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Properties of epoxy polymer concrete matrix: Effect of resin-to-filler ratio and determination of optimal mix for composite railway sleepers

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HIGHLIGHTS

- Study on the effect of resin-to-filler ratio on the properties of polymer matrix.
- Thermal, physical, mechanical and durability properties of epoxy based matrix.
- Mixes containing 30–50% filler are found suitable mix for coating sleepers.
- Analytic Hierarchy Process is conducted to select the best mix in different cases.

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ABSTRACT

The lack of knowledge of the behaviour of an epoxy polymer matrix has become a challenging issue for the design of a serviceable, durable and economic matrix. This study investigated the effect of the resin-to-filler ratio on the thermal, physical, mechanical and durability properties of polymer matrices composed with epoxy resin and light weight filler materials. This ratio was considered the experimental variable on which the properties of a polymer matrix are primarily dependent. The control mix was composed of 100% resin to which an amount of filler material of up to 60% of its volume was added in increment of 10%. No mix with more than 60% filler (that is, one containing 40% resin) was considered because it would not be a workable mix when prepared. A matrix's fundamental properties, including its generation of heat during mixing and glass transition temperature (thermal), density and porosity (physical), flexural and compressive behaviour (mechanical) and the effect of ultraviolet radiation (durability) were investigated. The results showed that, although adding a filler to the resin could improve the matrices thermal and durability properties as well as reduces its cost, there was a consequent decrease in its physical and mechanical properties. In maintaining a good balance among thermal, physical, mechanical and durability properties and cost, it was observed that mixes containing fillers from 30% to 50% could meet the requirements for coating of composite railway sleepers. Therefore, to select the most suitable one from the range of acceptable mixes an Analytic Hierarchy Process (AHP) was applied. The results from AHP showed that the 30% filler mix was the optimal one when priority was to obtain mechanical properties. However, if the cost of the matrix was considered the most important criterion for selecting the optimal mix, the mix containing 50% filler was the best choice. If durability was the priority, it was suggested that either a 30% or 50% filler mix be used depending on the relative importance of the mechanical properties and cost factors.

1. Introduction

The weakness of an Ordinary Portland Cement (OPC) mortar in terms of its tensile strength, modulus and strain, rapid strength development, drying shrinkage and resistance to chemical attacks has led to the utilisation of polymer matrices for bridge decks, concrete crack repairs, the coating and binding of composite panels, pavement overlays, hazardous waste containers, waste-water pipes, decorative construction panels and other structures in aggressive environmental conditions [1–4]. Unlike an OPC mortar, a polymer matrix consists of a thermoset resin with filler materials. The chemistry behind the development of polymer matrix is

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governed by the chemical reaction between resin and hardener. Generally, this reaction is exothermic (i.e., generated heat) and forms long polymer chains during the curing process which create the matrix's flexibility and strength. The properties of a polymer matrix depends largely on the type and amount of resin, type of filler and curing conditions used [5,6].

Different types of thermoset resins are available in the market. The choice of a particular one depends mainly on its tensile and compressive properties, glass transition temperature, durability, material availability, ease of processing, cost and specific user demand. In the past, researchers have investigated different resin systems in polymer concrete with the most commonly used resins epoxy [7], polyester [8] and vinyl-ester [2]. Despite the cost benefits of vinyl-ester and polyester compared with epoxy, they are not suitable if excellent mechanical and thermal properties, superior resistance to humidity, low shrinkage and high elongation are required in order to produce a durable and flexible polymer matrix [9]. Moreover, epoxy can provide a unique balance of chemical and mechanical properties combined with extreme processing versatility. Because of its superior mechanical, durability and thermal properties compared with those of other types of resins, this study examined whether epoxy is a suitable material in a polymer matrix for a coating of civil infrastructure. However, its high cost is identified as the primary obstacle.

To minimise the cost of an epoxy polymer matrix, light weight filler materials can be added to the resin. Research on the effects of different filler materials such as fly ash [6,10,11] and silica fume [6], on the polymer concrete have been investigated by several researchers, with the use of the former shown to improve the mechanical, chemical and durability properties of polymer concrete [11]. A comparative study of the performances of fly ash and silica fume with epoxy resin reported that a combination of fly ash and epoxy can provide higher mechanical strength than one of epoxy and silica fume [6]. The addition of a filler can also improve a matrix's compressive and tensile properties although its flexural strength may decrease [6]. However, Lokuge and Aravinthan [2] found that the addition of fly ash showed trends of increasing compressive strength but decreasing tensile and flexural strengths. In contrast to the traditional concept of using fly ash as a filler, this study incorporated two other filler materials, a fire retardant filler and hollow microsphere to improve fire and shrinkage performances respectively which are two important properties required for coating materials.

The fibre composites are the load carrying components of the existing and emerging composite sleeper technologies. Research and development projects on composite railway sleepers are now looking for an effective coating material to protect the load-carrying components of a sleeper against unfavourable weather conditions, particularly from ultraviolet (UV) radiation. The outdoor application of railway sleepers are routinely exposed to the UV radiation that can degrade the performance and needs a suitable coating to protect the fibre reinforcement [12]. Although the superior properties of an epoxy polymer matrix support its use as a coating material, a procedure for its mix design is not well established. In a previous study, the mix proportions of polymer concrete were arbitrarily selected and significant research carried out to investigate their behaviours [2]. For an economical design of a polymer concrete matrix, it has been recommended that minimum amount of resin is used to minimise the cost [2], and therefore, it is important to optimise the mix proportions. However, the effect on the properties of a polymer matrix due to an introduction of filler is still unknown. This study investigated the effects of different resin-to-filler ratios on the thermal, physical, mechanical and durability properties of a polymer matrix and determined an optimal one for coating of composite railway sleepers.

2. Materials and method

2.1. Materials

The materials employed in this investigation were an epoxy resin and light-weight filler.

2.1.1. Resin

In this study, two main components of the resin systems were DGEBA type epoxy resin (Part-A) and an amine-based curing agent (Part-B). Epoxy resins are blended, filled, or modified with reactive and nonreactive components. The resin producer furnished an Epoxy Equivalent Weight (EEW) of 190 g for Part-A and Amine Hydrogen Equivalent Weight (AHEW) of 60 g for Part-B. To make the resin mix reactive, one equivalent weight quantity of the amine curative required one equivalent weight quantity of DGEBA epoxy resin. Therefore, 100 g of Part-A are required to mix with 32 g of Part-B to maintain the mixing ratio.

2.1.2. Filler

Three different filler materials, as Fire Retardant Filler (FRF), Hollow Microsphere (HM) and Fly Ash (FA), were mixed together in approximate percentages to obtain an effective filler mix. The FRF used was non-toxic and had low abrasiveness, acid resistance, chemical inertness, smoke suppression and electric arc resistance. The HM was added to reduce the weight, control shrinkage and increase the thermal insulation of a polymer matrix while the FA could improve its performance in terms of resisting UV and reducing the permeability of water and aggressive chemicals.

2.2. Preparation of polymer matrices

Filler amounts of up to 60% of a matrix's volume were added in 10% increments as a mix with more than 60% filler was found unworkable. Seven mixes with different amounts of filler were prepared, and the mixes with no filler considered the control sample. The mixes were denoted according to their volumes of filler, e.g., F_{30} indicates a mix containing 30% filler and 70% resin, as detailed in Table 1.

All the specimens were prepared in two different moulds: (a) plastic cups – suitable for measuring the heat generation, glass transition temperature, porosity, flexural strength and UV resistance, and (b) sealed-bottom cylindrical plastic pipes – suitable for measuring the density and compressive strength. All specimens were cured at room temperature for up to 24 h (Fig. 1). It was observed that the increase in the amount of filler increased the darkness of the samples as the fly ash was grey in colour.

2.3. Thermal behaviour

2.3.1. Heat generation

During the preparation of specimens at room temperature, the resin (Part-A) and hardener (Part-B) created an exothermic reaction when mixed. The mixes produced heat, and the generated temperature was measured by a temperature gun at approximately 10-min intervals for 240 min after casting.

Table 1
Mix proportions of polymer matrices.

Acronym of the mix		F_0	F_{10}	F_{20}	F_{30}	F_{40}	F_{50}	F_{60}
% Resin/Filler (by volume)		100/0	90/10	80/20	70/30	60/40	50/50	40/60
Resin	Part-A (g)	124	112	100	87	75	62	50
	Part-B (g)	40	36	32	28	24	20	16
Filler (g)		0	30	59	89	119	148	178