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Review

# An overview of mechanical properties and durability of glass-fibre reinforced recycled mixed plastic waste composites

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ABSTRACT

In recent years, there has been an increasing interest in seeking the potential applications of recycled mixed plastic wastes in building and construction sectors to relieve the pressure on landfills. This paper presents the recent developments and applications of composite materials made from recycled mixed plastics and glass fibre. Some of the first uses for such composites are as an alternative to non-load bearing applications like park benches and picnic tables. With its inherent resistance to rot and insect attack, these composites can in fact be used as a replacement for chemically treated woods in various larger-scale outdoor applications such as railroad crossties and bridges. However, the properties of the structural components made from recycled mixed plastics are not well understood. Information on the behaviour of such composites under applied loading and at different environmental conditions such as elevated temperature and ultraviolet rays are crucial for the utilisation of recycled mixed plastic materials in construction. This paper presents an overview of the mechanical properties and durability of recycled mixed plastic waste composites. The paper identifies research needs critical in the effective design and utilisation of these composite materials in civil engineering and construction.



## 1. Introduction

The combination of three forces has created an opportunity for recycled mixed plastic composites. The first of these is the continuing population explosion, which has created a growing worldwide demand for building materials [1]. The second force is the increased price of the construction materials and decreased availability of quality timber. The third force is the plastic solid waste (PSW) crisis. Ever since the first industrial scale production of synthetic polymers (plastics) took place in the 1940s, the production, consumption and waste generation rate of PSW have increased considerably [2]. The world's annual consumption of plastic materials has increased from around 5 million tons in the 1950s to nearly 100 million tons in 2007 [3]. More and more plastics have been used in packaging, automotive and industrial applications, medical delivery systems, artificial implants, other healthcare applications, water desalination, land/soil conservation, flood prevention, preservation and distribution of food, 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 [4]. Table 1 presents the amount of municipal solid waste (MSW) and PSW generated in Australia, UK and USA. These data shows that the plastic waste comprises 10–16% of MSW by weight. In fact, plastics waste has become one of the largest categories in MSW, particularly in industrialized countries [5]. Due to the lower density of plastics, it contributes to an ever increasing volume in the solid waste stream. Relevant statistics showed that the disposal of plastics would soon become a major problem.

One of the best options to manage the PSW is recycling rather than incineration to decrease the waste volume and reduce environmental issue [6]. Thus, PSW recycling has been a focus of many researchers in the past few decades. Furthermore, the increasing cost and decreasing space of landfills are forcing considerations of alternative options for PSW disposal [7]. Such research is also driven by the changes in social and environmental issues [8]. Although plastics recycling are important, the data shown in Table 1 indicates that only about one-fourth post-consumer plastics waste is recycled around the world while most of them continue to be disposed in landfill and harm the environment.

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**Table 1**
Plastic waste data.

| | MSW generated (million tons) | PSW generated (million tons) | Recycling rate (%) | Reference |
|---|---|---|---|---|
| Australia in 2008 | 14 | 2.3 | 23 | [9] |
| UK in 2008 | 32 | 3.2 | 24 | [10] |
| USA in 2011 | 250 | 32 | 8.3 | [11] |

While recycling of plastic products is actively promoted, most of the recycled plastic cannot be used for the same application for reasons of health and environmental protection [12]. One of the efforts to meet this challenge is to convert these plastic wastes into products suitable for housing and construction. Composites manufactured from recycled mixed plastics offer the promise of relieving the pressures on both the landfills and the forests. Recycled mixed plastic extruded in the shape of lumber, generally called 'plastic lumber' is now extensively used in construction [13]. These materials have many advantages including recyclable, natural resistance to rot and insect attack, low energy consumption, low cost, light weight, and good specific mechanical properties [14]. Being lightweight, these materials are easy, fast and economic to install as it requires minimal handling and reduces energy in transportation. More importantly, they offer a totally recyclable material compared to thermoset polymer composites which is now becoming a major environmental hazard in many countries [15]. However, the material properties of the currently available plastic lumber technologies are lower in comparison to solid wood. Their modulus of elasticity is typically one-fourth or less than those of the solid wood which is seen as the main limitation of its usage in civil engineering applications [16]. To expand the available markets for building products manufactured from recycled plastic wastes, the strength and stiffness properties of these materials must be enhanced by adding reinforcement and other chemical additives.

This paper provides an overview on the current research and developments on recycled mixed plastic composites and information on their mechanical properties and durability under different environmental conditions. The effect of fibre reinforcement and chemical additives on the performance of recycled mixed plastic is presented. Critical issues crucial to their effective design and utilisation in civil engineering and construction are also discussed.

## 2. Current application of recycled mixed plastics composites

New materials and various combinations of recycled materials are constantly being proposed and used in the construction industry. Converting mixed plastic wastes into plastic lumber is considered as an effective alternative to landfilling. Some of the first uses for plastic lumber were in items like park benches and picnic tables as shown in Fig. 1. 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.

Recycled plastics have already been used on several civil engineering materials. Rebeiz, Fowler [18] have studied the behaviour of recycled plastics in polymer concrete where they found that the combination of these materials can provide an economical and technological attractive material system for a variety of engineering applications. Saadeghvaziri, MacBain [19] have 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. Babu and Chouksey [20] have used the plastic waste as reinforcement material in soil for ground improvement, sub-bases and subgrade preparation in road construction. They observed that the strength of the soil is improved and the compressibility is reduced significantly with the addition of small percentage of plastic waste to the soil. These studies have focused on using unreinforced thermoplastics in the development of structural products.

Plastic lumber has in fact been used as a replacement for chemically treated woods in various larger-scale outdoor applications due to its inherent resistance to rot and insect attack. Reinforced with glass fibre, recycled mixed plastic composites have been developed for infrastructure, railroad crossties and bridges. 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. This has great potential because the high quality wood for construction is now becoming less available. Some of the bridges built from recycled thermoplastic are shown in Fig. 2. These bridges were made by nearly 100% recycled post-consumer and industrial plastics and were developed by the researchers at Rutgers University, New Jersey and manufactured by Axion International, Inc. [21]. In 1998, the first vehicular bridge made up of polystyrene (PS)/high density polyethylene (HDPE) with a rectangular cross-section was constructed at Fort Leonard Wood, Missouri. The bridge used steel girders to support the plastic section. Although it has high initial cost, there was no maintenance which makes it a cost effective than traditional construction materials. In 2002, 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. In 2010, Fort Eustis in Virginia opened the world's first thermoplastic railroad bridges to replace two aged railroad timber bridges. This suggests that it is possible to apply these new generation materials to beam and/or column.

Nosker et al. [22] 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 ties exceeded the established targets. The permanent deformation under lateral loads and rail seat compression were both tested in the laboratory and found to sufficiently meet the performance criteria. This resulted in the installation of the 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 Fig. 3. Another six ties were installed in the mainline service on Conrail's Pittsburgh Line in October 1996. The authors mentioned that there is no evidence of tie plate cutting, spike loosening, or any other sign of degradation on these ties suggesting the suitability of recycled plastic materials in this application.

Although several commercial products on glass-fibre reinforced recycled products have appeared in recent years. There is no detailed scientific study and lack of published academic work on glass fibre reinforced recycled mixed plastic wastes. There are also a number of issues on the application of these materials in building and construction which are discussed in the following sections.

## 3. Properties of plastic solid waste

Most plastics in use today are thermoplastics, which mean that the material can be melted and re-shaped. These plastics have the