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An Assessment of the Compressive Strength of Glass Reinforced Plastic Waste Filled Concrete for Potential Applications in Construction

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Abstract

Efforts were made to recycle Glass reinforced plastic (GRP) waste powder in concrete products and assess its compressive strength to comply with British Standards for use in construction applications. More than 90 GRP waste-filled concrete specimens were developed using the concentration of 5%, 15%, 30% and 50% (w/w). The findings revealed that the increase in concentration of GRP waste decreased the compressive strength. However, increase in curing duration resulted in improving the compressive strength of concrete. The findings of this work pave the way for further GRP waste recycling in precast construction products for use in various applications.

Keywords: Glass reinforced plastic waste; Concrete composite; Compressive strength; Recycling potential; Construction

1. Introduction

Around 55,000 tonnes of GRP waste are currently produced each year in the United Kingdom and the quantity is expected to increases by 10 per cent annually [1]. In the European Union as well as in most parts of the world, the manufacturing of thermoplastic polymer composites is higher than the thermoset composites. The thermoset polymer composites share was about 18.5% (i.e.7350000 tonnes) in the Western Europe during 2003 [2]. Landfill and incineration are the most commonly adopted methods for disposal of thermoset polymer composites including GRP composites waste [3, 4]. In the United Kingdom, about 90% of the GRP waste is being sent for landfill. Growing technological innovations, ample market value and demand for GRP composites all over the world has trigged interest in optimising GRP waste recovery; however, few solutions for recycling into value added construction products are being explored. Hence, in the present study, efforts were made to explore the viability of GRP waste concrete potential applications in construction.

2. Glass reinforced plastic (GRP) recycling

It was reported that the use of GRP waste ground fibre, as replacement for fine aggregate in foamed concrete, increased strength with reduced weight [5]. Moreover, the study revealed that the

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fire resistant properties of GRP filled foamed concrete were suitable for structural and semi-structural applications in lightweight partitions, wall and floor panels. A study on GRP waste recycling showed that glass fibres recovered from polymeric chemicals could replace up to 20% of the virgin glass fibres used in dough moulding compound [3]. Virgin glass fibre has been used in making thin sheets of flat, corrugated or complex shaped panels as precast concrete products for construction [6], although the studies on GRP waste recycling revealed that the ground glass fibres removed from granules were used with wood flour in high density polyethylene (HDPE) to increase tensile and flexural modulus [7]. However, the polymeric compound and glass fibre in GRP waste still needs to find recovery alternatives. Attempts were also made to recycle concrete and masonry materials along with unsaturated polyester resins and polyethylene terephthalate (PET) plastic waste and reported that the resin addition increased the strength of polymer concrete [8]. Moreover, the acid and alkali elements were found not to affect the polymer concrete. Efforts were also made to characterise the properties of recycled glass fibre reinforced polymide, but the suitability and their recycling potentials are not yet well established [9, 10]. The work reported so far is very limited and did not show viable applications for GRP waste recycling in concrete.

3. Methodology and materials

GRP waste powdered materials with a little quantity of varying length of glass fibre were acquired from Hambleside Danelaw Rooflights and Cladding Limited, Scotland, the United Kingdom [1]. Attempts were made to recycle GRP waste powder in precast concrete composites (i.e. concrete paving blocks).

Mix design was in accordance with Building Research Establishment (BRE) 1988 mix design [11], and concrete specimens were prepared as per BS EN 12390-2:2000 [12] using different proportions of cement, aggregate as shown in Table 1. Processed GRP waste powder was used as a partial substitute for fine aggregates at the concentration of 5%, 15%, 30% and 50% (w/w). In each experiment, concrete cubes specimens size of 100×100×100 mm were casted into moulds and compacted under vibrating conditions at laboratory room temperature. More than 90 concrete specimens were developed and triplicate specimens were tested to check the reproducibility of results. After, 14 days, 28 and 180 days of curing, developed concrete specimens were tested to assess their suitability for construction applications.

TABLE 1: MIX PROPORTION OF CONCRETE WITH INCORPORATION OF GRP WASTE POWDER

Experimental trials	Fine Aggregate			NCA (kg/m^3)	Cement (kg/m^3)	w/c ratio
	NFA	GRP powder				
	(kg/m^3)	(kg/m^3)	(%)			
1	750	0	0	1250	430	0.50
2	712	38	5	1250	430	0.55
3	637	113	15	1250	430	0.57
4	525	225	30	1250	430	0.68
5	337	337	50	1250	430	0.71

4. Results and discussion

The compressive strength of precast concrete composites (cubes) developed using different proportionate of GRP waste powder under water curing and oven curing were tested at 14 days, 28 days and 180 days and the results are reported and discussed in the sections below. Figure 1 (a, b) shows the testing compressive strength of concrete specimen. The results of 14 days, 28 days and 180 days compressive strength of concrete is are shown in Table 2.

(a) (b)

Figure 1 (a, b). Testing compressive strength of concrete specimens: (a) specimens before testing; (b) after testing

TABLE 2: EFFECT OF GRP WASTE POWDER ON COMPRESSIVE STRENGTH OF CONCRETE (N/MM2) UNDER DIFFERENT CURRING CONDITIONS.

Exp. NO.	%GRP powder	Water cured specimen (N/mm^2) (Mean of triplicate specimens)			Oven Cured specimen ((N/mm^2) (Mean of triplicate specimens)		
		14 Days	28 Days	180 days	14 Days	28 Days	180 days
1	0%	43.61±0.37	47.67 ±0.69	46.23±0.57	32.31±0.6	34.37 ±0.56	39.20±0.67
2	5%	32.4±0.86	37.08 ±0.77	45.74±0.69	36.08±0.15	37.9 ±1.32	47.17±0.64
3	15%	27.95±0.25	34.09 ±0.90	44.38±0.42	29.21±0.48	35.11 ±0.37	46.24±0.57
4	30%	22.4±1.12	29.58 ±1.66	30.82±0.64	25.76±0.39	30.62 ±1.03	34.39±0.23
5	50%	14.13±0.59	19.05 ±0.88	21.31±0.03	17.02±0.1	21.61 ±0.72	24.24±0.38

4.1. *Effect of GRP Waste Powder on 14 Days Compressive Strength of Concrete Composites*

As shown in Table 2, the 14 days compressive strength of concrete made with 5% GRP waste powder under water curing was 32 N/mm^2 with standard deviation of 0.86, was 25% lower than that of the control specimens where no GRP waste was applied. However, 5% GRP waste substitution under oven curing resulted in a 13% decrease in compressive strength of concrete as compared to the control specimens. Nevertheless, overall the compressive strength was higher about 9% with oven curing as compared to the water curing. This was mainly due to the effect of temperature on the polymeric content present in the GRP waste powder. This is supported by an earlier study, where addition of polymeric materials with cement, during hydration, polymer film formation occur which resulted in co-matrix under which polymer was intermingled with cement hydrate under heating condition [2]. In this study, GRP waste powder was a combination of polymer and glass fibre, and due to the presence of polymeric compounds, the compressive strength of oven cured specimens might have showed higher strength over water cured specimens. The increase in compressive strength of concrete with GRP waste application under oven curing may be due to the hydration process in which polymeric compound in GRP waste and cement might have formed a polymeric film under oven curing at above 40º C.

4.2. *Effect of GRP Waste Powder on 28 Days Compressive Strength of Concrete Composites*

Results revealed that the 28 days mean compressive strength of concrete made with 5% GRP waste powder under water curing attained 37N/mm^2 with standard deviation of 0.77 (Table 2). The compressive strength of oven cured concrete was higher than the water cured concrete specimens. However, the compressive strength of control concrete showed the optimum strength i.e. 47N/mm^2. The expected compressive strength of structural concrete is 45N/mm^2. These results are in line with the work reported earlier where the influence of polymer latex on

the properties of cement concrete showed that there was a decrease in compressive strength of concrete about 32% with addition of 10-20% polymeric materials [13]. The present investigation showed that there was a decrease of compressive strength of concrete about 21% and 27 % with 5% and 15% GRP waste substitution respectively.

It was reported that the polymer concrete is stronger than cement based concrete. Therefore, polymer concrete is used in many applications like box culvert, hazardous waste disposal site liner, trench lines, floor drains, pavement and bridges [8]. The mechanical properties of polymer concrete made of unsaturated polyester resins from recycled polyethylene terephthalate (PET) plastic waste showed a proportional correlation between an increase in compressive strength and resin content. However, the strength remains unchanged beyond 17% resin content. Moreover, the polymer concrete with a resin content of 9% did not affect the durability characteristics, especially the acid treatment [8].

4.3. *Effect of GRP Waste Powder on 180 Days Compressive Strength of Concrete Composites*

Interestingly, it was recorded that with GRP waste application, there was an increase in compressive strength of concrete with longer curing periods. This was confirmed while comparing the compressive strength of concrete tested under different curing period from 14 days to 180 days (Table 2). The mean compressive strength of concrete developed using 5% GRP waste powder under 180 days water curing and oven curing was 45.74 ± 0.76 N/mm^2 and 47.17 ± 0.64 N/mm^2 respectively. Moreover, the compressive strength of concrete with 15% GRP waste powder attained 44.38 ± 0.42 N/mm^2 and 46.24 ± 0.57 N/mm^2 under water curing and oven curing respectively. Nevertheless, the compressive strength of control concrete at 180 days (without GRP waste powder) remained almost the same to that of 28 days compressive strength under water curing but decreased under oven curing.

An earlier work showed that application of 9% polyester resin (virgin materials) in recycling unsaturated polyester resins from recycled polyethylene terephthalate (PET) plastic waste and recycled concrete aggregates with normal fine and coarse aggregate up to 70% attained a compressive strength of 39 N/mm^2 [8]. It was expected that the glass fibre content in GRP waste may contribute to increase in the reinforcement of concrete. Conversely, the work done by other researcher showed that no significant results were recorded on the compressive strength of concrete developed with recycled glass and about 16% strength was reduced when 20% of Portland cement was substituted [14]. This was due to the inherent smooth surface, poor water absorption and contamination of raw materials which resulted in inconsistency of the concrete mix, lack of bonding between glass particle and cement matrix leading to low compressive strength.

5. Conclusion

The use of GRP waste in concrete contributes to cost savings associated with waste handling, transport, storage and landfill tax payment. GRP waste substitution to fine aggregates in concrete should save approximately 15% of fine aggregate cost (substitute to sand). Currently, almost all the GRP waste in United Kingdom is sent to landfill and the escalating costs associated with environmental legislation, namely, the Landfill Tax, will ultimately increase the incentive to recycle GRP waste. The key findings of the use of GRP waste in concrete composites testing programme are as follows:

- The mean compressive strength of concrete using 5%, 15%, 30% and 50% GRP waste powder attained 37N/mm2, 34N/mm2, 29.5N/mm2 and 19N/mm2 respectively. However, there was an increase in the compressive strength of concrete with GRP application and the optimum compressive strength (180 days) was 45.75N/mm2.
- Increased proportions of GRP waste in concrete decreased the density (12%) and minimum

density was 2140 kg/m3 with 50% GRP waste powder.

The findings of this preliminary study showed a viable technological option for the use of GRP waste in precast concrete products such as pre-cast paving slabs, roof tiles, pre-cast concrete wall elements, light weight concrete, concrete paving blocks and architectural cladding materials. However, full compliance tests such as durability and fire properties for specific applications in particular; and comparative Life Cycle Analysis between GRP waste-filled concrete and standard concrete in general are recommended. The findings of the present investigation has showed quite encouraging results and opened an avenue for recycling of GRP waste ground powder and fibre in concrete and cement composites.

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