

A Critical Review of Research on Reuse of Mechanically Recycled FRP Production and End-of-Life Waste for Construction

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ABSTRACT: The objective of this paper is to develop and recycle FRP(fiber reinforced polymer production) at the end of life waste for construction .From the past years, fiber reinforced polymer (FRP) composite materials has been used in the leading engineering industries. Management of thisFRP (fiber reinforced polymer)waste is becoming an major problem because of growth in the production of the FRP materials. In this articlethe FRP waste managingmethods of fiber reinforced polymer(FRP) arediscussed and reviewed. The major use of FRP waste is the replacementof aggregates in cementitious materials. A number of recentinvestigations conducted on the usage of the fiber reinforced polymer (FRP) waste in concrete are reviewed. The results from these recent investigations tell thatthese FRP aggregates lower the strength of cementitious materials with slight effect on durability. In the future research on FRP is to provide the stronger concretes in fiber reinforced polymer (FRP) production and end of its life waste.

KEYWORDS: aggregate (cementitious materials); concrete (bonding); fiber reinforced polymer (FRP); filler; mechanical properties (strength, flexibility); recycling.

I.INTRODUCTION

Fiber-reinforced polymer (FRP) composite materials are used extensively and increasingly in major industries including aerospace, marine, construction, electrical, automobiles, domestic, furniture, and sports equipment. FRP composite materials used in these industries typically consist of glass, carbon, or aramid fibers, which are either continuous or discrete, in the thermosetting resins matrixes that have fibre in the range of 12%to60% in volume [1], and inorganic fillers typically, are in the range between 0 to 20% by volume as bulk moulding compounds (BMC) contains fillers like:calcium carbonate, talcum.Which is of 50% of the composite weight (which for BMC materials is close to the volume fraction) [2]. FRP (fiber reinforced polymer) composite materials have important advantages over many traditional construction engineering materials (such as steel and concrete, and timber. These advantages decreasedensities; higher mechanical properties are ease of production in different shapes, ease of installation, and greater durability in harshchemical and aqua environments. Disadvantages to conventional construction materials typically include higher costs, lower temperature resistance and fire performance, lack of standard profiles and partsare veryhard to recycle. According to the American Composite Manufacturers Association (ACMA), the first invented FRP (fiber reinforced polymer) products was produced less than century ago in1930s in an experiment production of a boat hull using fibreglass andpolyester resin [3]. Use of FRP (fiber reinforced polymer) for structural engineering in construction become popular in 1990s [4]. The use of FRP in the marine engineering started about years ago and has increased number of reinforced plastic and working boats, ships, fishing boats, the vast majority being fibreglass (glass

fiber reinforced polyester). The International Council of Marine Industry has graphed that there are more than 5.92 million boats are in Europe [5]. However, the FRP-incorporated vessels and structural members resulting in a growing rate of waste accumulation. Another source of FRP waste is the scrap from the production process of FRP materials, parts and sections; in all production processes portions of the raw material and the final product are rendered unusable.

The composite materials were manufactured in European Composites Industry Association (EuCIA)[8]. In 2010, Osmani and Asokan [9] reported that in the UK (United Kingdom) the total production of GFRP (glass fiber reinforced polyester) waste was more than 50,000 tonnes. The annual production increases of 10%. Almost of the entire disposal waste was land filled. According to Asokan in the United Kingdom (UK), about 89% of the GFRP (glass fiber reinforced polyester) waste is land filled [9].

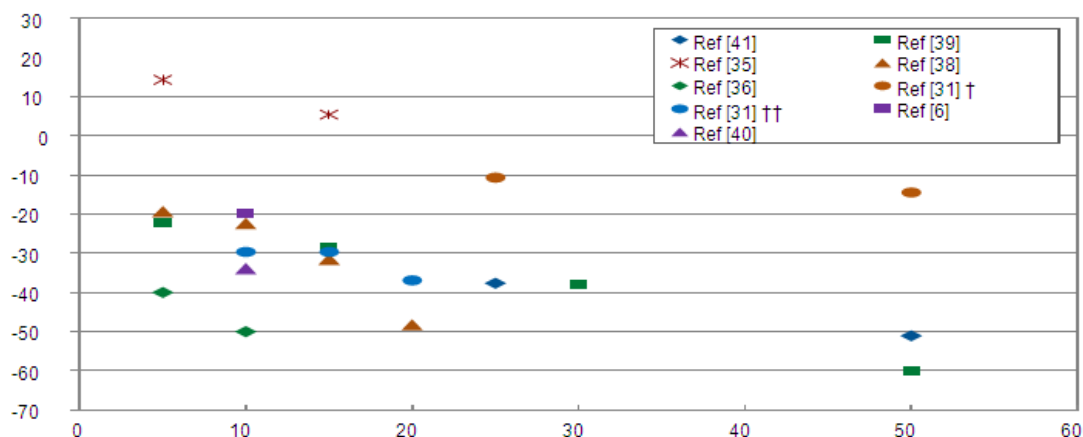
1. Fiber-Reinforced Polymer (FRP) Waste Managing Method for reuse:

FRP waste can sometimes be directly used in construction. There are three ways for the reuse of FRP: (1) land filling, (2) incineration, and (3) recycling. Land filling remains the popular solution to reuse FRP waste [10]. In highly efficient processes such as pultrusion, waste (scrap) is in the range of 3%–5%, while in less efficient hand lay-up processes, it typically approaches 15% [11, 12]. In aerospace parts production, CRFP pre-preg scrap can approach 40% [12]. A mean value of 10% is reported in [11]. Land filling costs are to increase sufficiently to waste disposal in the future [13]. The high costs of land filling FRP waste increases the overall cost of FRP products. Land filling in U.S. was in the range of \$40–\$200 per tonne. In addition, land filling is the least sustainable option. In several European countries, including Germany, land filling regulations for FRP waste is mostly implied.

II. MECHANICAL PROPERTIES

The main issue caused by using and recycling FRP appears to be a very good in impact resistance and also with the mechanical performance. Figure 1 presents results from the key major investigations that have studied the effect of replacing aggregates (fillers) with mechanically recycled FRP on the compressive strength. Which has been replaced with recycled FRP waste? It is important to point out that in every one of these major investigations some of the materials, characteristics, specifications, and ratios (weight or volume) used were different so that the data plotted in Figure 1 is intended to show trends in the behaviour.

Figure 1. The effect of replacing aggregates in cementitious materials with fiber reinforced polymer (FRP) waste on the compressive strength of concrete as reported by different investigators. (†: glass fiber reinforced polymer (GFRP) waste used in self-compacting concrete; ††: GFRP waste used in mortar) [6, 31, 35, 36, 38–41].



Portion of aggregates replaced by FRP waste, %:

Replacement of Fine Aggregates:

Asokan *et al.* [39] used GFRP waste powder. Fifty percent of the GFRP waste powder particles were below 18 μm and almost 90% of the GFRP waste powder particles were below 63 μm . They produced replacements of 5%, 15%, 30%, and 50%. Such a reduction in w/c ratio causes an approximately 40% decrease in compressive strength [42]. Asokan *et al.* [35] performed another study in which super plasticizer (2.0% by the weight of cement) was used in concrete batches with 5% and 15% replacement of fine aggregates with ground GFRP..

Tittarelli *et al.* [36] used a GFRP waste powder bought from a ship terminal as an industrial product and to replace the natural silica sand in the mortars and in concretes. The GFRP powder composition was about 20% by volume of glass fibers and 80% by volume of polyester resin. SEM observation caused significant reductions of approximately 40% and 50% in compressive strength, respectively (based on the graphs presented in their article). The reductions in flexural strength were approximately 17% and 20%. In another study, Tittarelli and Shah [6] observed that replacing 10% of natural silica sand with the GFRP powder in mortars with a w/c ratio of 0.50 resulted in a decrease of 50% in compressive strength when wet curing was adopted. They observed that when the concrete specimens were dry-cured (as in the open air or in the oven), the mechanical penalization due to GFRP dust addition was partially recovered. A similar observation was made by Asokan *et al.* [39]. Tittarelli and Moriconi [31] used the GFRP powder as partial replacement calcareous sand in mortars of higher w/c ratio (0.62). Their results show that replacing 20% of sand with the GFRP powder resulted in an approximately 35% decrease in the compressive strength (based on the graphs presented in their article). They also used the GFRP powder to replace 25% and 50% of sand in self-compacting concrete with a w/c ratio of 0.62 and observed relatively low values (10% and 15%, respectively) of decrease in compressive strength.

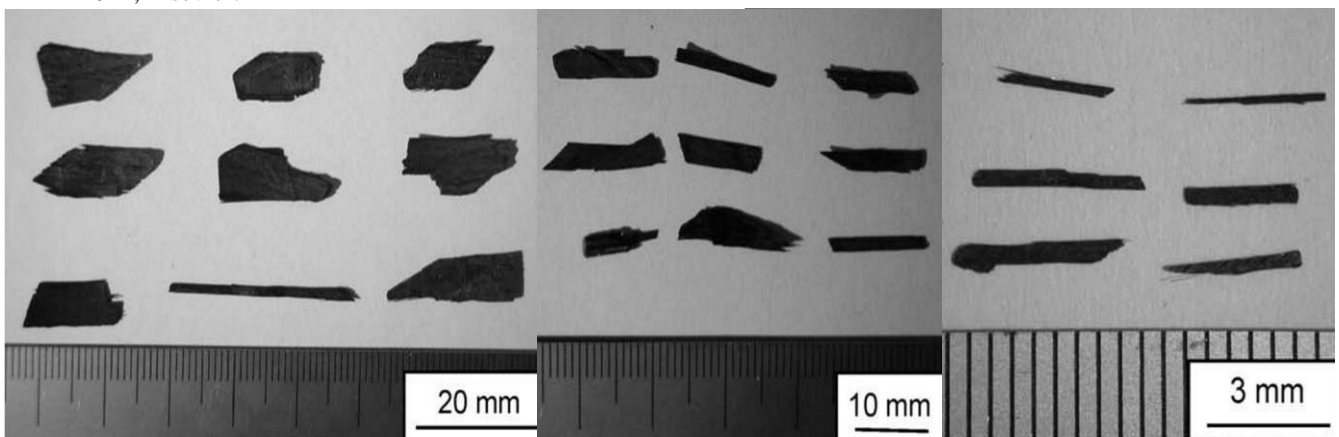
Correia *et al.* [38] used the grinded particles generated during the manufacturing of GFRP products by the cutting of individual profiles. Ninety-six percent of the GFRP particles were smaller than 63 μm . These particles were used as the partial replacement of fine aggregates in concrete. These reductions are in part due to the higher w/c ratio in the GFRP mix.

Replacement of Coarse Aggregates:

Alam *et al.* [42] used GFRP waste that was from the composite manufacturing process for casting the waterslides. The GFRP was covered with a thin layer of solid and liquid to make it smooth. The long strips of the scrap were recycled by simply cutting them into small squares using an abrasive wet tile saw. The recycled GFRP was used to replace portions of (25% and 50% by volume) coarse aggregate in concrete with a water to cement ratio (w/c) of 0.4. The GFRP particles and coarse aggregate had similar maximum particle sizes. However, the GFRP particles had similar sizes while the coarse aggregates were well-graded. Replacement of aggregates with non use GFRP resulted in up to 50% and 40% lower in the compressive strength and flexible strength of concrete, respectively.

They crushed CFRP to relatively flat pieces of three different size categories with average length by width values of 3.4 mm \times 0.4 mm, 9.9 mm \times 2.2 mm, and 21 mm \times 7.7 mm. The thickness of CFRP pieces was in the range of 0.05–0.2 mm. They produced concrete batches with CFRP to coarse aggregate weight ratios ranging from 0% to 22% (volume ratios are not reported). However it was observed that small CFRP particles tended to increase the strength of concrete while the larger CFRP particles tended to slightly reduce the strength of concrete. One the initiation and opening of cracks, and thereby enhance bonding of concrete.

Figure 2: Recycled CFRF used in concrete by Ogi *et al.* [43]. Reprinted with permission from [43], copyright 2014, Elsevier.

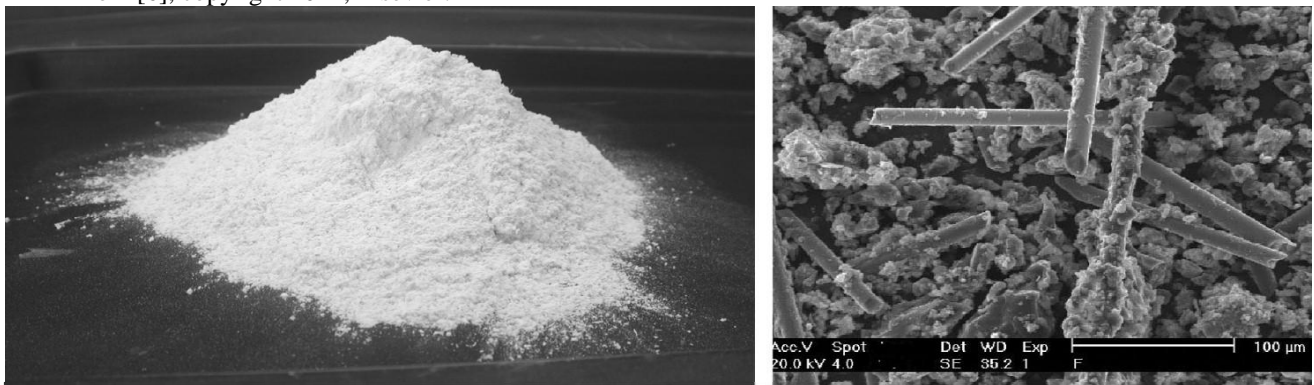


For example, it has been reviewed that substitution of up to 89% of the calcium carbonate filler in sheet moulding compounds by finesmall particulate recycled FRP.

Three filler characteristics affect the mechanical performance of a composite material: (1) strength of the filler, (2) Young's modulus, or in general the stiffness, of the filler, and (3) the filler-matrix interface bond strength. Natural aggregates are the strongest component of normal-strength concrete. Alexander [51] has presented a comprehensive list of the mechanical properties of different types rocks used as aggregates on concrete. The compressive strength of most rocks above 100 MPa, while that of hydrated cement is below 100 MPa; according to Cong *et al.* [52] the compressive strength of cement paste with *w/c* ratios in the range of 0.39 down to 0.30 is from 70 MPa to 100 MPa. The failure of concrete carrying increasing compressive stress occurs due to the formation and propagation of crack in weakest zones, namely (1) the interfacial transition zone (ITZ), which is the most porous portion of cementitious matrix (hydrated cement) around aggregates, and (2) the cementitious matrix itself.

The strength of FRP materials vary widely depending on the type of the composite. The Vacuum Assisted Resin Transfer Molding (VARTM) method can be higher than 500 MPa when reinforced with glass fibers or 1000 MPa when reinforced with carbon fibers [1]. In addition, FRP composite materials are of good strength anisotropic and have different strength values in directions. For example, the longitudinal compressive strength of the commonly used glass-reinforced pultrudedvinylester is in the range of 207–359 MPa while their transverse strength is within 110–138 MPa [53, 54]. However, the longitudinal compressive and Young's modulus of the same FRP is approximately the same as that of hydrated cement paste FRP materials are not the main or only the cause of the reported significant drop in the strength of FRP-waste-incorporated concrete.

Figure 3. GFRP powder used by Tittarelli and Shah [6] and relative SEM image. Reprinted with permission from [6], copyright 2014, Elsevier.



To the knowledge of the authors, two studies have been performed on replacing coarse aggregates with similar-size or large pieces of FRP (reported in Section 3). In the investigations of Alam *et al.* [42], the excess from the casting of waterslides were used, which were coated with a layer of polymer (“gel-coat”) to make them smooth. Figure 4 shows that this smooth surface resulted in a poor bond between the pieces of FRP and concrete matrix, and was the main cause of the poor mechanical performance of the FRP-incorporated concrete. Since all FRP closed mould processes use a release agent to prevent the polymer sticking to the mould on curing, it is likely that this will be a similar issue with recycled FRP from these processes. The major investigation pieces of FRP in concrete were conducted by Ogi *et al.* [43]. The crushed rough surfaces of CFRP (Figure 2). As can be seen in Figure 2, (1) the FRP particles have rough surfaces, and (2) each particle can be regarded as a composite material. As they told earlier, Ogi *et al.* did not observe any type of reduction on the compressive strength of concrete due to the replacement of coarse aggregate with the non used CFRP. To further assess this hypothesis, similar investigations must be performed on FRP waste with different sizes, different fiber types, and different fiber contents.

Figure 4. Fractured surface in concrete including pieces of FRP waste used by Alam *et al.* [42] as a partial replacement of the aggregates.



Figure 5. Waste glass rovings and mats in production of GFRP parts , from two FRP manufacturers: (a) Strongwell, and (b,c) Creative Pultrusions.



(a)



(b)



(c)

Using ground glass in concrete is a way for waste management polymers. As told earlier, Tittarelli and Moriconi [31] investigated the alkali–silica reactivity of finely ground GFRP and did not find any potential deleterious reactivity due to the glassy part present in the waste. Rajabipour *et al.* [64] used scanning electron microscopy (SEM) with X-ray energy dispersive spectroscopy (EDS) capability, as well as the ASTM C1260 [65]. The ASR is minimal and insignificant. Based on this invention the use of ground waste and glass rovings and mats will not cause ASR in cementitious materials. Properties and performance of the materials incorporating waste.

This issue can be resolved or mitigated in three ways: (1) using waste with known properties before combining it with the waste from other sources; and (2) developing criteria and procedures for characterizing the properties of the recycled waste materials

III.CONCLUSION

The critical research and review and discussion presented in this article leads to a number of important conclusions:

- Land filling FRP will become more restricted, as it already is in certain countries, including Germany.
- The most of the researches in FRP application of mechanically recycled waste is to be used as a partial replacement as fillers as composite materials. This reduces the mechanical properties according of the new composite material.
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