Coventry University and
The University of Wisconsin Milwaukee Centre for By-products Utilization,
Second International Conference on Sustainable Construction Materials and Technologies
June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
Main Proceedings ed. J Zachar, P Claisse, T R Naik, E Ganjian. ISBN 978-1-4507-1490-7
http://www.claisse.info/Proceedings.htm

# Utilisation of Glass Reinforced Plastic Waste in Concrete and Cement Composites

**Osmani M.**[1] **and Pappu A.**[2]

[1]*Department of Civil and Building Engineering, Loughborough University, UK.; Email: <m.osmani@lboro.ac.uk>*
[2] *Advanced Materials &Processes Research Institute (AMPRI), Bhopal, India; Email: <pasok67@yahoo.com>*

## ABSTRACT

In the United Kingdom, most glass reinforced plastic (GRP) waste is currently sent to landfill due to its intrinsic thermoset composite nature, lack of information relating to its characteristics and insufficient knowledge of potential recycling options. Experimental attempts were made to recycle GRP waste in concrete composites and cement. As such, more than 190 concrete specimens were prepared in accordance with BS EN12390-2:2000 and BRE 1988 mix design for normal concrete and used GRP waste powder content varying from 5% to 50% as replacement for fine aggregates. Results showed that GRP waste can be used as a partial replacement for fine aggregate as well as an admixture in cement concrete. Additionally, the presence of polymer and short glass fibre content in GRP waste powder can significantly contribute to improve the quality of various concrete products and has ample scope for use in several applications in the construction sector.

## INTRODUCTION

Around 55,000 tonnes of GRP waste are currently produced each year in the United Kingdom and the quantity is expected to increase by 10 per cent annually [Khan 2007]. Landfill and incineration are the most commonly adopted methods for disposal of thermoset polymer composites including GRP composites waste [Broekel and Scharr 2005]. 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. The work reported so far is very limited and did not show viable applications for GRP waste recycling in concrete. Hence, in the present study, efforts were made to recycle ground GRP waste powder as an admixture and substitute to fine aggregate in concrete composites and GRP waste fibre as structural reinforcement materials in architectural cladding panels.

## CURRENT GLASS REINFORCED PLASTIC (GRP) RECYCLING TRENDS

It was reported that the use of GRP waste ground fibre, as replacement for fine aggregate in foamed concrete, increased strength with reduced weight [Gemert et al 2005]. Moreover, the study revealed that the 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 [Jo et al 2008]. Virgin glass fibre has been used in making thin sheets of flat, corrugated or complex shaped panels as precast concrete products for construction [Broekel and Scharr 2005], 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 [Khan 2007]. 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 [Jones et al 2005]. 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 [Bentur and Mindess 1990]. The work reported so far is very limited and did not show viable applications for GRP waste recycling in concrete.

## EXPERIMENTAL PROGRAMME

In order to assess the potential of GRP waste recycling in precast concrete, two sets of experimental programme were conducted. In the first experiment, attempts were made to recycle GRP waste powder in precast concrete composites (i.e. concrete paving blocks) and the second experiment was on recycling GRP waste fibre in developing cement composites (i.e. architectural cladding panels).

### Development of concrete composites

Detailed experiments were conducted on the use of GRP waste in concrete composites. Mix design was in accordance with Building Research Establishment (BRE) 1988 mix], and concrete specimens were prepared as per BS EN 12390-2:2000 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). The waste GRP powder consisted of primary size reduction of the GRP post consumer and manufacturing waste, which was fed into a grinding machine where it was reduced to a fine resin/glass powder.

Control concrete specimens were also cast to compare properties to the GRP waste admixed concrete. Normal Fine Aggregate (NFA) was used as per the BS 882. Normal Coarse Aggregate (NCA) was used as per the BS 882 where the aggregate size was 5- 20 mm.

**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 ($kg/m^3$) | GRP powder ($kg/m^3$) | GRP powder (%) | | | |
| 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 |

**Development of cement composites**

For the second set of experiments, attempts were made to explore the potential of using GRP waste fibre in cement composites (precast architectural cladding panels). Two different panel sizes: 300mm x 300mm x 8mm and 300mm x 300mm x 12mm were prepared. Panel preparation and testing were done in accordance with the British Standard on fibre-cement flat sheets product specification and test method [BS EN 12467]. Several methods are available for making fibre cement composite sheets [Bentur and Mindess 1990]. In this process, 5% GRP waste fibre (w/w of cement content) was premixed with mortar (1:1.6 cement to sand ratios) along with 2% superplasticiser (Polycarboxylate). The aggregates and cement were mixed thoroughly with GRP waste fibre using water and casted in wooden moulds without vibration. The water cement ratio was 0.33 and 0.3 with 5% GRP waste fibre and without GRP waste fibre respectively.

Casted panels were removed from the moulds and curing was done in water at 20º ±2ºC. After 28 days of curing, specimens were tested to assess their suitability for use as architectural cladding panels. Fig. 1 (a, b) shows the mix proportionate (GRP waste fibre, fine aggregate and cement) in making cement composites.

(a) (b)

**Fig. 1 (a,b). Mix proportionate (GRP waste fibre, fine aggregate and cement) in making cement composite: (a) before mixing, (b) mixing process**

To assess the physical and mechanical characteristics (bending strength), panels were cut into specimens dimension of 95mmx300mmx12mm and 95mmx300mmx8mm using diamond cutter and bending strength was tested using Universal testing machine, Instron, 5500R (100 KN load capacity) at the speed of 1 mm per min. The bending strength and density of the panel products were tested to comply with British Standard [BS EN 12467]. The calculation used in determining the bending strength as modulus of rupture (MOR) is as follows:

$$\text{Modulus of Rupture} = 3Fls/2\ be^2$$

F- breaking load (Newton)
ls- span between the axis of support (mm)
b - width of the test specimen (mm)
e - thickness of the test specimen (mm)

## RESULTS AND DISCUSSIONS

### Effect of GRP waste powder on compressive strength of concrete composites

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, shown in Table 2, are reported and discussed below.

### Effect of GRP waste powder on 14 days compressive strength of concrete composites

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 (Table 2). This is further 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 [Gemert et al 2005]. 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. Furthermore, Tabor (1987) reported that the presence of polymer particles in the dispersion is restricted to the capillary force at the interface of the aggregate and the bulk polymer-cement phase. In the bulk liquid phase, hydrates are produced which form a combined inorganic and organic products. The fraction of the polymer cement products is formed depend on the ratio of polymer and cement. The polymer products included in these hydration products do not contribute to the strength development. This has been further supported with the results of earlier researchers that no influence of polymer modification on the strength is noticed in standard cured and water cured specimens as long us no dry curing is applied [Dionys et al., 2005].

**Table 2. Effect of GRP waste powder on compressive strength of concrete (N/mm$^2$) under different curing 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 |

**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. 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, however, the flexural and tensile strength found to be increased [Lewis and Lewis 1990]. 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 [Jo et al 2008]. 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 [Jo et al 2003].

**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. 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) as remain 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$^2$ [Jo et al 2003]. 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 [Taha and Nounu 2008]. 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. Since, polymerisation temperature ranges from 40ºC to 110ºC [BS 12], in the present study cement metric and GRP waste powder blend together and were casted as solid monolithic structure and cured in 50ºC in which it was expected to form polymeric film contributing to increase in the compressive strength of concrete when compared to water cured samples. Hence, the present study explored possible recycling options to improve the quality of concrete with applications of GRP waste powder. It was anticipated that the presence of ground glass fibre in GRP waste may contribute to an increase of concrete reinforcement.

It was also reported that glass powder can be used as replacement for cement up to 10% to increase the compressive strength of concrete [Schwarz et al 2008]. The presence of polymer particles in the dispersion is restricted to the capillary force at the interface of the aggregate and the bulk polymer-cement phase and the polymer products included in these hydration products do not contribute to the strength development. This has been further supported with the results of earlier researchers that no influence of polymer modification on the strength was noticed in standard cured and water cured specimens as long as they are not dry cured [Gemert et al 2005]. This suggests that the polymeric powder in the GRP waste might have degraded from its virgin resin characteristics and hence, the presence of polymeric compound in GRP waste powder might have not contributed to enhance the compressive strength. However, the present investigation revealed that the compressive strength of concrete specimens developed using GRP waste powder found to be higher than that of the normal requirement for precast concrete walling element (>5 MPa), light weight concrete (>5 MPa), and concrete blocks (7 to 35 MPa) and confirmed the potential applications of GRP waste as an additive or filler in concrete.

**Effect of GRP waste powder on density of concrete composites**

The density of the concrete was studied under 28 days of curing in water and in oven. Results revealed from the present study that the mean density of concrete developed with 5% and 15% GRP waste powder under water curing was 2340 kg/m$^3$ and 2270 kg/m$^3$ respectively. However, the mean density of concrete made with 30% and 50% GRP waste was 2220 kg/m$^3$ and 2120 kg/m$^3$ respectively. Due to the synergetic behaviour between polymer and cementations matrices, the impact on performance of materials largely affects the weight ratio. This was significantly influenced the density of construction materials [Gemert et al 2005]. It is apparent from the results of this study that increased proportions of GRP waste in concrete decreased the density about 12% and the minimum density was 2120 kg/m$^3$ with 50% GRP waste powder. However, little variation was recorded with oven cured specimens as compared to water cured specimen. This is due to the fact that the density of the polymer is lower than the cement and aggregates used in GRP waste admixed concrete.

**Effect of GRP waste fibre on cement composites: precast architectural cladding panels**

There were two different experimental prototypes of cement composites developed using 5% GRP waste fibre (Fig. 2 a, b) and assessed their bending strength and density to confirm their suitability to use as architectural cladding panels.

**Effect of GRP waste fibre on bending strength of architectural cladding panels**

The effect of GRP waste fibre on the bending strength of cement composites is shown in Table 3, where R1, R2 and R3 are replicate test results. Results revealed that the mean bending strength in terms of modules of rupture (MOR) of 12 mm thick panels developed using 5% GRP waste fibre attained 16.55N/mm$^2$ with standard deviation of 1.12.

**(a)** **(b)**

**Fig. 2 (a,b). Architectural cladding panels developed using GRP waste fibre: (a) 12 mm thick and (b) 8 mm thick panels**

The bending strength of 12 mm thick panel with 5% GRP waste fibre was 46% higher than that of 8 mm thick panels. Application of GRP waste fibre increased the bending strength of architectural cladding panel about 36% over control specimens. Moreover, with application of 5% GRP waste fibre, the bending strength of 8mm thick panel increased about 25% as compared to without GRP waste fibre. Since, the quantity of cement used in this study was lower than that of the normally used cement to sand ratio (i.e. 1:0.5 to 1:1), the bending strength was found to be lower than the conventional and commercially available products which is in concurrence with the work of Bentur and Mindess, (1990). Moreover, the GRP waste fibre characterisation results from this study revealed that GRP waste fibre sample had a wide particle size ranging from 500 micro meter to 2 millimetre. Consistent quality of GRP waste fibre was expected to improve the bending strength of cement composites.

**Table 3 Effect of GRP waste fibre (5%) on the bending strength of cement composites**

| **Panel specimens** | | **Bending strength of architectural cladding panel ($N/mm^2$)** | |
|---|---|---|---|
| | | **GRP waste fibre (5%)** | **without GRP waste fibre** |
| **Panel dimension : 300 mm x 300 mm 12 mm thickness** | | | |
| | R1 | 17.42 | 11.99 |
| | R2 | 15.28 | 9.65 |
| | R3 | 16.95 | 9.86 |
| Mean | | 16.55 | 10.50 |
| Standard deviation | | 1.12 | 1.30 |
| **Panel dimension :300 mm x 300 mm 8 mm thickness** | | | |
| | R1 | 8.12 | 6.30 |
| | R2 | 9.43 | 6.73 |
| | R3 | 9.08 | 6.99 |
| Mean | | 8.88 | 6.67 |
| Standard deviation | | 0.68 | 0.35 |

One of the commercial grade panel products developed by Marley Eternit using vacuum spray manufacturers' process showed that the bending strength of cladding panels developed using virgin class fibre varies from $17N/mm^2$ to $24N/mm^2$ [Marley Eternit 2009]. However, it was reported that the use of about 5% virgin class fibre with 1:1 cement to sand ratio by hand moulded premix process resulted $9.8N/mm^2$ [Bentur and Mindess 1990]. Without the addition of a superplasticiser with sand to cement ratio 1:1.6, panel products could not be casted due to poor workability. The results of this research revealed that the use of GRP waste fibre with superplasticiser improved the quality of cement composites as compared to the control specimen (without GRP waste).

The incorporation of glass fibre in cement composites contributed to the reinforcement between the matrices and increased the strength and toughness; and detained crack propagation of the composites. It was reported that the high surface area and low thickness of glass reinforced composite panels can lead to an increase in drying shrinkage resulting in distortion, wrapping and poor strength [Dolan and Nanni 1994]. The chemical reaction of cement on fibre reinforced plastic is not well established and long-term durability is needed to be defined. However, the studies on chemical interactions between glass fibre and cement showed that the glass fibre produced from oxides of sodium oxide, silica and zirconium composition in the powder form are inherently alkali resistant and suitable for reinforcement with cement composites [Larner et al 1976]. These types of glass fibres are currently being used commercially and expected not to produce any adverse impact on the long terms durability. The thin cement composite sheet using 5% virgin glass fibre impregnated in epoxy and dispersed in concrete mix has been used mostly in Europe [Bentur and Mindess 1990]. In making cement composites sheets, the glass fibre in the form of continuous fibre, or chopped fibre or as a mat can be used. The present study revealed that the application of GRP waste fibre has improved the bending strength and reduced the crack propagation of the cement composites. It was interesting to note that the control specimens (without GRP waste fibre) showed multiple cracks and low bending strength.

**Effect of GRP waste fibre on density of architectural cladding panels**

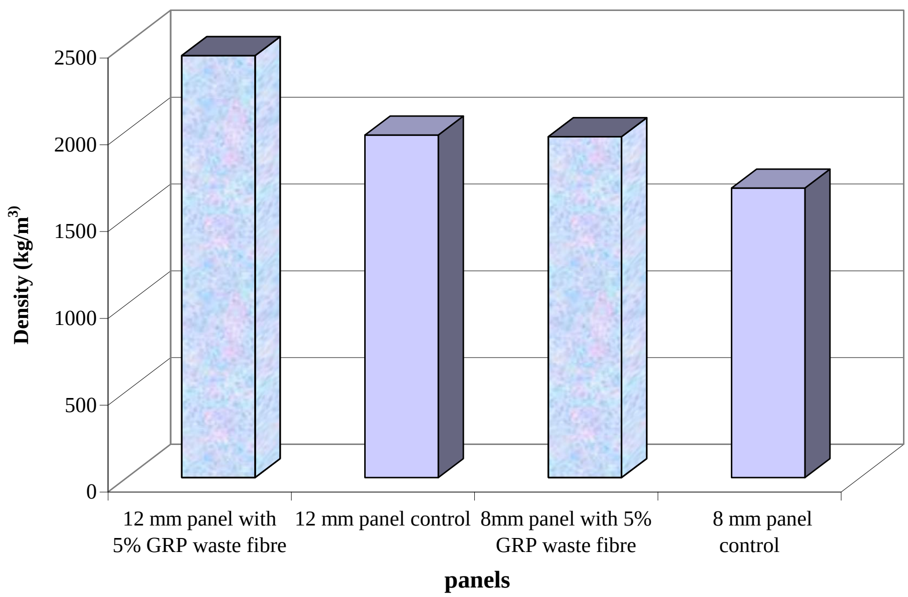


**Fig. 3. Effect of GRP waste fibre on the density of architectural cladding panels**

The mean density of 12mm thick cement composites developed using 5% GRP waste fibre was 18% higher than that of control specimens (Fig. 3). Similarly, the mean density of 8mm thick panels developed with 5% GRP waste fibre was 15% higher as compared to control samples. Since, the density of glass fibre varied from 2540 $kg/m^3$ to 2780 $kg/m^3$, addition of 5% GRP waste fibre in cement composites might have contributed to increase the density of panels. Moreover, application of superplasticiser reduced the water content and contributed towards more compaction and increased the quantity of cement composites leading to higher density. The mean density of 8 mm panels developed without GRP waste fibre was 1668 $kg/m^3$.

## CONCLUSIONS

The key findings of the use of GRP waste in concrete and cement composites testing programme are as follows.

- The mean compressive strength of concrete using 5% and 15% GRP waste powder without additives under water curing attained $37N/mm^2$ and $34N/mm^2$ respectively.
- Application of 30% and 50% GRP waste powder in concrete attained $29.5N/mm^2$ and $19N/mm^2$ compressive strength respectively.

- Increased proportions of GRP waste in concrete decreased the density (12%) and minimum density was 2140 kg/$m^3$ with 50% GRP waste powder.
- There was an increase in the compressive strength of concrete with GRP application and the optimum compressive strength (180 days) was 45.75N/$mm^2$.
- The bending strength in terms of modules of rupture (MOR) of 8 mm and 12 mm thick architectural panels exhibits 8.8 N/$mm^2$ and 16.5 N/$mm^2$ respectively.
- CaO, $Al_2O_3$ and $SiO_2$ and other polymeric compounds in GRP waste have the potential to act as additives to improve the binding and adhesion of concrete. The glass fibre content improved the reinforcement in the cement composites.

Although the 28 days compressive strength was not higher than the standard structural concrete values, i.e. 45 N/$mm^2$, the findings of this preliminary study showed a viable technological option for 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. The properties of panel products depend on the consistency and quality of GRP waste fibre, and access to specialised architectural cladding manufacturing facilities. Furthermore, full compliance tests such as durability and fire properties for specific applications 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.

**ACKNOWLDGEMENTS**

The authors are thankful to the Technology Strategy Board (UK) for the opportunity to conduct this research; all the BEAWARE project partners and their members for their support and cooperation; and Hambleside Danelaw Rooflights and Cladding Limited, Scotland for supplying GRP waste powder and fibre. Also thanks are extended to the technicians and supporting staffs of the Institute of Polymer Technology and Materials Engineering and Department of Civil and Building Engineering at Loughborough University for the technical support.

## REFERENCES

Bentur A and Mindess S. (1990) Fibre Reinforced Cementitious Composites. Elsevier Science Publishers Ltd, England; ISBN 1-85166-393-2.

Broekel J and Scharr G. (2005) The specialities of fibre-reinforced plastics in terms of product lifecycle management. *Journal of Materials Processing Technology*, 162–163, 725–729.

BS 12: Specification for Portland cement (1996) British Standards Institution.

BS EN 12467: Fibre-cement flat sheets - Product specification and test methods (2004) British Standards Institution, Amendments Nos.1 and 2.

Dolan C.W and Nanni A. (1994) Status of Fibre-Reinforced Plastic Reinforcement Development and Cement Based Research Needs. *Advn Cem Bas Mat*,1, 185-191.

Gemert DV., Czarnecki L, Maultzsch M, Schorn H, Beeldens A, Łukowski P, Knapen E. (2005) Cement concrete and concrete–polymer composites: Two merging worlds. A report from 11th ICPIC Congress in Berlin. *Cement & Concrete Composites*, 27, 926–933.

Jo BW, Park SK, Park JC. (2008) Mechanical properties of polymer concrete made with recycled PET and recycled concrete aggregates. *Construction and Building Materials*, 22(12), 2281-2291.

Jones, M., Mccarthy, A. and Dhir, R. (2005) Recycled and secondary aggregates in foamed concrete, DTI/WRAP Aggregates Research Programme STBF13/13C, ISBN: 1-84405-184-6.

Khan R. (2007) Industry survey on production availability and cost of GRP waste in the UK. Hambleside Danelaw Rooflights and Cladding Limited, Inverness, Scotland.

Lewis WJ, Lewis G. (1990) The influence of polymer latex modifiers on the properties of concrete. *Composites*, 21(6), 487-494.

Marley Eternit (2009) home page. Assessed on 13th September 2009. http://www.marleyeternit.co.uk/Products/Default.aspx

Larner LJ, Speakman K, (1976) Majumdar AJ. Chemical interaction s between glass fibre and cement. *Journal of Non Crystalline Solids*, 20, 43-74.

Schwarz N, Cam H, Neithalath N.( 2008) Influence of a fine glass powder on the durability characteristics of concrete and its comparison to fly ash. *Cement & Concrete Composites*, 30, 486–496.

Tabor LJ.( 2005:) Dispersed polymers, revision of concrete society technical report no. 9-polymer concrete. Contribution to the fifth international congress on polymers in concrete. Brighton. 212-115.

Taha B and Nounu G. (2008) Properties of concrete contains mixed colour waste recycled glass as sand and cement replacement. Construction and Building Materials; 22 :713–720.