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GLASS FIBRE AND RECYCLED MIXED PLASTIC WASTES: RECENT DEVELOPMENTS AND APPLICATIONS

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ABSTRACT

In recent years, there has been an increasing interest in seeking for potential civil engineering applications of recycled mixed plastic wastes to relieve the pressure on landfills. This paper presents the recent developments on new generation of composites made from mixed recycled plastics and glass fibre. Glass fibres are one of the most cost-effective reinforcements which can be compounded with recycled thermoplastics to obtain products with improved mechanical property. Some of the first uses for such composites are for the replacement for traditional wooden items like park benches and picnic tables. While these composites are appropriate for such small-scale products, using them in structural applications would consume much greater volume of waste plastics. With its inherent resistance to rot and insect attack, these composites can in fact be used as a replacement for chemically treated timber in various large scale outdoor applications such as railroad crossties and bridges. However, the behaviour of such composites under different environmental conditions such as elevated temperature and ultraviolet rays are crucial. This paper provides an overview of the on-going efforts to address the critical issues for the effective usage of recycled mixed plastics composites in civil engineering and construction.

KEYWORDS

Recycled mixed plastic composites, glass-fibre, developments, applications.

INTRODUCTION

Ever since the first industrial scale production of synthetic polymers (plastics) took place in the 1940s, the production, consumption and waste generation rate of plastic solid waste (PSW) has increased considerably (Al-Salem et al. 2009). More and more plastics have been used in packaging, automotive and industrial applications, medical delivery systems, healthcare applications, water desalination, land/soil conservation, flood prevention, housing, communication materials, security systems and other uses. With such large and varying applications, plastics contribute to an ever increasing volume in the solid waste stream. In Australia, the plastic solid waste comprises 16% by weight of the municipal solid waste and only about one-fourth of these plastic wastes are recycled (DSEWPC 2012). Relevant statistics also showed that the disposal of plastic would soon become a major problem. Thus, PSW recycling has been a focus of many researchers in the past few decades. Such research is also driven by changes in social and environmental issues. One of the efforts to meet this challenge is by converting these plastic wastes into building products for housing and construction.

In Australia, the largest component of the plastic waste is high density polyethylene (HDPE) at about 22.5%, followed by 16% of polypropylene (PP), 15.6% of low density polyethylene/linear low density polyethylene (LDPE), 14.4% of polyvinyl chloride (PVC), 8.6% of polyethylene terephthalate (PET) and 22.9% of other types (PACIA 2011). Mølgaard (1995) found that PSW should be separated to produce a recycled plastic with properties comparable to virgin plastic. However, mixed plastic wastes are reprocessed directly to avoid the costly separation step. As the majority of plastic found in mixed plastic waste are immiscible, when melt blended, such plastic form complex dispersed morphologies and often have inferior mechanical properties and poor surface properties (La Mantia 2003). Thus, products made up of mixed plastic waste are used for less-demanding, non-load bearing applications, such as out-door furniture, decking or traffic barriers. To expand the available markets for building products manufactured from recycled plastic, the strength and stiffness of these new generation composites must be enhanced.

EFFECT OF GLASS FIBRES AND COMPATIBILISERS ON PROPERTIES OF RECYCLED MIXED PLASTICS

Glass fibres are one of the most cost-effective reinforcements for plastic. They can be easily obtained from a range of manufacturers and their production process is quite energy efficient, so that their use into recycled products does not significantly affect the environmental performance. As discussed on the recent review by Scelsi et al. (2011), the main interest in using glass fibres in polymer products is their better and more consistent performance compared to other fillers and reinforcements. Generally, the addition of glass fibre from 10-40% by weight result in substantial increase in elastic modulus, accompanied by an increase in strength with reduced ductility. A comparison of the effect of the amount of glass fibre reinforcement based on the results of studies conducted by several researchers is shown in Figure 1. It shows that the tensile strength and tensile modulus can be increased by up to 2.5 times and 3.5 times respectively with the addition of 30% glass fibre. This is due to the high aspect ratio of the fibres (whose diameter is in the range of 10-20 μm and final length in the range of 0.5 mm), which translates into an excellent reinforcing ability. The increase in material integrity and performance when adding glass fibre to recycled mixed plastic has been interpreted by Shenian (1992) in terms of physical compatibilisation, i.e. binding of dissimilar resin domains through the fibres.

Glass is an inorganic material whereas the polymer is organic. These two materials are naturally incompatible and do not form hydrolytically stable bonds. Compatibilising agents are most often used to improve the interfacial adhesion between blended polymers. By adding compatibilisers with reactive functional groups, it is expected that improved adhesion at the polymer/filler interface will result in more efficient stress transfer and better dispersion (Kulkarni and Mahanwar 2013). Several studies have been done regarding the effect of compatibilisers on the mechanical properties of polymers. Biswal et al. (2012) observed that the presence of 5% maleic anhydride polypropylene copolymer in banana fibre reinforced polypropylene composites results in an increase of tensile and flexural strength by 41% and 45%, respectively. Similarly, Fu et al. (2010) studied the mechanical properties of short glass fibre-reinforced polypropylene with the addition of three different compatibiliser namely octane–ethylene copolymer, maleic anhydride grafted octane–ethylene copolymer and maleic anhydride grafted polypropylene (PP-g-MAH). Their results show that the PP-g-MAH outperforms other compatibilisers increasing the tensile strength from 30 MPa to 65 MPa with the addition of 2wt% of PP-g-MAH.

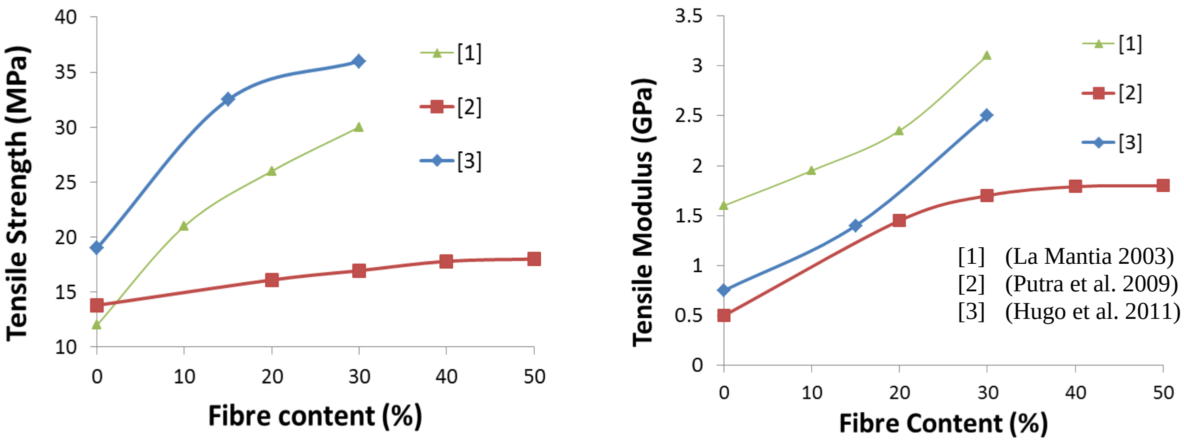

Figure 1. Glass fibre and recycled mixed plastic composites

APPLICATIONS OF RECYCLED PLASTIC COMPOSITE MATERIALS

New materials and combinations of recycled materials are constantly being proposed and used in construction industry. Conversion into plastic lumber is considered as a possible processing alternative to landfilling for mixed plastics waste. Some of the first uses for plastic lumber were items like fencing and park benches as shown in Figure 2, which are subject to degradation by constant environmental exposure. While the use of plastic lumber to make such small-scale products is completely appropriate, using recycled mixed plastics in load-bearing and structural applications would consume much greater volumes of plastics waste. With its inherent resistance to rot and insect attack, plastic lumber has in fact been used as a replacement for chemically treated timbers in various larger-scale outdoor applications.

Recycled mixed plastics have already been used on several civil engineering materials. Saadeghvaziri et al. (2000) presented the design and construction of an innovative dual-purpose screen using recycled plastics that can block headlight glare while having adequate height to deter pedestrian crossover. They found that the strength and stiffness of the recycled plastic materials satisfy the structural and geometric requirements for the intended application. Sivakumar Babu and Chouksey (2011) developed an analytical model for stress-strain response of plastic waste mixed soil. These studies have focused on using only a single type of thermoplastics in the development of structural products.

(a) Fencing in South Australia (b) Seating at Xavier College, South Australia

Figure 2. Non-Structural recycled mixed plastic products (Replas 2012)

One of the major applications of recycled mixed plastic composites in the USA has been in the infrastructure sector such as marine use, bridges and railroad crossties. As these composites do not contain toxic preservatives such as chromated copper arsenate that may leak into seawater and cause environmental problems, it can replace the preservative-treated lumber for marine use. Indeed, this has great potential because high quality wood is becoming less available. In 1998, the first vehicular bridge made up of polystyrene/ high density polyethylene having rectangular cross-section was constructed at Fort Leonard Wood, Missouri as shown in Figure 3(a). The bridge was made by nearly 100% recycled post-consumer and industrial plastics and was developed by the researchers at Rutgers University, New Jersey and manufactured by Axion International, Inc. Although it has high initial cost but there was no maintenance which makes it cost effective than traditional construction materials. In 2002, similar to Fort Leonard Wood, a bridge with I-beam cross sections was constructed at Wharton State Forest, New Jersey. In 2009, the first bridge in the world made of recycled plastics reinforced with glass fibre was built at Fort Bragg, North Carolina. All bridge components including girders, pier caps, decking, railings and pilings were made from recycled plastics (Kim and Chandra 2011).

(a) Fort Leonard Wood

(b) Installation of recycled plastic composite ties

Figure 3. Structural application of recycled mixed plastic
(Nosker et al. 2012)

Nosker et al. (1998) have discussed about the performance-based approach to the development of a recycled plastic/composite crosstie. It was found that the physical properties of the composite railroad tie exceeded the established targets. This resulted in the installation of first ten plastic ties at Rose Yard in Altoona in October 1995. The ties were non-consecutive and were intermingled with twenty wood crossties. In April 1996, two consecutive ties were placed in a 5-degree curve in the FAST track at the American Association of Railroads (AAR) Transportation Technology Center in Pueblo, Co as shown in Figure 3(b). Another six ties were installed in the mainline service on Conrail's Pittsburgh Line. The authors further mentioned that there was no evidence of tie plate cutting, spike loosening, or any other sign of degradation in these ties for two years suggesting the suitability of recycled plastic materials in this application.

CRITICAL ISSUES AND SUGGESTED SOLUTIONS

Ultra Violet Degradation

Polyolefin should be impervious to ultra violet (UV) degradation and should not absorb the UV radiation present in sunlight like pure aliphatic hydrocarbons. It is generally assumed that impurities or chromophores, which absorb UV light, initiate the photo-oxidation of commercial polyolefin (Rabek 1995). This situation has been validated by many researchers. The study conducted by Shokrieh and Bayat (2007) on glass/polyester composites showed a decrease of up to 15% in average failure strain, a decrease of up to 30% in ultimate strength, and 18% decrease in tensile modulus after 100 hours of exposure. The reduction on mechanical strength and stiffness is due to chain scission and reduced fibre-matrix interfacial bonding (Beg and Pickering 2008). Similarly, Goel et al. (2008) studied the effect of UV exposure on the mechanical properties of long fibre thermoplastic composites.They mentioned that in the case of glass fibre reinforced polymer, more chromophores are added in the form of functional groups present in the sizing applied to the glass fibre for better bonding with the polymers. These chromophores accelerate the photo-oxidation of polymer and hence more damage is seen in the surface layer of the composites in terms of greater change in crystallinity and modulus. Thus, this is an important property that needs to be determined for glass fibre reinforced recycled mixed plastic composites in order for its increase acceptance and wide utilization in civil engineering applications.

Elevated Temperature

A critical technical barrier for widespread use of FRP in structural engineering application is the influence of temperature on the material (Hollaway 2010). The influence of temperature on polymers can be separated into two effects, namely short term and long term. The short-term effect is generally physical and is reversible when the temperature returns to its original state, whereas the long-term effect is generally dominated by chemical change which is not reversible. The study conducted by Gupta et al. (1989) on the effect of elevated temperature on the tensile properties of glass fibre reinforced PP showed that there is 50% reduction in tensile strength for the rise in temperature from $20^{o}C$ to $55^{o}C$. He found that at low temperatures, the sample shows brittle behaviour whereas at higher temperature, it shows ductile behaviour. The above information suggests that the knowledge on the effect of elevated temperature on the mechanical properties of the thermoplastic is an important aspect which must be investigated so that this material can be used as a civil engineering material.

CONCLUSION

This paper provides an overview on the recent development and application of glass fibre reinforced recycled mixed plastic composites. The addition of glass fibre results in stiff and strong composites with higher strength and stiffness than those of its matrices but with reduced ductility. Although several commercial products on glass fibre reinforced recycled products have appeared in recent years, published academic work on glass fibre and recycled mixed plastic waste is very limited. In addition, limited studies have been conducted to investigate the behaviour of these materials under different environmental conditions such as elevated temperature and ultraviolet rays. These are crucial for the utilisation of recycled plastic materials in building and construction. In light of this, there is a need to expand the research on glass-fibre reinforced recycled mixed plastic composites regarding the structural performance under these conditions.

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