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Characterisation of recycled mixed plastic solid wastes: Coupon and full-scale investigation

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A B S T R A C T

In Australia, the plastic solid waste (PSW) comprises 16% by weight of municipal solid waste but only about one-fourth are recycled. One of the best options to increase the recycling rate of mixed PSW is to convert them into products suitable for construction. However, a comprehensive understanding on the mechanical behaviour of mixed PSW under different loading conditions is important for their widespread use as a construction material. This study focuses on investigating the mechanical behaviour of recycled mixed PSW containing HDPE, LDPE and PP using coupon and full-scale specimens. From coupon test, the strength values were found to be 14.8, 19.8, 20, 5.6 MPa in tension, compression, flexure and shear respectively, while the modulus of elasticity are 0.91, 1.03, 0.72 GPa in tension, compression and flexure respectively. The coefficient of variance of the measured properties for coupon and fullscale specimens was less than 10% indicating that consistent material properties can be obtained for mixed PSW. More importantly, the strength properties of mixed PSW are comparable to softwood structural timber. The flexural behaviour of full-scale specimens was also predicted using fibre model analysis and finite element modelling. Comparison showed that using coupon specimen's properties, the flexural behaviour of the full-scale specimens can be predicted reliably which can eliminate the costly and time consuming arrangements for full-scale experimental tests.

1. Introduction

Since the first industrial scale production of plastics in the 1940s, both the production and consumption of plastics have increased exponentially, ultimately giving rise to significant waste generation (Al-Salem et al., 2009). The recycling of plastics has become extremely important in the industrial world as plastics are now an integral part of modern living. With their large and varying applications, plastics contribute to an ever increasing volume of the solid waste stream (Siddique et al., 2008). For instance, in Australia, 14 million tons of municipal solid waste (MSW) was generated in 2008. Measured by weight, 16% of this MSW was plastic solid waste (PSW) (DSEWPC, 2012). In the same year, United Kingdom generated 32 million of MSW out of which 3.2 million ton were PSW (DEFRA, 2011). In the USA, the plastic waste generated in 2012 was 31.75 million tonnes, which is 40% higher than in 1998 (EPA, 2013).

Furthermore, with the increasing cost and decreasing space of landfills, there is a growing worldwide concern that the disposal of plastic solid waste will soon become a major problem. One of the best options for managing the plastic solid waste is recycling rather than incineration to decrease the waste volume and reduce environmental issues (Rajendran et al., 2012). Although plastics recycling is important, only about one-fourth of plastic solid waste is recycled and the remainder is disposed in landfills. One of the main reason for the low recycling rate is that most recycled plastic cannot be used for the same application for reasons of health and environmental protection (European Commission, 1998). Another is due to the fact that the plastics obtained from landfills are often blends of numerous polymers and it is not economically feasible to separate them (Nosker et al., 1993). An effective way to increase the recycling rate and reduce the separation cost is converting the mixed plastic solid waste into products suited for buildings and construction.

Currently, most construction practices and materials used within the building and construction industry leave a large ecological

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footprint in the waste generation. In 2008/09, Australia generated 46.8 million tons of waste as municipal solid waste (MSW), commercial and industrial waste (C&I), and construction and demolition waste (C&D) streams (DSEWPC, 2012). Of this waste, the construction and demolition waste stream contributed the most significant share at 19.7 million tons, with a total disposal to landfill of about 8.5 million tons (Fig. 1). Therefore, converting plastic solid waste into products suitable for the building and construction industry can reduce both MSW and C&D waste by producing recyclable products.

This paper deals with the characterisation of the mechanical behaviour of mixed plastic waste containing a mixture of high density polyethylene (HDPE), low density polyethylene (LDPE) and polypropylene (PP), which makes this material unique from other thermoplastics. There are two main benefits of recycling mixed HDPE, LDPE and PP. One is that HDPE, LDPE and PP, commonly known as polyolefin, are the highest plastics consumed covering about 50–60% in Australia (Fig. 2) whereas polyvinyl chloride (PVC), polyethylene terephthalate (PET) and polystyrene (PS) make up the remaining with polyurethane, nylon, acrylic polymers, polycarbonate and polyamide (PACIA, 2011). This is also true in the plastics waste stream in the USA where polyethylene and polypropylene forms the largest fraction which is around 60–65% of MSW (Subramanian, 2000). Another is that by using the floatation method, these three polyolefin can be easily separated from the other plastics obtained from municipal post-consumer plastic waste which reduces the separation cost.

Since polyethylene and polypropylene are generally immiscible and incompatible, their mixtures are expected to be poor in mechanical properties (Teh et al., 1994). However, HDPE/PP blend studied by Schürmann et al. (1998) exhibited a maximum impact strength at a certain composition which means they are not incompatible. This suggests that if the mixed plastic is designed correctly then specific mechanical properties can be achieved. Hence, there is extensive literature on the properties of the blends of polyethylene and polypropylene. This literature includes Tai et al. (2000), Bertin and Robin (2002), Şirin and Balcan (2010), who studied PP/LDPE blends and Bartlett et al. (1982), Schürmann et al. (1998), who studied PP/HDPE blends. However, studies dealing with the blends of three polyolefin (HDPE/LDPE/PP) are not many. To mention the few research, Putra et al. (2009) studied the effect of mineral filler reinforcement on the tensile and flexural behaviour of mixed PSW containing 70–80% of HDPE/LDPE/PP. Many other studies conducted on mixed PSW either contains proprietary blends or composition of some other plastics (Hugo et al. (2011), Xanthos et al. (1995), La Mantia and Ma (1995)). Only the research conducted by Dintcheva et al. (2001) studied the mixed PSW containing HDPE, LDPE and PP blends. However, their research focused on the effect of filler type and processing apparatus on the tensile and impact behaviour of mixed PSW. As reported by the review conducted by Bajracharya et al. (2014), most researchers have focused on the tensile characterisation of fibre reinforced mixed PSW. Similarly, little work has been conducted to discover the behaviour of mixed PSW containing HDPE, LDPE and PP under different loading conditions which are used as a matrix in those composites. This paper focuses on important mechanical properties of the recycled mixed PSW needed in design and construction including tensile, compression, flexural, and shear. Understanding these properties can help to facilitate the widespread use of mixed PSW as a construction material or a matrix of a composite material. This will give enough engineering data to provide designers, engineers and builders with sufficient information specifying requirements, predicting full-scale behaviour and giving end-users confidence in the quality of the mixed PSW.

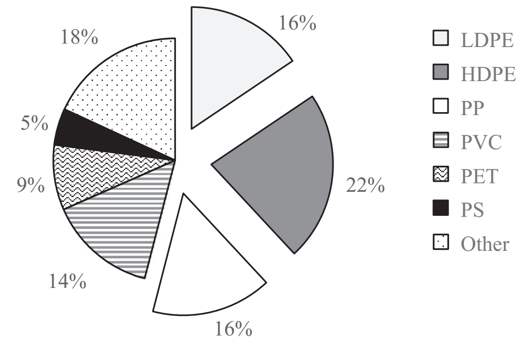

Fig. 2. Plastic consumption in Australia for year 2011 (PACIA, 2011).

Several researchers have attempted to predict the mechanical behaviour of plastic blends. Tai et al. (2000) used the Halpin–Tsai equation to predict the elastic modulus of PP/HDPE and PP/LDPE blends. Yousef et al. (2011) predicted the mechanical properties of PE/PP blends using artificial neural networks. Similarly, Deng et al. (2011) used the dynamic density functional theory approach to investigate the mechanical behaviour of binary polymer blends PS/PP by the continuous mesoscopic simulation method. However, for these model to work, the exact composition of each plastic component is needed. In case of mixed PSW collected from post-consumer waste, the quantity of each component is rarely known. Hence, the best way to predict the behaviour of the full-scale specimen produced from mixed PSW would be using coupon specimens' properties. This research proposes to use fibre model analysis (FMA) and finite element model (FEM) to predict the behaviour of the full-scale specimen using coupon specimens' properties.

The overall objective of the present work is to characterise the mechanical properties of mixed PSW under tensile, compression, flexural and shear loading using coupon specimen and find the consistency of mixed PSW behaviour. Furthermore, investigation of the behaviour of the full-scale recycled plastic beam is conducted. The flexural behaviour of the plastic beam is then predicted theoretically and numerically using the properties

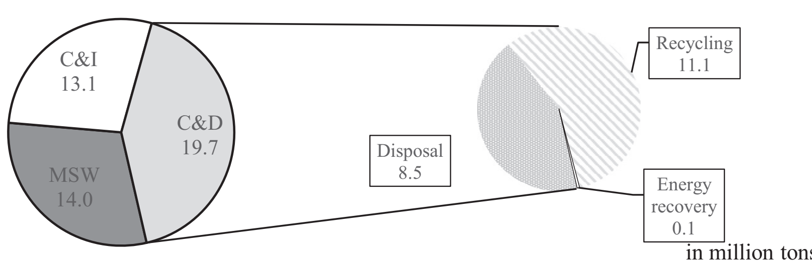

Fig. 1. Waste generation and disposal in Australia in 2008/09 (DSEWPC, 2012).