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DESIGN OF EPOXY RESIN BASED POLYMER CONCRETE MATRIX FOR COMPOSITE RAILWAY SLEEPER

Wahid Ferdous*
Centre of Excellence in Engineered Fibre Composite (CEEFC),
School of Civil Engineering and Surveying, University of Southern Queensland
Toowoomba, QLD, 4350, Australia. md.ferdous@usq.edu.au (Corresponding Author)

Allan Manalo
Centre of Excellence in Engineered Fibre Composite (CEEFC),
School of Civil Engineering and Surveying, University of Southern Queensland
Toowoomba, QLD, 4350, Australia. manalo@usq.edu.au

Thiru Aravinthan
Centre of Excellence in Engineered Fibre Composite (CEEFC),
School of Civil Engineering and Surveying, University of Southern Queensland
Toowoomba, QLD, 4350, Australia. thiru.aravinthan@usq.edu.au

Gerard Van Erp
CarbonLoc Pty. Ltd.
Toowoomba, QLD, 4350, Australia. gvanerp@loccomposites.com.au

ABSTRACT

A new type of railway sleeper made from composite materials is now being developed to replace deteriorating timber sleepers. To protect it from unfavorable environments and to increase the strength at rail-seat area, the sleeper is coated with epoxy based polymer concrete. This paper investigates the properties of the polymer concrete matrix with different percentages of epoxy resin binder and light-weight particulate filler. The mixing proportion of Particulate Filled Resin (PFR) was optimised while targeting a specific strength and workability. The content of epoxy resin was varied from 40 to 100% whereas the filler material ranged from 0 to 60%. The flexural performance of PFR was evaluated using three-point bending tests and the most suitable mix proportion is determined based on the experimental results.

KEYWORDS

Polymer concrete matrix, epoxy resin, three-point bending, optimisation.

INTRODUCTION

Research and developments on fibre composite railway sleeper are now looking for an effective sleeper coating material which is readily available, has a good mechanical properties, durable, rapid strengthening, good resistance to chemical attack, possesses low permeability, offers longer service life and, most importantly, is environmentally friendly. Polymer Concrete (PC) has been considered for this purpose which has been potential to meet all of those requirements (Lokuge and Aravinthan 2012). Similar to ordinary cement concrete, PC consists of aggregates bonded together by resin instead of cement binder. The chemistry behind PC is governed by the chemical reaction of the resin. In most cases this reaction is exothermic (generated heat) and long polymer chains are formed during the curing process. These long chains give the PC its flexibility and strength. The properties of PC largely depend on the type and amount of resin content, shape and size of aggregates, type of filler and curing conditions (Kirlikovali 1981; Bărbuţă et al. 2010). Because of the size of the structural element and the need to limit shrinkage, the polymer concrete used in this research is based on epoxy resin with filler materials.

For the manufacturing of PC, the choice of particular resin mainly depends on their availability and cost, desired properties, the type of applications and the specific demand of the users (Bedi et al. 2013). In the past, researchers have investigated several resin systems in PC including epoxy (Lokuge and Aravinthan 2012), polyester (Ferreira et al. 2000), vinylester (Lokuge and Aravinthan 2012) and furan (Muthukumar and Mohan 2004a). Among them, epoxy and polyester are the most commonly used resin system. Vinylester PC usually provides lower range of compressive strength when it is compared with epoxy and polyester based PC (Lokuge and Aravinthan 2013) . Although furan resin offers excellent resistance against heat, acid, bases and organic solvent (Muthukumar and Mohan 2004a) but it does not work with alkaline surface which results in a brittle product (Hausmann and Lander 1967). In this research, epoxy is considered as the promising choice because of their superior mechanical and durable properties over polyester resin (Bedi et al. 2013).

Research on the effect of different filler materials on PC such as fly ash (Bărbuţă et al. 2010; Rebeiz et al. 2004) and silica fume (Bărbuţă et al. 2010) have been investigated by several researchers. A comparative study between the performance of fly ash and silica fume with epoxy resin reported that the fly ash and epoxy combination can provide higher mechanical strength than epoxy with silica fume. The addition of filler can also improve the compressive and tensile properties but the flexural strength may decrease (Bărbuţă et al. 2010). Moreover, Lokuge and Aravinthan (2013) found an increasing trend for compressive strength but decreasing curve for tensile and flexural strength with the addition of fly ash. In contrast with the traditional concept of using fly ash as filler, this study incorporates two other filler materials, a fire retardant and hollow microsphere to improve the fire and shrinkage performance, respectively.

Polymer concrete shows excellent performance in rapid strengthening which is the precondition for precast concrete application. It is reported that PC can achieved almost 70% of its final strength within a day whereas in this period the normal cement concrete gained only 20% of its 28-day strength (Bedi et al. 2013). Another study found the strength gaining of 80-85% within only 6 hours of casting (Németh 2012). This achievement can be even higher if PC goes through high temperature curing. For field use and ease of operation, room temperature curing is desirable and 7 days room temperature curing is considered as optimum period of curing because PC gained a negligible strength after 7 days (Bedi et al. 2013).

Despite of its good properties, the uptake of PC in construction is rather slow due to their high cost over the traditional cement concrete and lack of familiarity (Rebeiz 2004). PC is approximately 5-10 times more expensive than standard concrete but it is still inexpensive while comparing with the cost of glass fibre reinforced composite which is widely used in construction purposes. The procedure of mix design for PC is not well established so far and therefore, to minimise the cost it is important to optimise the mix proportion. It is recommended to use minimum amount of resin and the best method of curing for economical design of PC (Lokuge and Aravinthan 2013). This study highlighted the optimum mix proportion for PC matrix that may be suitable for the coating of the recently developed sandwich composite railway sleeper.

MATERIALS AND METHODS

Materials

The materials employed in this investigation were epoxy resin and light-weight filler. Like cement in the normal concrete, epoxy resin works as a binder in polymer concrete. Its main function is to bind the aggregates together and provides the strength in concrete. The two main components of the epoxy resin are a DGEBA type (Part A) and an amine based curing agent (Part B). The resin producer furnishes the Epoxy Equivalent Weight (EEW) of 190 gm for Part A and Amine Hydrogen Equivalent Weight (AHEW) of 60 gm for Part B. To make the resin mix reactive, one equivalent weight quantity of amine curative will require for one equivalent weight quantity of an epoxy resin. Therefore, 32 gm of Part B is required to react with 100 gm of Part A.

Resin is the most expensive ingredients of PC and to make the concrete cost effective, light-weight filler materials were added to resin and the final product is called particulate filled resin. The addition of coarse aggregate with PFR can increase material stiffness and compressive strength and this formulation is called PC. Three different filler materials, Fire Retardant Filler (FRF), Hollow Microsphere (HM) and fly ash were mixed together by a certain percentage to get the effective filler mix. This mixing formulation was established after several trial mixes by CarbonLoc and due to the commercial in confidence, could not be included in this paper. The fire retardant used is non-toxic and has low abrasiveness, acid resistance, chemically inertness, electrical arc resistance and smoke suppression properties. On the other hand, hollow microspheres can contribute in reducing weight, controlling shrinkage, increasing thermal insulation of the PC. The by-product fly ash can improve the performance of concrete by resisting UV and reducing permeability of water and aggressive chemicals.

PFR (PC matrix) = Resin (Part A + Part B) + Filler materials (FRF + HM + Fly ash)
PC = PFR + Coarse aggregate

Specimen Preparation

The mix proportions of polymer concrete were arbitrarily selected although a significant research has been carried out to investigate their behaviour. It is observed that the high percentage of filler or low resin content in PFR results in a brittle product. Furthermore, the mix becomes dry and difficult to work with. Considering those criteria, the filler materials were added up to 60% by volume with an increment of 10%. No further mix was considered beyond 60% filler as it was not workable. A total of 7 mixes of sample were prepared in which different amounts of filler were added except for mix-1, which is considered as the control sample. The details of mixes are provided in Table 1.

Table 1. Mix proportions of PFR

		Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6	Mix 7
% Resin/Filler (by volume)		100/0	90/10	80/20	70/30	60/40	50/50	40/60
Resin	Part A, (gm)	124	112	100	87	75	62	50
	Part B, (gm)	40	36	32	28	24	20	16
Filler (FRF+ HM+ Fly Ash), (gm)		0	30	59	89	119	148	178

All the specimens were prepared into the plastic mould and cured in the room temperature up to 24 hours for getting the samples hardened (Figure 1b). It was observed that the increase of filler material increase the darkness of samples as the fly ash itself is grey in colour. The solid specimen was removed from the plastic mould and cut to nominal dimensions of 80 × 10 × 10 mm by machine. Three specimens were prepared for flexural testing from each mix.

(a) PFR ingredients (b) PFR sample preparation

Figure 1. PFR ingredients and its preparation

Characterisation

Before characterising the flexural properties of solid specimen, the density of each ingredient was measured for better understanding of the amount of voids in solid sample. The density of ingredients and solid specimen were measured by electronic balance and helium pycnometer which can be used for measuring the volume of powders, fibres, porous materials and solids. The densities of the PFR ingredients are given in Table 2.

Table 2. Density of PFR ingredients

Ingredients	Density, (g/cm^3)
Part A	1.068
Part B	1.183
FRF	2.411
HM	0.752
Fly ash	2.006

The specimens were tested under three-point bending using a 10 kN capacity testing machine with a span length of 64 mm and test speed of 2 mm/min. To facilitate the smooth rotation and minimise membrane stresses, frictionless paper was placed at the load and support points during testing. All the specimens failed at the mid-span as shown in Figure 2.

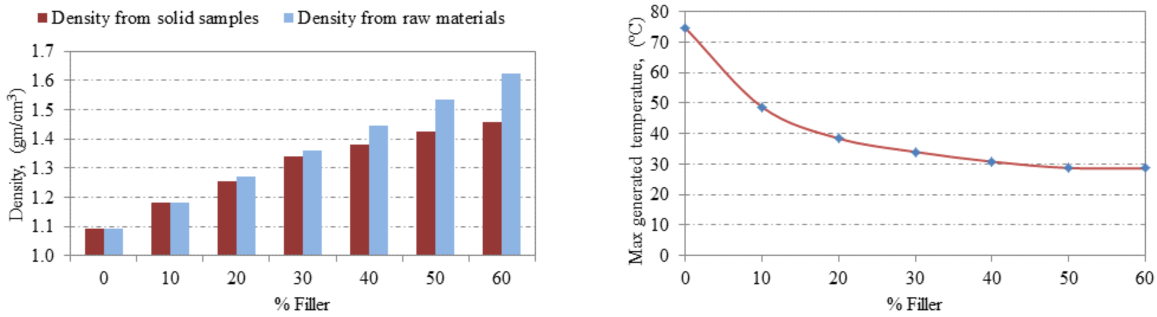
(a) Bending test of PFR (b) Failure of the samples

Figure 2. Test set-up and failure mode of different specimen

RESULTS AND DISCUSSIONS

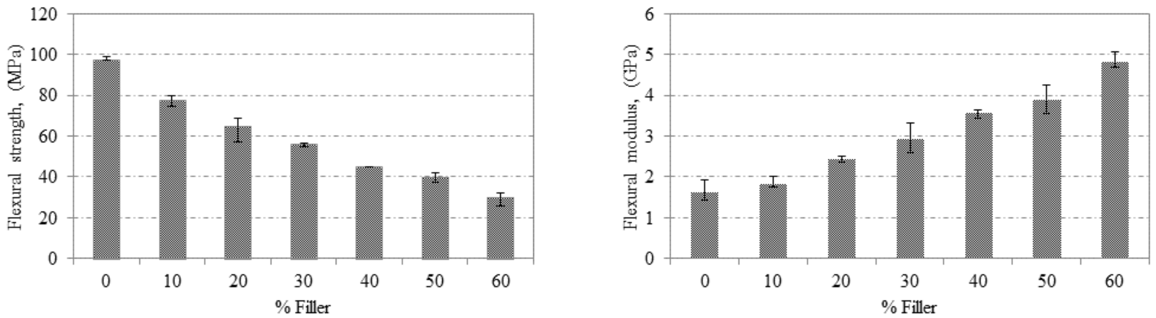
Based on the experimental results, it has been observed (Figure 3a) that the density of solid PFR samples gradually decreases from the density of its raw material with the increase of filler loading. This is due to the formation of voids in solid sample which is one of the key factors for optimising mix proportion (Muthukumar and Mohan 2004b). The void formation generally depends on the workability of the mix which found low workable when the filler content is high. During sample preparations, a very dry mix obtained while the filler content in the mix was more than 60% in volume and therefore, no further mix was considered beyond 60% in this investigation. The density of solid specimens gradually increases from 1.093 to 1.458 g/cm^3 with the increase of filler as the combined density of filler is higher than the resin (Table 2).

During specimen preparation in room temperature, when the two resins mixed with each other, an exothermic reaction happened which produced heat in the mix and the generated temperature was measured by a temperature gun at approximately 10 minutes interval. The variation of peak temperature of the mix with different amounts of filler is plotted in Figure 3(b). In zero filler mix, the peak temperature was recorded of 75 ℃ which decreased to 29 ℃ for the mix with 60% filler materials. This happened due to the absorption of heat by filler materials. No significant heat was generated when the filler content was more than 40% which is convenient for easy operations and handling or in other words, the low heat concrete is easy to work with.



(a) Variations of solid density from raw material (b) Heat produced by exothermic reaction
Figure 3. Variations of density and produced heat with filler content

To investigate the effect of filler loading on the flexural properties of PFR, three-point bending tests were carried out from which the flexural behaviour is presented in Figure 4. The highest strength obtained is 98 MPa when the filler content is 0% and the lowest is 30 MPa at 60%. A decreasing trend in flexural strength can be seen with the increase of filler loading (Figure 4a). This phenomenon can be attributed to the decrease of resin content on which the strength of polymer matrix mainly depends. The resin itself has good tensile properties and the addition of filler materials reduces the tensile capacity of PFR and subsequently lower flexural strength can achieve. In contrast with flexural strength, the flexural modulus of elasticity is increased with the increase of filler in the range between 1.65 to 4.83 GPa (Figure 4b). The increase of filler materials and consequently larger surface area can create a rigid bond with resin which demonstrated an inflexible polymer matrix and the compound exhibits lower strain. This formation enhances the stiffness properties and explains why the flexural modulus increased with filler loading. It is important to mention that the higher modulus of elasticity does not indicate the high strength because the specimen fails quickly due to the deficiency of resin.



(a) Variations of flexural strength with filler (b) Variations of flexural modulus with filler
Figure 4. Effect of filler loading on the flexural properties of PFR

In strength point of view, the best performance is obtained in the mix with zero filler loading but this mix is not recommended for the coating of railway sleeper due to its high cost, low modulus and low resistance to protect ultraviolet (UV) radiation. On the other hand, the mix with 60% filler provided the highest modulus and has better UV protection but its low strength and poor workability as well as large percentage of voids in the polymer matrix makes them inappropriate for use as coating of railway sleeper. The resistance against UV radiation is one of the limitations of epoxy resin which can be improved by adding fly ash in the mix as the fly ash is grey in colour (Figure 1b) that can protect the polymer matrix by blocking the UV ray. Moreover, the experimental investigation (Manalo et al. 2010) showed that the flexural modulus of glue laminated sandwich beam is approximately 4 GPa. Therefore, to avoid the cracking of coating materials on the main structural component of sleeper, the required polymer matrix should have the modulus of elasticity lower than 4 GPa. Considering all those criteria, the polymer matrix composed with 60% resin and 40% filler (Mix 5) is recommended for the coating of railway sleeper. Moreover, this matrix showed the most consistent properties. The strength and modulus of elasticity of the recommended mix is 45 MPa and 3.5 GPa respectively which satisfy the corresponding requirements of 13.8 MPa and 1.17 GPa for polymer composite sleeper according to American Railway Engineering and Maintenance-of-Way Association (AREMA) standard.

CONCLUSIONS

The effect of the amount of filler materials on the epoxy based polymer concrete matrix has been investigated from which the following conclusions are drawn:

1. The higher resin can produce more heat in the mix but this production is insignificant when the filler contents is more than 40% as the filler materials can absorb heat.
2. The voids in the polymer matrix increases with the increase of filler loading and the mix becomes unworkable when the volume of filler is more than 60%.
3. The flexural strength of epoxy based polymer concrete decreases from 98 to 30 MPa when the filler increases from 0 to 60%.
4. The filler materials have a significant effect on the flexural modulus of polymer matrix. The flexural modulus increases from 1.65 to 4.83 GPa with the increase of filler from 0 to 60%.
5. The recommended polymer matrix mix proportion for composite railway sleeper coating is 60% resin with 40% filler due to its reasonable strength, stiffness and workability.

RECOMMENDATIONS FOR FUTURE STUDY

Research on the compressive and shrinkage behaviour and the effect of UV is recommended for PFR.

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