 2%, can significantly enhance the brick's compressive strength, while also contributing to its overall durability [19]. Moreover, gypsum is added in varying proportions, generally ranging between 3 and 10% [20, 21]. Gypsum serves to bind the brick's components together, making the bricks more workable and further improving their durability. The varying proportions of these two components allow for flexibility in achieving the desired strength and durability of the bricks. The compressive strength ranged between 1 and 5.1 Megapascals after 28 days of curing [19–21].

2.2 Cement Additives

The application of cement as an additive in the composition of Traditional Stabilized Rammed Earth (TSRE) bricks has been extensively explored by researchers. Researchers have predominantly focused on analyzing the effect of cement content in the range of 2% to 12% in the composition of TSRE bricks. These investigations have revealed a direct, linear relationship between the cement content and the compressive strength of the bricks as shown in Fig. 1. This implies that as the proportion of cement in the TSRE bricks increases, the compressive strength of the bricks correspondingly increases. This linear correlation allows for flexibility and predictability in manipulating the physical characteristics of the bricks based on specific construction requirements. In a particular study by [22], they discovered that the bulk density of the TSRE bricks also had a significant effect on their compressive strength. They found that increasing the bulk density of the SRE bricks from 1.7 g/cm3 to 1.8 g/cm3 could enhance their compressive strength by 35–40%. This demonstrated that not only the composition but also the physical characteristics of the TSRE bricks, such as their bulk density, can be tuned to achieve desired strength levels, further endorsing the versatility of these sustainable construction materials.

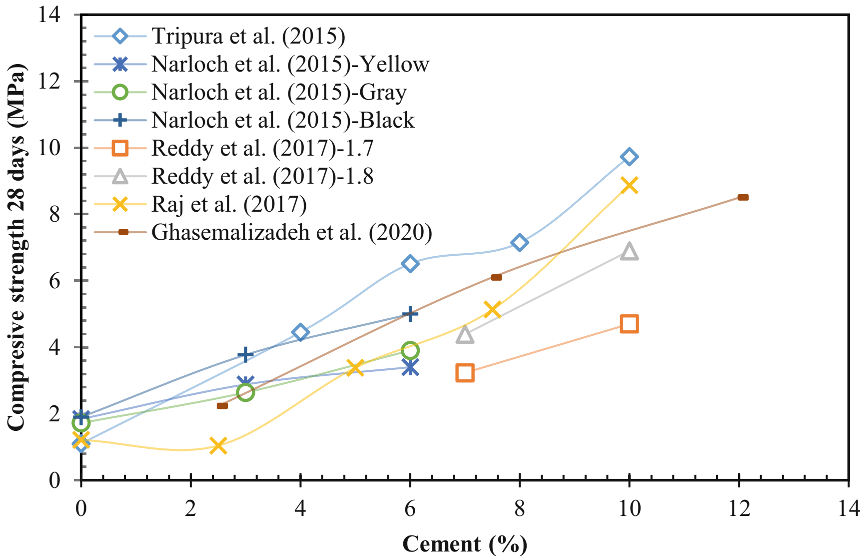

Fig. 1. Effect of cement content on the compressive strength of TSRE bricks.

2.3 Fiber Utilization in TSRE

To further enhance the mechanical properties of Traditional Stabilized Rammed Earth (TSRE) bricks, researchers have turned their attention towards incorporating various types of fibers into the TSRE matrix. This innovative approach aims to boost both compressive and flexural strength, two key parameters defining the robustness of these construction materials. Research by [20] demonstrated that incorporating polypropylene fiber, straw, and plastic fiber into the composition of Traditional Stabilized Rammed Earth (TSRE) bricks at varying percentages (0.5%, 2%, and 1% respectively) can significantly enhance the compressive strength of the resulting bricks. However, the flexural strength, another critical parameter, was found to remain unchanged. This revelation is of considerable significance as it suggests that these additive materials can contribute to producing more robust and resilient structures using TSRE bricks. Subsequent research, such as that conducted by [37], delved deeper into this aspect by experimenting with different concentrations of polypropylene fiber in the TSRE mixture, varying from 0.2% up to 1%. They discovered that both compressive and flexural strength of the TSRE bricks peaked at a polypropylene fiber concentration of 0.4%, beyond which both parameters began to decrease. The inclusion of marble dust in the TSRE bricks was also investigated by [19]. The study revealed that adding marble dust could enhance the compressive strength of TSRE bricks. On the other hand, the addition of polypropylene resulted in a decrease in compressive strength. Interestingly, flexural strength improved with the inclusion of 10% marble dust, but a higher concentration of 20% resulted in a decline. Polypropylene, in contrast, was seen to enhance flexural strength up to a concentration of 0.5%, but any increase beyond this concentration led to a reduction. [39] further investigated the impact of polypropylene fiber on TSRE bricks, incorporating it at concentrations of 0.25%, 0.5%, and 1%. Their findings indicated that the compressive strength of TSRE bricks increased up to a fiber concentration of 0.25%, after which it decreased. On the other hand, flexural strength was observed to improve across all mixtures, suggesting promising prospects for enhancing the mechanical performance of TSRE bricks. A more recent study by [38] explored the inclusion of Polyethylene terephthalate (PET) in TSRE bricks at concentrations of 0.5%, 1%, and 1.5%. Their research indicated that the compressive strength of TSRE bricks increased up to a PET concentration of 1%, after which the strength started to decline. Furthermore, the flexural strength was only found to increase for mixtures that included the lowest PET concentration.

3 Alkali Activation of SRE

Alkali activation is an innovative technique employed to enhance the mechanical properties and durability of construction materials including Stabilized Rammed Earth (SRE) bricks. It involves the utilization of alkaline substances to induce a reaction with pozzolanic materials, creating a robust and resilient binder that confers improved strength to the bricks. The principal components used in this process are fly ash, granulated blast furnace slag, and calcined clay. Fly ash, a by-product of coal combustion in power plants, contains a high proportion of silicon dioxide (SiO2) and aluminum oxide (Al2O3), making it an excellent candidate for alkali activation. Granulated blast furnace slag, another industrial by-product derived from the ironmaking process, is also rich in SiO2 and

Al2O3, along with calcium oxide (CaO). Calcined clay, in turn, serves as a readily available source of reactive silica. The alkaline activation is initiated by agents such as liquid sodium silicate, potassium hydroxide, and Portland cement. Sodium silicate and potassium hydroxide contribute sodium and potassium ions respectively, which act as the alkali component in the reaction. These substances dissolve the reactive silicate and aluminate species from the pozzolanic materials, leading to the formation of a complex aluminosilicate gel, often termed as geopolymer. This geopolymer gel hardens over time, providing the material with its binding strength. Portland cement plays a dual role in the process. Besides acting as an alkali activator, it also provides calcium ions. These calcium ions can react with the alumina present in the fly ash, slag, or clay to form additional calcium-alumino-silicate hydrate (C-A-S-H) phases. These C-A-S-H phases are similar to those formed in conventional cement hydration reactions, which contribute to the overall strength of concrete. Hence, the inclusion of Portland cement enhances both the binding capacity and the overall compressive strength of the SRE bricks. Alkali activation, therefore, provides a significant enhancement to the properties of SRE bricks. It facilitates the production of a more robust and sustainable building material, providing a potential avenue for the beneficial use of industrial by-products and reducing the environmental impact of construction.

3.1 Fly Ash Based SRE

Several studies have explored this domain, shedding light on various aspects of this process and its implications on SRE's compressive strength as shown in Table 1. [27] investigated the use of cementitious binders consisting of fly ash in combination with either lime or granulated blast furnace slag (GBFS) in a 50% by weight of dry soil ratio. Their results exhibited a significant difference in compressive strength based on the type of binder used. The fly ash and lime mixture resulted in a compressive strength of 7 MPa, while the combination of fly ash and GBFS yielded a superior result of 17.1 MPa. This significant strength disparity underscored the importance of the type of binder utilized with fly ash in the manufacture of SRE blocks. [28] focused on alkali-activated SRE bricks using class F (low calcium) fly ash as the binder and potassium hydroxide (KOH) as the activating agent. They noticed that the compressive strength was maximized at a 60% replacement of the clay-sand mixture with the binder, indicating that an optimal balance exists between the soil and binder proportions for strength enhancement. Without any replacement, the compressive strength was significantly registering 0.3 MPa only, underscoring the binder's role in strength augmentation. [29] studied the impact of composition variations on the compressive strength of alkali-activated SRE bricks. Their research suggested that increasing the molarity of sodium silicate and a higher proportion of GBFS in the binder generally yielded higher compressive strengths. However, a higher clay content typically led to reduced compressive strength, suggesting that an optimized soil composition is vital for strength performance. In a similar vein, [31] examined the effects of varying the replacement of the clay-sand mixture with Fly Ash (FA) on the compressive strength of alkali-activated SRE bricks. Their findings indicated that as the percentage of FA replacement increased, the compressive strength of the SRE bricks decreased, highlighting the importance of careful calibration of the binder quantity. In the absence of an alkali activator, the strength drastically reduced, demonstrating the activator's crucial role in the alkali-activated SRE process. Alkali-activated SRE with fly ash exhibits promising results for sustainable construction applications. Still, its success largely depends on the careful optimization of various factors such as binder type, replacement ratio, and alkali activator use. Future research should focus on fine-tuning these parameters to optimize the strength and durability of alkali-activated SRE structures.

Table 1. Fly Ash Based SRE compressive strength at 28 days.

Researcher	Clay (%)	Sand (%)	Binder	Activator	Replacement (%)	Compressive Strength (MPa)
Rivera et al. (2020)	50	50	80% Fly ash and 20% Lime	Liquid sodium silicate (NaOH M = 10)	50	7
Rivera et al. (2020)	50	50	80% Fly ash and 20% GBFS	Liquid sodium silicate (NaOH M = 10)	50	17.1
Teing et al. (2019)	95	5	Class F fly ash	KOH	40–70	0.3–4.7
Toufigh et al. (2022)	7.5–22.5	92.5–77.5	75% FA and 25% GBFS, 25% FA and 75% GBFS	Liquid sodium silicate (NaOH M = 8–12)	15	1.68–16.03
Rios et al. (2016)	33	67	15–25% FA	Liquid sodium silicate (NaOH M = 7.5) or none	15–25	0.05–2.3

3.2 Fly Ash and Cement Based SRE

Two seminal studies conducted by [25, 26], which investigated the impact of different replacement percentages of binders (cement, and fly ash) on the compressive strength and elastic modulus of alkali activated SRE. In the study by [25], the authors highlighted the potential of cement and fly ash as binders in alkali-activated SRE. Their experimental setup kept a constant clay to sand ratio (67:33) while varying the replacement percentage of the binder in the clay-sand mixture. The findings revealed that as the cement replacement percentage increased from 4% to 10%, there was a corresponding rise in the compressive strength from 4.45 MPa to 5.98 MPa, and the elastic modulus from 4 MPa to 5.55 MPa. However, when the fly ash replacement percentage increased in the absence of cement, both the compressive strength and the elastic modulus showed a decrease. Moreover, when both 7% cement and 1% to 4% fly ash simultaneously replaced the mixture, the performance decreased with an increase in the fly ash replacement percentage, even when cement was present. In contrast, [26] broadened the investigation by introducing calcium bentonite alongside cement and fly ash. Their study employed a different clay to sand proportion (28:72) and a wide range of binder replacement percentages. Echoing Narani et al.'s findings, an increase in cement replacement percentage led to an increase in both compressive strength and elastic modulus. However, as the replacement percentage of fly ash increased, an inconsistent pattern emerged in the compressive strength and elastic modulus, indicating a complex relationship between the two. Furthermore, the researchers found that when cement, fly ash, and calcium bentonite each replaced 15% of the mixture, the strength characteristics varied, underlining the importance of careful binder selection and proportioning. Both studies provide insightful observations on the complex interplay of binder types and replacement percentages in shaping the mechanical properties of alkali-activated SRE. The studies suggest that cement plays a critical role in enhancing the mechanical properties of SRE. However, the intricate performance trends observed with different percentages of fly ash and calcium bentonite underscore the need for further research to determine the optimal binder combinations and proportions.

3.3 Calcined Clay Based SRE

In recent years, there has been a growing interest in the potential of calcined clay as a binder in alkali-activated Stabilized Rammed Earth (SRE). The studies by [23, 30] provide valuable insights into the role of calcined clay and the alkali activator's molarity in enhancing the compressive strength of SRE. [23] concentrated on the impact of calcined clay as a binder on SRE's compressive strength, bulk density, and flexural strength, maintaining constant proportions of clay and sand at 65.1% and 34.9%, respectively. The experiment used liquid sodium silicate with a molarity of 8 (NaOH $M = 8$) as the activator. The study found that as the binder replacement percentage of calcined clay increased, significant improvements were observed in all parameters, notably in compressive strength. Particularly noteworthy were the results with a 20% binder replacement, which yielded the highest compressive strength (20.1 MPa), bulk density (1.81 g/cm3), and flexural strength (3.1 MPa). These findings underline the promising role of calcined clay as a binder in enhancing the mechanical properties of alkali-activated SRE. Simultaneously, [30] shed light on how the interplay between calcined clay and sodium hydroxide molarity (Fig. 2) can influence the compressive strength of alkali-activated SRE. The study varied calcined clay percentages in the SRE mixtures from 14% to 40%. Remarkably, even in the absence of an alkali activator, an increase in calcined clay percentage led to a significant improvement in compressive strength. The study further demonstrated that coupling sodium hydroxide and higher calcined clay percentages could considerably enhance compressive strength. Moreover,

[30] explored the impact of varying sodium hydroxide molarity, demonstrating a gradual increase in compressive strength as the molarity increased to 2 and 3. Intriguingly, a downward trend in compressive strength was observed beyond a molarity of 3, suggesting an optimal sodium hydroxide molarity for the activation process. The highest compressive strength was achieved with a sodium hydroxide molarity of 3 and a calcined clay percentage of 40%. Both studies confirm the valuable contribution of calcined clay as a binder in alkali-activated SRE. They underscore the importance of determining an optimal binder replacement percentage and sodium hydroxide molarity to achieve maximum compressive strength. The exploration of these parameters paves the way for the optimized use of calcined clay in the production of high-performance SRE.

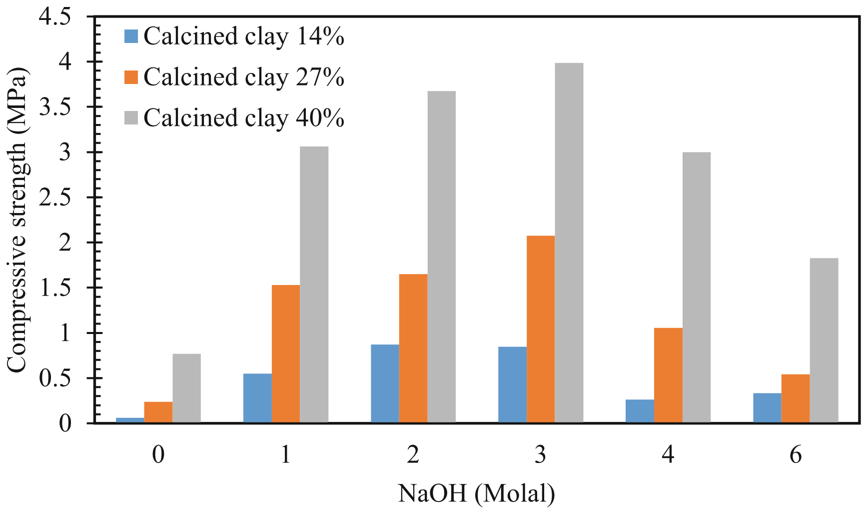

Fig. 2. Effect of NaOH molarity on the compressive strength of alkali activated calcined clay based SRE bricks.

4 Conclusion

In conclusion, this comprehensive review highlights the potential of alkali activation as a promising approach to enhance the mechanical properties of Stabilized Rammed Earth (SRE). The construction industry's increasing demand for sustainable practices has led to a renewed interest in SRE as a low-carbon and affordable alternative to conventional building materials. However, the widespread adoption of SRE has been limited by its relatively low strength and durability. Alkali activation, through the utilization of alkaline solutions and pozzolanic materials such as fly ash, slag, or calcined clay, offers a solution to overcome these limitations. By forming a hardened binder, alkali activation can significantly improve the structural integrity, durability, and overall performance of SRE. This review explored and compared the mechanical properties of traditional stabilized rammed earth and its alkali-activated counterparts, shedding light on the effects of alkali activation on SRE. Moreover, the review discussed the diverse methodologies of alkali activation, including the use of different binders and activators, as well as the inclusion of additives such as lime, gypsum, cement, and fibers. These factors play a crucial role in optimizing the strength and durability of SRE, making it a versatile and adaptable option for sustainable construction. The findings underscore the importance of careful selection and calibration of binder compositions, replacement percentages, and activators to achieve high-performance alkali-activated SRE. Further research is needed to fine-tune these parameters and establish standardized guidelines for the industry. Overall, alkali activation holds significant potential for transforming SRE into a robust and environmentally friendly building material, contributing to the construction industry's sustainability goals. By enhancing the mechanical properties of SRE, alkali activation opens new avenues for widespread adoption and application of this innovative construction technique.

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