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Review Article

Utilization of Polymer Composite for Development of Sustainable Construction Material

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Polymers have gained an extensive application due to their versatility of properties and benefits. Hence, the polymer blends and composites reinforced with different infusions at different scales, macro to nanofillers, can be fabricated, leading to specific tailormade applications. The main objective of this investigation is to overview the various studies carried out to reuse the waste materials like electroplating sludge, fly ash, etc. For the development of construction materials. This paper summarizes the use of polymers in composite material formulations for the development of building materials such as lightweight concrete, protective coatings, paver blocks, bricks, and structural components. Different tests, namely viscosity, density, flash point, amine value, and epoxy equivalent weight, were performed on polymers to find their suitability as binder materials. Various laboratory tests such as compressive strength, water absorption, tear resistance, flexural strength, and split tensile tests were carried out to determine the mechanical properties of the developed materials. By using polymers with the addition of sustainable filler and waste materials, the replacement of costly raw material can be achieved by more than 50% in the case of paver blocks, up to 60% in bitumen-polymer composite, 80% in case of lightweight concrete and polymer-based panels. This insight gives the framework for the selection of different materials, optimization of combining ratio of materials, and their testing for the development of polymer-based materials.

1. Introduction

Polymers assume a significant job in our everyday lives. Polymers can be clarified by parceling the word polymer to “Poly” which implies “numerous” and “mer” which means part or portion. Polymers are the developments of numerous particles, called monomers, as chains or other convoluted structures. They are one of the most valuable materials at any point made. Polymers can be rubbery or unbending and can be formed into an unending assortment of articles, extending from vehicle guards to squeezable jugs and delicate textures. Then comes the derived products from them which are called as polymer composite materials which are made by adding two or more polymers, filler materials, or reinforcing materials so that the blend obtained gives better product with large scale application [1, 2]. These engineered polymer composites offer properties such as high strength modulus to weight ratios which make the composites lightweight and relatively strong and toughened, with high resilience and cost-effectiveness.

Synthetic or artificial resins are scientifically produced resins, especially viscous materials, which transform through the curing process into rigid polymers. Resins undergo the curing transformation of the chemically active end groups. These synthetic polymers are manufactured and fabricated by the esterification of organic compounds [3]. The different types are broadly categorized into thermosetting and thermoplastic resins as shown in Figure 1. Here the word “resin”

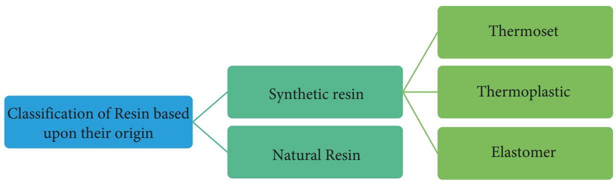

Figure 1: Classification of resins.

depicts the reactant or the product or sometimes both. Resin is a term used for one or two monomers in a copolymer and the other part of the polymer is known as a hardener.

(i) Thermosetting Resin, also known as the thermoset or thermosetting plastic, is basically a petrochemical substance. These cannot be heated up again and liquified to be shaped differently once it gets hardened. Thermoset materials are generally more robust than thermoplastic materials; hence, they are better apt for application in high-temperature conditions [3].

(ii) Thermoplastic Resin is also named thermo softening polymer, which becomes pliable or mouldable over a specific temperature condition and hardens upon cooling.

Taxonomy related to Polymer Composites: The main elements of the composite are fibers, fillers, and additives, etc. Each constituent plays an integral role in the formulation of different material composites specified for different functions. As depicted in Figure 2, the composite comprises the polymer base filler and reinforcing material. Polymer base can be of any type namely thermoplastic, thermosetting, and elastomer type. They can be of one component or two or more component polymers in regard to resin and hardener proportioning. The function of this blend is to provide a base for the reinforcing material by providing it with a chemical structure imparting the required shape for the fabrication of the composite. The selection of the blend altogether depends on the intent of the composite product usage [2, 3]. Reinforcement depicts the framework of composition and provides its the required bulk modulus, rigidity, and mechanical strength. Different types of reinforcements are filamentary in nature and occur in forms ranging from organic to inorganic fiber or on the basis of shape, i.e., either the elongated particle or continuous. Filler refers to the inert material which, when added to the mix or the base polymer, effectively enhances the composite structure by modifying its physical, chemical, mechanical, and thermal properties [1, 3]. This is achieved by improving ductility, temperature resistance, and surface appearance of the base material or desired product performance in different conditions. At the same time resulting in a reduction in the cost of the developed product [4–6].

Use of Polymer in Civil Engineering: Polymeric materials are widely used in the construction industry in both structural and nonstructural applications. The main applications of polymer-based products are as follows:

Admixture in concrete.

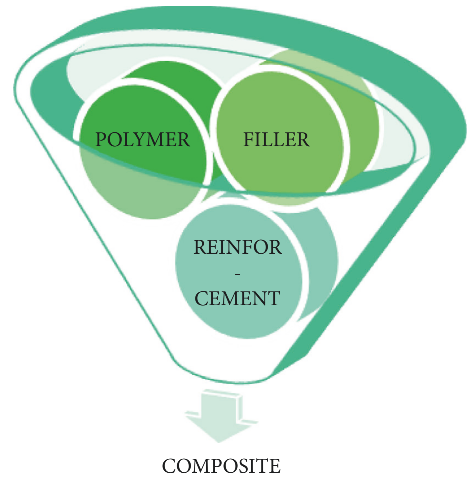

Figure 2: Polymer composite composition.

Cables (used for pulleys to travel on-site).

FRP (Fibre Reinforced Plastic) sheets.

Piping materials for drainage, water, gas, industrial waste, sewage, and chemical plants.

Ribs: As barriers to water movement occurring in walls and floor slabs.

Adhesives and sealants: for woodworking and plumbing repairs.

Cladding and decoration: on the exterior wall surface.

Surface/barrier coatings.

All paints contain a major portion as a polymeric binder.

In civil engineering, there are diverse uses of polymers in repair and rehabilitation of structures. Many R&D works across the globe have shown the dynamic involvement towards the improvisation of many building materials. These exhibit unparallel properties in terms of the processing, structure, performance, and properties (PSPP) in material science. This paper addresses the overview of past works with a framework for their development approach and their application in four different categories of polymer-based paver blocks/tiles, coatings, panels, and lightweight concrete [7–9].

2. Background

Systematic literature searching is acknowledged as the main approach for this review process. The input from different literature gaps and practical considerations, the adopted methodology for reviewing literature has been based on search strategies to retrieve articles that are potentially relevant [10–14]. Extensive investigations have been carried out by numerous researchers on the development of different sustainable construction materials. So, for better research problem emergence and identification of gaps, the literature review is categorized under four different applications of polymer-based construction material, namely lightweight concrete, protective coatings for concrete

Table 1: Summary of previous work related to polymer-based bricks, paver blocks, and tiles.

Reference No	Authors	Findings of work
4	Yu Zhang et al.	(1) The stabilization of electroplating waste sludge was done by using cement and coal fly ash. (2) After stabilization, samples were made with a binder content 30% [cement (15%) and coal fly ash (15%)]. (3) The efficiency of the stabilization process is affected by different parameters like the quantity of cement, curing time, and coal fly ash/cement ratio. (4) The stabilized sludge with no water content is suitable for highway construction as its unconfined compressive strength is as per requirements.
5	Haoxin Li et al.	(1) The main purpose of this investigation is to find out an innovative disposal method for electroplating waste sludge by mixing it into the preparation of decorative mortar as a green pigment. (2) Electroplating sludge was added to cement mortar for @5% of the total mix. The test results show that electroplating sludge can adjust the mortar color well. (3) Finally concluded that up to 5% of waste can be safely mixed in preparation of green pigment to make decorative mortar.
6	L. Pérez-Villarejo et al.	(1) The physical and chemical analysis of the galvanic waste sludge discovered that it contains quartz, calcite, etc. Therefore, it can be added to clay mix for production of bricks. (2) The addition of galvanic waste sludge (1–5 wt.%) to the clay mix endorsed a substantial change in the properties of the bricks. (3) The porosity of the bricks is reduced from 29% to 22% due to the mixing of galvanic waste sludge (up to 5 wt.%). (4) There is a reduction in the density and shrinkage of bricks due to the mixing of galvanic waste sludge.
7	Lyu Honghong et al.	(1) Investigated the stabilization of sludge from electroplating industry by using biochar and iron sulphide by modest technique of treatment of sludge using ecologically responsive additives Biochar (BC) and Iron Sulfide (F_eS). (2) The results recommend that biochar and iron sulphide are effective, economical, and environmentally responsive preservatives for the control of heavy metals in sludge before landfill disposal.
8	A Gordon C. C et al.	(1) Experimented on a mix of an equivalent quantity of electroplating waste and calcium carbonate waste sludge and heated @ 1000°C for 4 hours. (2) This heated waste blend mix displays pozzolanic and binding properties, so it can be used for partially replacing the cement as a binding material to stabilize the waste sludge. (3) Then, the cement was replaced with this blended mix up to 40% by weight. A specimen made with this mix has superior compressive strength and the leaching of heavy metals are also under control.
9	Ming Xia et al.	(1) Studied the solidification of sludge from electroplating process industry with the help of fly ash and cement for production of nonburnt bricks. (2) The five ingredient's, such as electroplating sludge, fly ash, cement, fine stone, and sand, were mixed in the ratio of 33%, 25%, 21%, 17%, 4%, and alkali activators like NaOH and Na_2SiO_3 were added, and nonburnt bricks were produced. (3) The compressive strength of bricks is up to 15 N/mm^2. The homemade device for simulating rainfall was used for the risk calculation of bricks. Finally concluded that these bricks can be used for construction purposes.

structures, paver blocks, tiles, bricks, and geopolymer panels subjected to flexural loading [15–19].

2.1. Polymer Based Construction Materials such as Bricks, Paver Tiles, and Paver Blocks. 2.2. Polymer Modified Coatings for Concrete Structures. 2.3. Polymer Based Light Weight Concrete. 2.4. Polymer Based Ferrocement Panels Subjected under Flexural Loading. Literature Gaps and Emergence of Research Problem:

Previous studies have researched conventional binders and techniques for the reutilization of waste materials in different construction materials for example as partial replacement of raw material or filler in concrete or bricks. In Table 1 some of the methods are neither eco-friendly nor energy efficient. Other environmental concerns of handling and disposal are also there. Henceforth, there is a need to identify and study the use of suitable alternate binders that is polymers for stabilization of the composite mix and achieving an optimized combination, as shown in Table 2. For example, the problem of leaching heavy metals while using waste sludge in construction materials can also be solved effectively by using polymers as a binder [20–23]. Also, the major concern is to research for substitute material whose low emission is a binding agent for concrete to minimize the environmental impact caused by cement manufacturing. Many significant industries, for example, sealants, fibres, plastics, rubbers, adhesives, and caulking compounds, depend upon synthetic resins as they offer ease of prefabrication with the value-added energy efficiency of constructions and purpose for reuse and recycling of the obsolete, surplus, and scrap remaining material as shown in

Table 2: Summary of previous work related to polymer-based coatings.

Reference No	Authors	Findings of work
10	Airey et al.	(1) The modification of bitumen with SBS was studied. Total of six specimens of polymer modified bitumen's (PMBs) were formed by combination of bitumen from two different crude oil sources with a SBS copolymer at different polymer percentage contents. (2) The experimental results show that the extent of SBS modification is basically a function of concentration of polymer as well as bitumen source hence emphasizing on bitumen-polymer compatibility. (3) When this optimal concentration of polymer, compatibility of bitumen-polymer matrix concedes a continuous polymer network to be established, where the characteristics of modification is stipulated by the formation of the network which is highly elastic in nature and hence with it increases the stiffness, viscosity and elastic response of matrix at high temperatures
11	Singh et al.	(1) The different modified bituminous networks were formulated by conventional liquid blending as well as in situ methods. Specimens were prepared from treated/SBS-modified bitumen and polyurethane polymers. (2) Because of deficiency of flexibility at lower temperatures in the modified bituminous blend manufactured by blending method limited its use for particularly for waterproofing and sealing purposes. (3) As per rheological studies, the polyurethane modified SBS-bituminous blend showed excellent properties in comparison to the other systems in regard to elongation, stiffness, and other properties offering a broad range of frequencies. (4) The fabricated modified bituminous composite meets all sets of requirements of the specifications of the relevant standards and can be befittingly used for the purpose of waterproofing as well as the sealing of concrete joints.
12	Stefan et al.	(1) The test results on the basic functional properties of polyurethane, its network/structure with the study of physiological comfort of microporous polyurethane membranes. (2) A feasible process system of the penetration of water vapours through the coating/membranes has also been formed. (3) The membranes examination showed their constancy within both high and low temperatures range, which offers high aptness for designing multilayered composite materials as the protective coatings for different substrates
13	Guo et al.	The performance of three waterproofing materials and concluded the results that the resistance offered again water permeation of waterproofing layer made from different material can be arranged as SBS modified asphalt > second order reaction waterproof material > SBR modified asphalt emulsion.
14	S T Wicaksono et al.	(1) Researcher established an exclusive review about the advanced composite materials based on the categorization that is thermoplastics, elastomers, or thermosetting polymers. (2) Composite materials formulation examined and discussed with the data on the fabrication of different matrices of macromolecular polymers such as polyether ketone, polyether ether ketone, polyether imide, polycarbonate, polyurethane, polyether sulfone, polyethylene terephthalates and epoxy resin

Table 3. However, many options are available in the market of waterproofing materials, but there is a need to go in-depth to explore other options of materials that provide a better life span and compatibility to structures [24, 25]. So, the development of an economic product for waterproofing that incorporates the beneficial properties of filler materials and polymers is needed to enhance the durability, as shown in Table 4.

3. Application of Polymer Composites as Construction Material

3.1. Paver Tiles, Blocks, and Bricks. Electroplating is one of the varieties of several techniques of metal finishing. Although the electroplating process has numerous applications, at the same time, it is considered among the 17 utmost polluting industries in India by CPCB (Central Pollution Control Board). The waste sludge generated by ETP (effluent treatment plant) of these electroplating industries is huge in quantity and comprises metal precipitates. This waste sludge can contain harmful pollutants like Ni, Ag, Sn, Cu, Zn, Cr, Pb, Cd, Fe, and ammonia, etc., and poses serious health risks [26]. The reclamation and recycling of these heavy metals from waste sludge are not feasible, therefore, causing disposal and dumping problems [27]. Currently, most of India's hazardous waste ends up in landfills that are common waste disposal facilities and not specially designed. Due to this, heavy metals are leached into the environment and contaminating air, soil, and even drinking water and thereby causing serious health risks to general public.

Although there are few alternative solutions known, these all are difficult to continue. Within these, firstly, reclamation and recycling of harmful metals from the waste sludge are neither possible nor feasible. Secondly, after converting into ash by burning, this waste sludge can be used as a fractional substitute for fine aggregates in cement concrete. In this process, the maximum percentage is used up to 20%, and in the process of converting sludge to ash

Table 3: Summary of previous work related to polymer-based lightweight concrete.

Reference No	Authors	Findings of work
15	Masoud Jamshidi	(1) Polymer concrete developed for replacement marble, binder, repair mortars and overlays in concrete structures, i.e., bridges, motorways, and pavements. These have points of fast curing, excessive mechanical strength. (2) Crushed gravel and natural sand had been used. Compressive strength of polymer concrete combinations was once 80–100 MPa at day 7, and remained almost consistent at greater a long time, and tensile splitting strength was three times greater and the quantity of chloride ion diffusion for experiments had been negligible. (3) Acid can no longer diffuse to polymer concretes due to the fact of barrier impact of resins. Therefore, greater chemical resistance resin reasons for higher overall performance of polymer concrete in acid solution.
16	Adhikary Suman Kumar, and Kumar Ashish Deepankar	(1) Aerogel is categorised into a hydrophilic and hydrophobic aerogel. Aerogel is a notably thermal insulating material with decrease mechanical properties. The demand for thermal insulating and sustainable cementitious composites is growing to reduce power consumption and enhance the building's thermal insulation. Incorporating carbon nanotubes into the aerogel concrete can extensively enhance mechanical performance. (2) He reviewed the following end result the compressive strength varies 0.1––150 MPA and density 198–2200 kg/m^3 and thermal conductivity 0.09–2.3 W/m.k. (3) An excessive attention of aerogel-based cement composite can also appreciably reduce the compressive strength; however, it gives outstanding thermal insulation performance.
17	Tomáš žlebek et al.	(1) Silica sand dorsilit was once used solely for reference compounds in order to examine resulting values. (2) The suitability of the use of waste glass in polymer anchor materials. Waste glass is appropriate filler due to its excessive silicon dioxide content, which has impeccable physical and mechanical properties and exact chemical resistance. (3) Waste glass with fractions varies from 0–0.63 mm. The substances with packaging glass exhibited the exceptional properties with the reference dorsilit sand.
18	Dora Foti	(1) The crack patterns got on the specimens have been analyzed to reveal the relevance of an appropriate thickness of the reinforcement to achieve an effective mechanical behavior of the strengthened concrete element over time. (2) Rheoplastic mortars is successful to enlarge the strength of structural factors in masonry buildings and strengthened concrete structures (3) A relative displacement between the surface of the reinforcement and the matrix reasons the improvement of an interfacial stress. (4) An appropriate and suitable thickness confining transverse reinforcement would be wished to keep away from a brittle fracture of the mortar, even though the latter can also have an excessive compressive strength.
19	S T wicaksono	(1) Thermal properties and mechanical strength of kenaf composite are most reliable to different kind of herbal fibre polymer composites, for that reason viewed as a appropriate applicant for high-performance herbal fibre polymer composites. (2) Hybrid composites had been fabricated by using keeping an unsaturated polyester (UP) loading of 80% by way of weight in all the composites. The addition of CaCO3 (CC) into kenaf/polyester composite was once evaluated. (3) Polyester (80 wt%) + kenaf fibre (17.5 wt%) + $CaCO_3$ (2.5 wt%) is higher than all. (4) When the degree of agglomeration increases, the interactions between the filler and the matrix come to be weaker and, as a result, the values of the tensile strength decrease

again, there is a possibility of air pollution. The cement industry of the world emits approximately 7% of global greenhouse gases [28]. Thirdly waste sludge can also be used as a partial replacement for clay in the manufacturing of bricks. The maximum percentage used is up to 30% in this process and the burning of bricks again causes air pollution. The brick production industry is considered to be the key contributor to the fast deterioration of air quality. Recently, attention has shifted to the use of polymers as other building materials. Polymers provide great opportunities for advances in building materials research and material property improvements [29]. The construction industry is one of the chief consumers of polymer composites. The potential benefits of polymers include high strength, high durability, fatigue efficiency, versatility, and low maintenance costs. The present construction industry is searching for superior quality materials with properties of durability, lightweight, easily installed, and also adaptable. Polymers are extensively used in the construction industry due to their exceptional strength-to-weight ratio, protecting properties,

Table 4: Summary of previous work related to polymer-based ferrocement panels.

Reference No	Authors	Findings of work
20	J P. Gorninski et al.	(1) The chemical resistance on different compositions of polymeric mortars using two different types of unsaturated polyester polymer resin such as orthophtalic and isophtalic polyester was assessed. (2) Specimens prepared were exposed to different acidic environmental conditions accounted for corrosive agencies. (3) No composition showed significant changes. Notable reduction in flexural strength on the specimens exposed to corrosive agents; however, flexural strength was still higher than samples prepared with PPC.
21	MarinelaBărbuţăet al.	(1) Researches regarding polymer-based concrete and mortars comprised of silica fume, epoxy resin, and crushed aggregates along with the different percentage of silica fume content ranging between 6.5% to 30% and 6.4% to 9.6% for polymer mortar and polymer concrete were elaborated, respectively. (2) The compressive strength increases as the silica fume dosage increased. Moreover, the split strength and flexure strength enhances with the reduction of dosage of silica fume
22	Sathia.R.et al.	(1) The testing of the durability property of the low calcium-fly ash-based polymer concrete was done and perceived that the rate of water absorption is lesser in geopolymer concrete than that in cement concrete. (2) The water absorption property was found to decrease with a rise in the strength of the concrete and the fly ash content present. (3) Additionally, the geopolymer concrete exhibited higher resistance to the acid attack in comparison to the cement concrete.
23	Criado. M. et al	(1) The effect on the rheology of alkali activated fly ash mix by various types of admixtures in their research work was studied. (2) It was seen that the rheological properties such as viscosity are higher in the case of fly ash blend than in the portland cement paste. (3) Whereas the yield stress is lower in case of fly ash blend. The yield stress value is almost the same in both fly ash blends, whether it is with or without the presence of admixtures.
24	Esther Obonyo et al.	(1) An evaluation study on improving the utilization of other inputs in geopolymer binding materials for sustainable composites was conducted. (2) It concluded that in addition to lowering the cost with regard to conventional ones, the use of geopolymer binders is more durable and environmentally advantageous. (3) Due to their unexplored potential, there remain many aspects uncovered related to the advantageous properties that geopolymer may exhibit.
25	Vincent Prabakar Rajaiah et al.	(1) An experimental investigation was conducted by analysis of flexural behaviour of geopolymer ferrocement panels by changing the number of layers of the wire mesh. (2) It was found out that the concrete panels having the wire mesh reinforcement shows enhanced flexural strength with minimum specified deflection; i.e., it is reduced in comparison to conventional ones accompanied by an excellent increase in the properties such as ductility and energy absorption capacity.

durability, and flexibility [30]. Stabilization and solidification remain unique strategies used to modify risky waste into an ecologically stable and friendly product [4]. To solve this universal problem, an attempt has been made to develop a unique process that is simple and eco-friendly for preparing durable and lightweight polymer-based construction materials like bricks/tiles/slabs from the most polluting waste sludge of electroplating industries. The process includes the leaching of heavy metals within the permissible limit and protects the environment from air, water, and soil pollution. The process does not require any burning/heating of sludge as well as it does not consume any natural resources such as soil and water. Finally, the process can replace up to 50% of sludge by weight without leaving any residual. Therefore, the process is helpful indeed and has a lot of applications in the environmental aspects. The flow chart for the design approach is mentioned in Figure 3.

3.1.1. Selection of Polymers. To find out the suitable polymer and its hardener, the following tests are required to be carried out as tabulated in Tables 5 and 6.

3.2. Procedure. In the present investigation, the polymers were successfully used as binders for the stabilization and solidification of electroplating waste sludge. The details of the different attempts/experiments are given below.

Trial 1: The waste sludge, after drying and pulverization, was used as a replacement for cement of cement concrete. Different grades of concrete, such as M15 and M20, are prepared by percentage replacement of 5%, 10%, 15%, and 20%. After testing cubes for 7 days and 28 days, it was observed that the maximum replacement possible was 15%. After this, the compressive strength of concrete starts decreasing. Therefore, the percentage

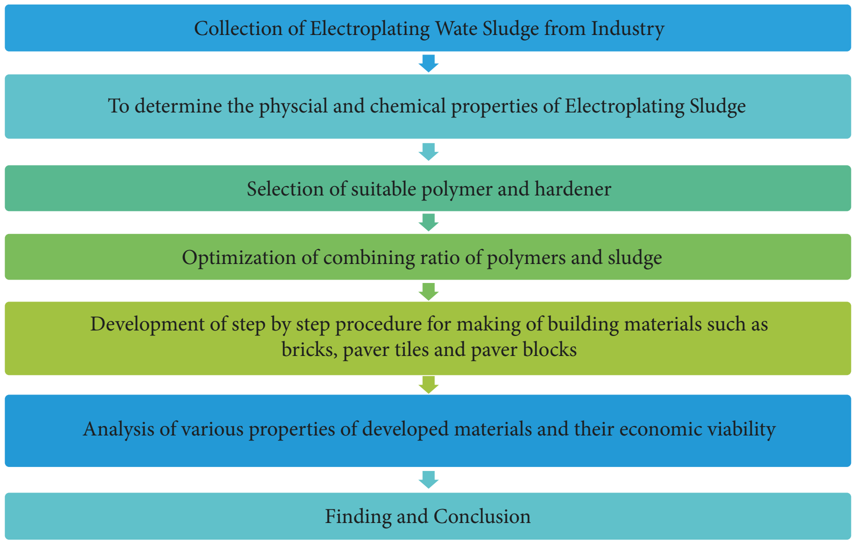

Figure 3: Development approach of paver blocks, tiles, and bricks.

Table 5: Tests on polyurethane resin and hardener.

S. No	Tests on polyurethane resin and polyurethane hardener
1	Appearance (DIN 52002)
2	Density (g/cm^3) 25°C (DIN 53217)
3	Viscosity (mpas) 20 C (ASTM 4878-88)
4	Flash point (°C) (DIN 51758)

Table 6: Tests on epoxy resin and epoxy hardener.

S. No	Tests on epoxy resin and epoxy hardener
1	Colour (ASTM D1544)
2	Viscosity (mpas) 25 C (ASTM D2196)
3	Epoxy equivalent weight (EEW) g/eq (ASTM D1652)
4	Amine value mg KOH/g (ASTM D2073)
5	Pot life 25 C (ASTM D2471)

of waste sludge in the final product made with concrete is less than 5%.

Trial 2: The waste sludge was converted into ash after burning and used as a sand replacement in the making of cement concrete. Different grades of concrete, such as M15 and M20, are prepared with percentage replacement of 10%, 15%, 20%, 25%, and 30%. After testing cubes for 7 days and 28 days, it was observed that the maximum replacement possible was 25%. Therefore, the percentage of waste sludge in the final product made with concrete is less than 10%. While converting the sludge into ash again, there is a danger of emission of harmful gases into the atmosphere.

Trial 3: Waste sludge was also used as a partial replacement of clay in the manufacturing of bricks. The maximum percentage used is up to 30% and these bricks are required to be burned at 1000 °C. While burning bricks again, there is a possibility of release of poisonous gases into the environment. To manufacture the construction materials from the waste sludge, the following are the important steps which are to be followed.

3.2.1. Step by Step Procedure.

(1) Collection of waste sludge from the electroplating process industry.

(2) The waste sludge may contain moisture up to 20-30%, so it is needed to make it dry under the sun for 2-3 days till moisture content of less than 5% is achieved.

(3) The dried waste sludge consists of lumps. So, it requires to be broken down into powder using a pulverization process. After pulverization, the sludge is required to sieve in a 600-micron sieve for uniform size.

(4) After taking the perfect quantity of polymer (Polyurethane/Epoxy) resin in a container as per the table below, add sludge up to 25% of the required quantity as per the table below. Then start mixing of contents with a stirrer for five minutes at a speed of 2000 rpm. Add another 25% of the sludge and mix the contents for five more minutes at a speed of 4000 rpm. Add another batch of 25% of the sludge and mix them at a speed of 6000 rpm for five more minutes. Finally, add the remaining 25% of the sludge and mix the contents for five minutes @8000 rpm.

(5) After proper mixing of polymer resin and sludge, the required quantity of suitable hardener as per the tables below is added and mixed for one minute @8000 rpm to obtain a slurry.

(6) Finally, pour the slurry into a mould (Paving tiles/Paver blocks/Bricks) after giving a wax/silicone coating to the mould.

(7) Allow the mould to cure at a temperature of 27°C for one day.

Effluent Treatment Plant (ETP) Sludge

ETP Sludge after pulverization

Paver Tile (Size 25 cm × 25 cm × 2 cm)

Paver Tile (Size 25 cm × 25 cm × 2 cm)

Brick (Size 19 cm × 9 cm × 4 cm)

Brick (Size 19 cm × 9 cm × 4 cm)

Brick (Size 19 cm × 19 cm × 9 cm)

Flexible Tiles (Size 20 cm × 20 cm × 1 cm)

Figure 4: Polymer based Paver Tiles, Paver Blocks and Bricks.

(8) Remove the mould and cure the products (Paving tiles/Paver Blocks/Bricks) at a temperature of 27°C for 07 days.

The outcomes of the product developed can be stated as follows:

(i) The developed paver tiles, paver blocks, and bricks, as shown in Figure 4 contain 50% of waste sludge and meet all the requirements of paver tiles, bricks, and blocks as per BIS standards (IS 13801-2013, IS 3495-1 to 4 (1992) and IS 15658 : 2006. The process includes the leaching of heavy metals within the permissible limit and protects the environment from air, water, and soil pollution. The process does not require any burning/heating of sludge as well as it does not consume any natural resources such as soil and water.

(ii) These developed materials are durable, lightweight, flexible, chemical resistant, soundproofing, and have glossy finish as compared to conventional products such as concrete paver tiles, concrete paver blocks, and brunt clay bricks available in market.

(iii) Industrial Application: The process does not require any burning/heating of sludge as well as it does not consume any natural resources such as soil or water. This unique process can replace up to 50% of sludge by weight without leaving any residual. Therefore, the process is helpful, efficient, and cost-effective indeed and has a lot of applications in the environmental and health aspects. The developed products are also beneficial for the pavements/building construction. Therefore, this process has greater industrial value and can be easily scaled up.

3.3. Protective Coating for Concrete Structures. Water permeation in concrete structures results in degradation of structural components leading to the corrosion of

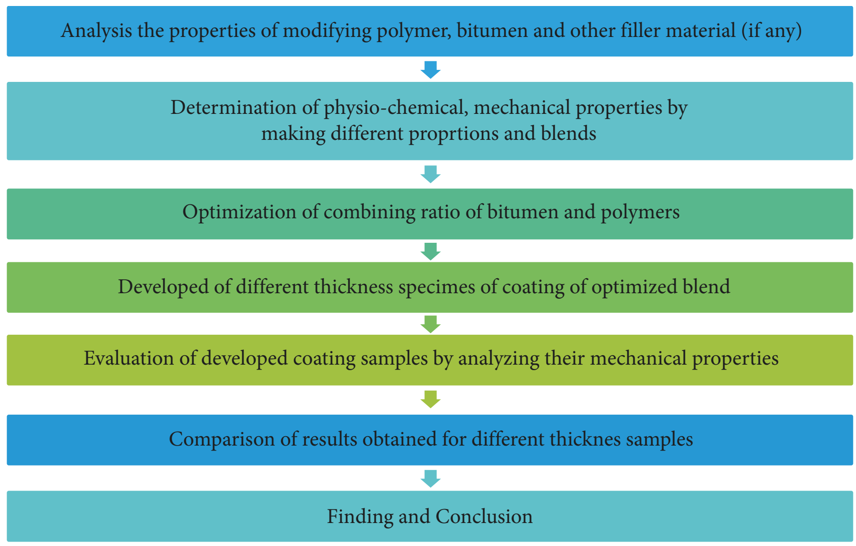

Figure 5: Development approach of protective coatings.

Composite blend preparation involving polyurethane and bitumen

Samples of developed protective coating

Figure 6: Polymer based protective coatings.

reinforcing steel of the structure, thus affecting the durability. The conditions of freezing and thawing aggravate the deterioration process, which in turn shortens concrete structures' life. Generally, a preventative approach of waterproofing is adopted that extends the service life of concrete components hence avoiding the additional incurred cost of repair and maintenance or retrofitting of subcomponents. This paper presents a review of these approaches of waterproofing concrete structures with different materials and additives in various forms such as membranes,

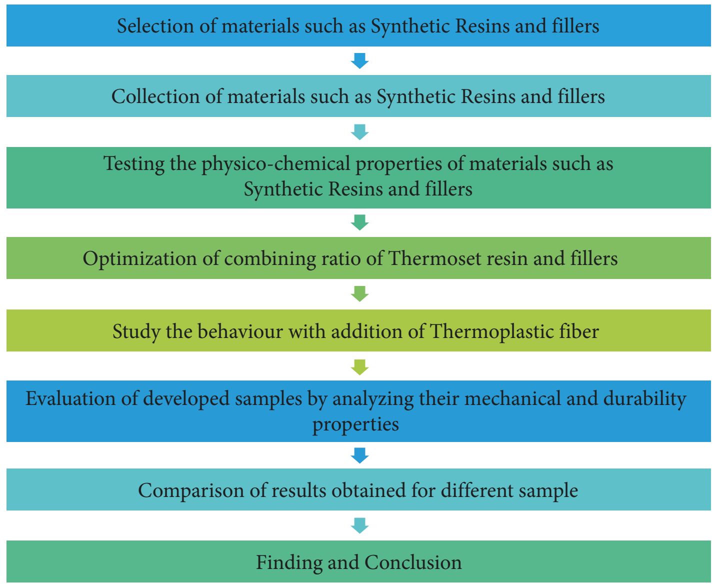

FIGURE 7: Development Approach of Polymer-Based lightweight concrete.

coatings, integral mixing, pore liner penetrants, and pore blocker tests to evaluate the waterproofing efficiency of concrete. It demonstrates the advancements in concrete waterproofing research, explaining the taxonomy highlighting the frequency collection of different materials or additives used and also the tests applied. The review also delineates various surface treatments and their effect on the physiomechanical properties of concrete elements. The main technique adopted is the surface treatments in the form of coating and membranes. As per a study carried out by Foti et al. (2018) [31], it was summarised that the polyurethane foams are appropriate for use in masonry walls because of their advantageous characteristics, speed of installation, and reduction in processing costs resulting in the reduction of the total cost. It was found out that the collapse is extended for higher values of the load in diagonal compression testing for the case of masonry with foam, and the observed deformations are similar to the M2-mortar masonry.

Such a study provides the researchers a detailed construct of research and thus helps to carry out the work in lesser explored approaches by developing new materials or composite materials for sustainable use in increasing the serviceability of the infrastructure. The methodology for the development of the coating is summarised in Figure 5. One such example of practically formulating the composite mix for the development of coating is shown in Figure 6.

In terms of outcomes of the manufactured product, it can be concluded that the developed membrane will have higher resistance to water permeability along with great thermal and sound insulation properties. The developed membrane will be eco-friendly and UV resistant.

TABLE 7: Proportion of fillers with a polyol of resin for choosing optimum ratio.

% Proportion of silica sand as filler	% Proportion of other fillers*
100	0
80	20
60	40
40	60
20	80

*Other fillers include Electroplating Sludge, Dolomite, Calcite, and Fly Ash.

3.4. Light Weight Composite Concrete. Composite Concrete with Synthetic Resin is analogous to ordinary cement concrete, but it comprises finer aggregates; however the different binder is totally substituted with a Synthetic Resin. Synthetic Resin composite contains no cement or water. The aggregates are bonded together by the addition of polymers. The properties of Synthetic Resin composite are mainly determined by the quantity and properties of the type of polymer (synthetic resin and hardener) in the composite concrete. Ordinary Portland cement is nowadays under precarious criticism because of the associated carbon dioxide ($CO2$) emissions released into the atmosphere. So, it is the need of the hour to research for substitute material that is a low emission binding agent for concrete to minimize the environmental impact caused by cement manufacturing. Many significant industries, for example, sealants, fibres, plastics, rubbers, adhesives, and caulking compounds are depending upon synthetic resins offering ease of prefabrication with value-added energy efficiency of constructions and purpose for reuse and recycling of the obsolete, surplus and scrap remaining material. As per the experimental investigation carried out by Foti, *D.* (2016) [32], it was concluded that the reinforcement in the concrete beam made with PET AND CFRP is arranged as continuous bars and strips, respectively, limiting the presence of the crack and avoid the corrosion process in reinforced concrete structural elements. Hence, the specimens reinforced with CFRP strips exhibit better behavior.

FLEXURE STRENGTH OF BEAM (SIZE 500 × 100 × 100 MM)

SHORE HARDNESS D TEST (SIZE 100 × 100 × 100 MM)

MIXING OF POLYOL

VISCOSITY TEST OF POLYOL

Figure 8: Polymer based lightweight concrete specimens.

The construction industry will face different confronts in terms of material application and manufacturing in the next few years, and polymer-based materials are the solution for it as they provide cost-effective answers to various scenarios. The basic prerequisite for high strength-to-weight ratio materials along with different high-quality architectural features is the driving forces for switching from conventional materials to polymer-based composite materials. Likewise methodology for the development of the approach of polymer-based lightweight concrete is shown in Figure 7 below.

Fillers include Silica sand, electroplating sludge, calcite, dolomite, and Flyash, and thermoplastic fibers include polyester fibre and polypropylene fibre. Basically, resin is a combination of polyol and harder, and fillers are added to reduce cost and achieve desirable properties in Table 7.

The outcomes of the developed lightweight concrete can be summed up as follows:

(i) The properties of synthetic resin composite concrete are better than normal concrete in terms of lightweight, flexure strength, chemical resistance, and soundproofing, etc.

(ii) Addition of thermoplastic fiber will enhance the engineering properties of Synthetic resin composite.

(iii) Synthetic resin composite concrete will have more shock-absorbing characteristics. They can be used for the foundation of heavy machines, which produce lots of vibration during the run.

(iv) If the resin dosage is high, it will give a glossy appearance but becomes costly.

(v) Forming Pu matrix composite resin having 1.2–1.3 density where epoxy resin matrix composite having 1.9–2.1

(vi) Consumption of fillers in epoxy resin is nearly twice as compared to Pu resin for the same quantity of volume

(vii) Pu resin composite may be used as precast because top surface covering is required during casting.

(viii) Synthetic resin composite can get 100% strength in 7 days and 70-80% of strength in just 24 hours, whereas 80–90% strength in 7 days and 100% strength in 28 days of conventional concrete.

(ix) Only Room temperature curing is required for gaining strength, so it diminishes water utilization as compared to conventional concrete, as shown in Figure 8.

3.5. Polymer Based Panels under Flexural Loading. Many of the research work studies have concentrated on conventional panels made with conventional mortar. There is a need to recognize and analyze the use of suitable resin materials or their mix blends by incorporating their desired properties and hence developing the further proficient product for replacing conventional panels.

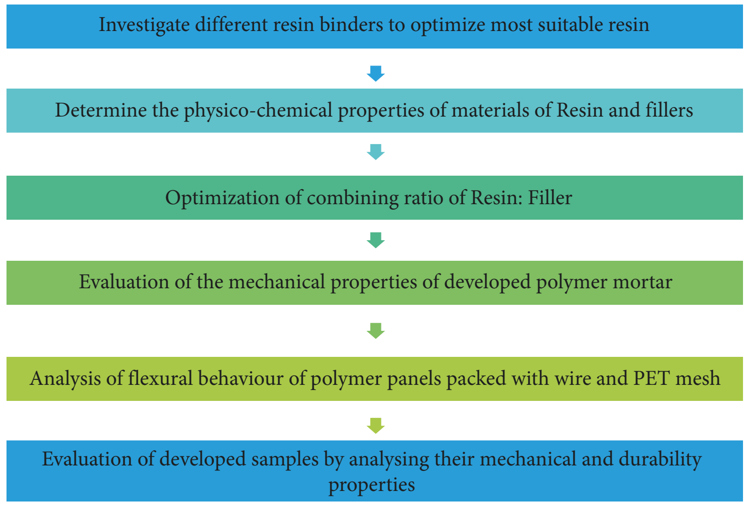

Figure 9: Development approach of polymer based panels.

Formation of cracks in panels tested under flexure   Wire meshes after cracking of the specimen

Figure 10: Polymer based flexural panels.

None of the investigations have perceived the extent of using the advantages of manufactured resin composite innovation as a growing structural member. Moreover, the panels generally use wire mesh, and there is a need to explore advanced innovative solutions to replace traditionally used wire mesh, which are efficient and, at the same time, sustainable in its application. Hence, aligning the research in this direction, the development and application of PET mesh have been proposed in the ongoing investigation. New endeavors and investigation of the advancement of resin and developed PET mesh for basic application ought to be taken so as to improve the mechanical properties. Henceforward, there is a deep requisite for the design, fabrication, and development of such material, which encompasses all the advantageous properties of the material with the addition of the polymer and also exploits the properties of PET waste as mesh for increasing the effectiveness in different situations making it a resourceful product in terms of mechanical strength, insulation properties, and better durability. As per Foti, D., and Lerna, *M.* (2020) [33], a feasibility study was conducted to depolymerize PET and use it as a replacement for sand in cement paste. Experiments were performed to study the effect on the mechanical and thermal properties of the modified paste. Great enhancement in different properties, such as heat transfer, was observed finally.

The properties of polymer-based panels are superior to conventional panels in terms of mechanical and durability point of view. The effect of reinforcing PET wire mesh will enhance the engineering properties like the flexural strength of polymer panels. Polymer panels can be used for secondary roofing panels, railway sleepers, bridge decks, concrete crack repairs, waste-water pipes, pavement overlays, parking, decorative construction panels, etc. Figure 9 shows the development approach for polymer-based panels, and Figure 10 shows the real image of testing of flexural panels.

4. Conclusion and Outlook

The significant findings of the present study and the application of polymer composites can be summarised as mentioned below:

(1) The developed polymer-based paver tiles, paver blocks, and bricks contain more than 50% of waste sludge and meet all the requirements of paver tiles, paver blocks, and bricks as per BIS standards (IS 13801-2013, IS 3495-1 to 4 (1992) and IS 15658 : 2006.

(2) These developed materials are durable, lightweight, flexible, chemical resistant, sound proofing, and have a glossy finish as compared to conventional products

such as concrete paver tiles, concrete paver blocks, and brunt clay bricks available in the market. The process does not require any burning or heating of sludge, and it does not consume any natural resources such as soil or water.

(3) This process can replace more than 50% of sludge by weight of the conventional material used in brick formation without leaving any residual. Therefore, the process is helpful, efficient, and cost-effective indeed and has a lot of applications in the environmental and health aspects. In regard to industrial application, the developed products are beneficial for pavements, walkways, and parking lots, as well as in building construction. Therefore, this process has greater industrial value and can be easily scaled up.

(4) In case of polymer-based coatings, the characteristics of polymer composite coatings entirely depend on the chemical structure of the base material, such as bitumen, epoxy, cement, and the interaction between base-resin-hardener and reinforcement and filler matrix. The whole process of polymer composite coating development makes it evident that these increase the life of the substrates and which in turn decrease the related maintenance costs to the infrastructure. Along with the enhancement in mechanical performance because of infusion with polymers, the coatings offer great resistance against weathering effects, UV effects, and waterproofing properties also are developed. The noteworthy facts concluded from this paper act as a guide for forthcoming research to develop protective coatings for different substrates such as concrete, steel, and timber.

(5) In case of polymer-based lightweight concrete, the developed material has better mechanical properties providing early strength in 7 days as compared to normal concrete. The compressive strength ranges from 20 MPA to 80 MPA entirely depending upon the grade and type of polymer used, which fulfill the minimum criteria of structural concrete (>17 MPa) as per relevant ASTM codes. The density of composite is less as compared to normal concrete making it lightweight and having good flexure and toughness. The work discussed provides a technical reference of specifications for the design and development of polymer-based materials.

(6) The developed polymer-based panels contain more than 50% of the fly ash and also use PET bottles as reinforcement. The resultant will be more durable, lightweight, and environmentally friendly. The vast majority of study has been done on conventional panels. Synthetic resin act as a binder that replaces cement which is the main binding constituent in conventional concrete, which have greenhouse gas emissions. Polymer panels can be used for secondary roofing panels, which will enhance the life of low-cost housing and also helps in reducing industrial waste, like fly ash, PET water bottles, etc.

Although, polymer composites offer a great range of sustainable and superior construction materials in terms of processing, structure, performance, and properties (PSPP). One of the main difficulties faced in developing composite is handling the usage of polymers. The temperature susceptibility and pot life of polymers is the reason for less workability of the mix obtained, leading to futile trials during fabrication of composite. But there is still a vast scope and potential that is unexplored in this field of material science in regard to polymer composites. Surely, with the advent of technologies and manufacturing processes, there can be more refined forms of materials that sustain the various complex loading conditions, weather constraints, etc.

Future scope: Future scope of the development of these materials remains vast as more replacement of waste materials can be achieved with the potential use of polymers. Many such future scope applications can be explored in depth.

(i) Utilization of acrylic resins in different finishes, binder in paint formulations, sealants, caulks, and safety glazing.

(ii) Concrete-polymer hybrids, polymer-impregnated concrete, and sulphur concrete.

(iii) Epoxy for different adhesives, binders, durable protective coatings and overlays, and fillers to patch voids or Rebar coatings in reinforced concrete.

(iv) Structural upgrade of steel members.

(v) Repair and rehabilitation of reinforced concrete members, wood members, and masonry walls.

(vi) FRPs for cladding, column wrapping, domes, fencing, masts, pipes, roofing, tanks, and towers.

(vii) Poly(vinyl butyral) (PVB) to be used as the optically clear vibration-stopping inner layer in top-of-the-line laminated glass soundproofing windows, etc.

Data Availability

The data used to support the findings of this study are included in the article. Should further data or information be required, they are available from the corresponding author upon request.

Disclosure

The study was performed as a part of the Employment Jimma University, Ethiopia.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] S. N. A. Azrie, M. T. H. Sultan, M. Jawaid, and K. Jayakrishna, "Impact behaviour of hybrid composites for structural applications: a review," *Composites Part B: Engineering*, vol. 133, pp. 112–121, 2018.
[2] N. Saba and M. Jawaid, "A review on thermomechanical properties of polymers and fibers reinforced polymer composites," *Journal of Industrial and Engineering Chemistry*, vol. 67, pp. 1–11, 2018.
[3] G. Martínez-Barrera, O. Gencel, and J. M. L. Reis, "Civil Engineering Applications of Polymer Composites," *Civil Engineering Applications of Polymer Composites*, vol. 2016, Article ID 3941504, 2 pages, 2016.
[4] Y. Zhang, P. Shi, L. Chen, and Q. Tang, "Utilization of electroplating sludge as subgrade backfill materials: mechanical and environmental risk evaluation," *Advances in Civil Engineering*, vol. 2018, Article ID 4891418, 9 pages, 2018.
[5] H. Li, X. Yang, W. Xu et al., "Application of dry composite electroplating sludge into preparation of cement-based decorative mortar as green pigment," *Journal of Cleaner Production*, vol. 66, pp. 101–106, 2014.
[6] L. Pérez-Villarejo, S. Martínez-Martínez, B. Carrasco-Hurtado, D. Eliche-Quesada, C. Ureña-Nieto, and P. Sanchez-Soto, "Valorization and inertization of galvanic sludge waste in clay bricks," *Applied Clay Science*, vol. 105-106, pp. 89–99, 2015.
[7] H. Lyu, Y. Gong, J. Tang, Y. Huang, and Q. Wang, "Immobilization of heavy metals in electroplating sludge by biochar and iron sulfide," *Environmental Science and Pollution Research*, vol. 23, no. 14, Article ID 14472, 2016.
[8] G. C. C. Yang and K.-L. Kao, "Electroplating and calcium carbonate sludges as binding material for sludge solidification," *Water Environment Research*, vol. 68, no. 2, pp. 215–221, 1996.
[9] M. Xia, F. Muhammad, S. Li et al., "Solidification of electroplating sludge with alkali-activated fly ash to prepare a non-burnt brick and its risk assessment," *RSC Advances*, vol. 10, no. 8, pp. 4640–4649, 2020.
[10] G. D. Airey, J. R. A. Grenfell, A. Apeagyei, A. Subhy, and D. Lo Presti, "Time dependent viscoelastic rheological response of pure, modified and synthetic bituminous binders," *Mechanics of Time-Dependent Materials*, vol. 20, no. 3, pp. 455–480, 2016.
[11] B. Singh, M. Gupta, and L. Kumar, "Bituminous polyurethane network: preparation, properties, and end use," *Journal of Applied Polymer Science*, vol. 101, no. 1, pp. 217–226, 2006.
[12] D. Marcinkowska and A. Kaleta, "Structure and properties of microporous polyurethane membranes designed for textile-polymeric composite systems," *Fibres and Textiles in Eastern Europe*, vol. 13, no. 6, 2005.
[13] M. Guo, Y. Tan, L. Wang et al., "Study on water permeability, shear and pull-off performance of waterproof bonding layer for highway bridge," *International Journal of Pavement Research and Technology*, vol. 11, no. 4, pp. 396–400, 2018.
[14] R. Hsissou, R. Seghiri, Z. Benzekri, M. Hilali, M. Rafik, and A. Elharfi, "Polymer composite materials: a comprehensive review," *Composite Structures*, vol. 262, Article ID 113640, 2021.
[15] M. Jamshidi and A. R. Pourkhorshidi, "Modified polyester resins as an effective binder for polymer concretes," *Materials and Structures*, vol. 45, no. 4, pp. 521–527, 2012.
[16] S. Kumar Adhikary, D. Kumar Ashish, and Z Rudžionis, "Aerogel based thermal insulating cementitious composites," *A review" Energy & Buildings*, vol. 245, pp. 1–25, 2021.
[17] T. Žlebek, J. Hodul, and R. Drochytka, "Experimental testing suitability of the waste glass into the polymer anchor materials based on epoxy resin," *Procedia Engineering*, vol. 195, pp. 220–227, 2017.
[18] D. Foti and S. Vacca, "Comportamiento mecánico de columnas de hormigón armado reforzadas con mortero reoplástico," *Materiales de Construcción*, vol. 63, no. 310, pp. 267–282, 2013.
[19] S. T. Wicaksono, A. H. Laksana, and H. Ardhyananta, "Effect of calcium carbonate on the tensile and density properties of kenaf/polyester hybrid composite," *IOP Conference Series: Materials Science and Engineering*, vol. 546, no. 4, Article ID 42019, 2019.
[20] J. P. Gorninski, D. C. Dal Molin, and C. S. Kazmierczak, "Strength degradation of polymer concrete in acidic environments," *Cement and Concrete Composites*, vol. 29, no. 8, pp. 637–645, 2007.
[21] M. Barbuta and M. Harja, "Experimental study on the characteristics of polymer concrete with epoxy resin," *Buletinul Institutului Politehnic din lasi. Sectia Constructii, Arhitectura*, vol. 54, no. 2, 2008.
[22] R. Sathia, K. Ganesh Babu, and S. Manu, "Durability study of low calcium fly ash geopolymer concrete," in *Proceedings of the 3rd ACF international conference-ACF/VCA*, vol. 2008Indian Institute of Technology Madras, Chennai, India, March 2008.
[23] M. Criado, A. Palomo, A. Fernández-Jiménez, and P. F. G. Banfill, "Alkali activated fly ash: effect of admixtures on paste rheology," *Rheologica Acta*, vol. 48, no. 4, pp. 447–455, 2009.
[24] E. Obonyo, E. Kamseu, U. Melo, and C. Leonelli, "Advancing the use of secondary inputs in geopolymer binders for sustainable cementitious composites: a review," *Sustainability*, vol. 3, no. 2, pp. 410–423, 2011.
[25] V. P. Rajaiah, S. Dharmar, and Dr S. Nagan, "Experimental investigation on flexural behaviour of folded ferrocement panels," *International journal of innovative research in science, engineering and technology*, vol. 3, no. 7, 2014.
[26] A. C. Sophia, K. Swaminathan, and K. Swaminathan, "Assessment of the mechanical stability and chemical leachability of immobilized electroplating waste," *Chemosphere*, vol. 58, no. 1, pp. 75–82, 2005.
[27] K. Varinder and J. Siby, "Use of electroplating industry sludge as a construction material," *MOJ Civil Engineering*, vol. 2, no. 1, pp. 28–34, 2017.
[28] L. Zhang, "Production of bricks from waste materials - a review," *Construction and Building Materials*, vol. 47, pp. 643–655, 2013.
[29] S. Adarsh and L. Manikanta, "Galeeb sha "application of polymer composites in civil engineering"," *International Journal of Innovative Research in Science and Engineering*, vol. 2, pp. 231–238, 2016.
[30] V.-I. Iftode, I. Olteanu-Dontov, P. Mihai, M. Budescu, and M. Harja, "Improving elastic properties of bricks by polyurethane matrices mean," *IOP Conference Series: Materials Science and Engineering*, vol. 586, no. 1, Article ID 12009, 2019.

[31] D. Foti, M. Lerna, and V. Vacca, “Experimental characterization of traditional mortars and polyurethane foams in masonry wall,” *Advances in Materials Science and Engineering*, vol. 2018, Article ID 8640351, 13 pages, 2018.

[32] D. Foti, “Innovative techniques for concrete reinforcement with polymers,” *Construction and Building Materials*, vol. 112, pp. 202–209, 2016.

[33] D. Foti and M. Lerna, “New mortar mixes with chemically depolymerized waste PET aggregates,” *Advances in Materials Science and Engineering*, vol. 2020, Article ID 8424936, 9 pages, 2020.