23rd Australasian Conference on the Mechanics of Structures and Materials

2014

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Publication details

Bajracharya, RM, Manalo, AC, Karunasena, W & Lau, KT 2014, 'Effect of elevated temperature on the tensile properties of recycled mixed plastic waste', in ST Smith (ed.), *23rd Australasian Conference on the Mechanics of Structures and Materials (ACMSM23)*, vol. I, Byron Bay, NSW, 9-12 December, Southern Cross University, Lismore, NSW, pp. 281-286. ISBN: 9780994152008.

EFFECT OF ELEVATED TEMPERATURE ON THE TENSILE PROPERTIES OF RECYCLED MIXED PLASTIC WASTE

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ABSTRACT

The production, consumption and waste generation rate of plastic has increased considerably ever since the first industrial scale production of synthetic polymers took place in the 1940s. In Australia, the plastic solid waste comprises 16% by weight of municipal solid waste and only about one-fourth of these plastic wastes are recycled. One of the best options to increase the recycling rate is to convert these plastic wastes into products suitable for housing and construction. However, a critical technical barrier for widespread use of plastic in structural engineering application is the influence of temperature on the material. This paper reports the effect of elevated temperature on the tensile properties of recycled mixed plastic waste. Recycled mixed plastic were prepared using an injection moulding process and tested using coupon specimens following the ISO 527 standard. The temperature was set at 23°C, 30°C, 40°C, 60°C, 80°C and 100°C. It was observed that when the temperature increases from 23°C to 100°C, the tensile strength and modulus reduced from 14.8 MPa and 906.2 MPa to 3.7 MPa and 179.4 MPa, respectively. This result emphasises to use thermal stabiliser and/or thermal coating to prevent the decrement of mechanical properties.

KEYWORDS

Recycled mixed plastics, tensile strength, tensile modulus, elevated temperature.

INTRODUCTION

In Australia, the plastic solid waste (PSW) comprises 16% by weight of the municipal solid waste (MSW) and only about one-fourth of these plastic wastes are recycled (DSEWPC 2012). In fact, plastics waste has become one of the largest categories in MSW, particularly in industrialized countries (Shent et al. 1999). 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 (Rajendran et al. 2012).

One of the efforts to meet this challenge is to convert these plastic wastes into products suitable for housing and construction. However, a critical technical barrier for widespread use of polymers 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 irreversible. When exposed to high temperature (300-500^{o}C), the polymer decomposes and releases heat and toxic volatiles. When heated to lower temperatures in the region of 100-200^{o}C, it will soften, creep and distort, and this degradation of the mechanical properties often leads to buckling failure mechanisms of load-bearing structures (Mouritz and Gibson 2007).

The effect of elevated temperature on properties of plastics has been studied by many researchers. A study performed on the polypropylene (PP) by Gupta et al. (1989) found that the tensile modulus decreased from 3.77GPa to 1.83 GPa when the temperature rises from -43^{o}C to 20^{o}C. Similarly, Carroll et al. (2001) conducted mechanical tests on the plastic lumber made up of recycled plastic and sawdust at -23.3^{o}C to simulate winter conditions and 40.6^{o}C to simulate summer conditions. They found that the strength and stiffness at high temperature was lower than at low temperature, thus the values at high temperature should be considered in the design. They further reported that the plastic lumber have properties comparable to wooden lumber during winter however during summer it would have much less strength than wooden lumber.

This paper presents the study of the effect of elevated temperature ranging from 23^{o}C to 100^{o}C on the tensile properties of recycled mixed plastic waste to provide useful information and help increase its acceptance in building and construction industry.

EXPERIMENTAL PROGRAM

Material

Recycled mixed plastic was provided by Repeat Plastic Australia Pty Ltd (Replas). The material was obtained from recycled post-industrial and post-consumer waste plastic which comprises of recycled high density polyethylene (rHDPE), recycled low density polyethylene (rLDPE), recycled polypropylene (rPP) and some other proprietary additives. These thermoplastic are considered as they account for most of the plastic consumed, about 54%, in Australia (PACIA 2011).

Sample Preparation

The coupon samples were prepared in Plastic and Rubber Technical Education Centre (PARTEC), Brisbane using the following steps.

Step 1: compaction of plastic flakes

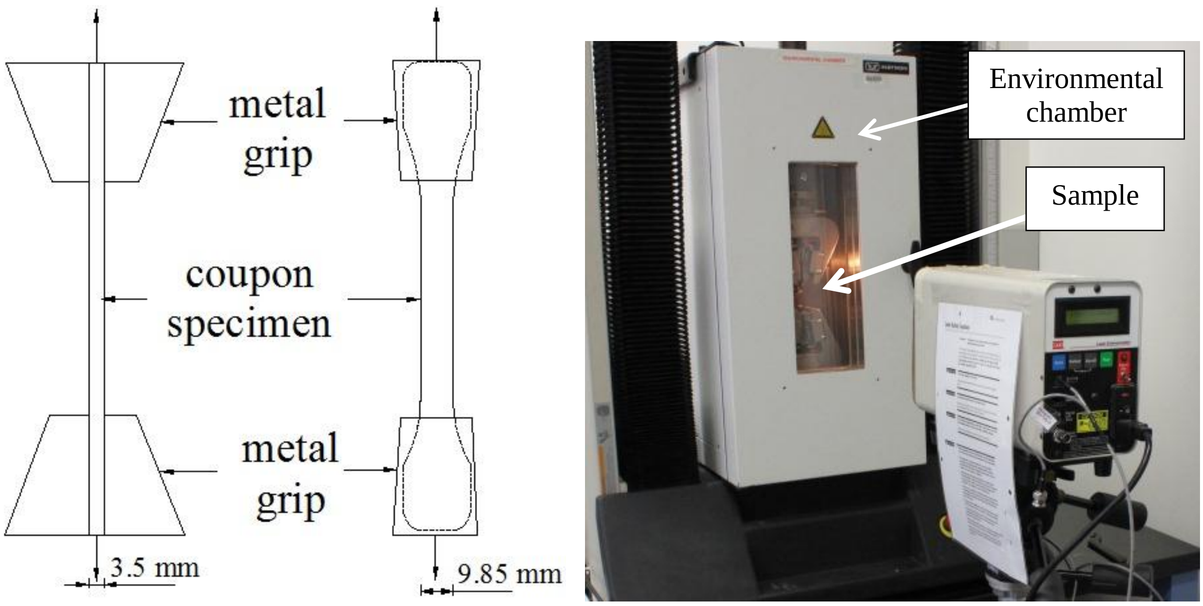
The plastic flake provided by Replas was fed into Chubu Kagaku Kikai's single screw extruder. The pellet was melted and extruded in the form of strand with the screw rotation of 87 rpm and the temperature was set at 170°C. The extruded plastic strand was chopped into small pellets having lengths of 4-5 mm in a granulator.

Step 2: injection moulding

Plastic pellet was injection moulded into specimen using 75 tonne Engel Injection Moulding Machine. The front, mixing and feeding temperature across the barrel was set at 220, 210 and 205°C, respectively.

Testing of Specimen

Figure 1 shows the schematic illustration and test set-up for the tensile test. The tensile test was carried out in accordance with ISO 527-1 (2012) standard inside the environmental chamber as shown in Figure 1(b) at different temperature. The temperature was set at 23°C, 30°C, 40°C, 60°C, 80°C and 100°C. Five replicates were tested for each test condition. The nominal length, width and thickness of the test specimen are 150 mm, 9.85 mm and 3.5 mm, respectively. The unsupported length of the specimen was around 50 mm. The specimen was tested using MTS Alliance RT/10 at a cross head speed of 5 mm/min. The end of the specimen was carefully clamped onto the testing jaws to prevent slipping at the gripping area. A laser extensometer was used to measure the extension for determination of strain.



(a) Schematic illustration of tensile test (b) Actual test set-up

Figure 1. Set-up for tensile test of the sample

EXPERIMENTAL RESULTS AND OBSERVATION

This study investigated how the elevated temperature affects the tensile properties of recycled mixed plastic. The stress-strain diagram of the recycled mixed plastics under tensile loading at different temperature is shown in Figure 2 which exhibits non-linear behaviour. The tensile strength of the sample tested is taken as the maximum stress in the stress-strain curve. It was determined by dividing the applied load by the average original cross-sectional area of the specimen. The strain was determined by dividing the change in length (measured by laser extensometer) by the original length. The modulus of elasticity was calculated on the basis of two specified strain values of 0.05% and 0.25%. From Figure 2, it can be observed that all the samples behave in a ductile manner for different temperature. Moreover, as the temperature increases, the ductility of the sample was increased. However, there is a reduction of both tensile strength and modulus with the increment of temperature.

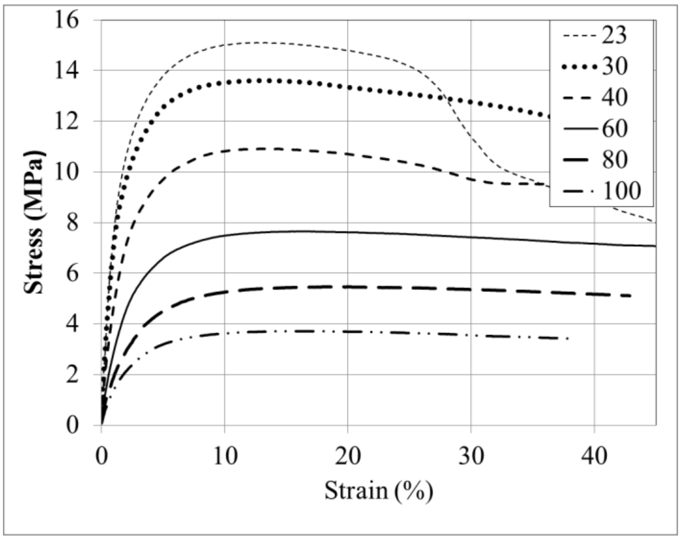


Figure 2. Typical stress-strain behaviour at different temperature

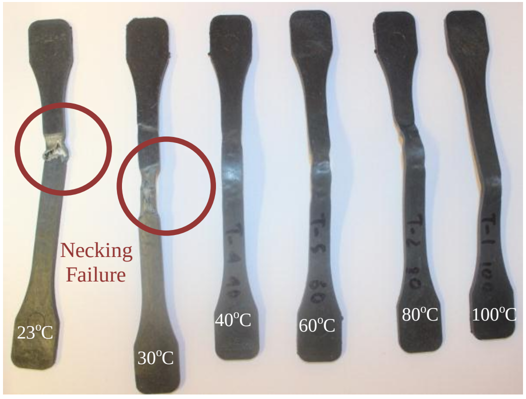


Figure 3. Failure behaviour of the sample at 23°C, 30°C, 40°C, 60°C, 80°C and 100°C from left to right

Figure 3 shows the failure behaviour of the sample at different temperature. It was observed that at low temperature (≤ 30⁰C), the necking failure of few specimens was observed. At higher temperature (≥ 40⁰C), the material was at a rubbery state and failure of the sample was not observed. In most cases, the test was stopped as the specimen kept on elongating. The sample at room temperature shows decrement of stress at around 30% strain; however the sample at elevated temperature does not show such response.

DISCUSSION

The summary of results of the tensile test is shown in Table 1. From table, it can be seen that the coefficient of variance (COV) for maximum tensile stress and modulus lies between 2.1 to 6.2% and 5.4 to 10.4%, respectively. The reason for the variance of the material properties for the mixed recycled plastics is due to the presence of voids in the test specimen. However, this variation is not significant which indicates the consistency of the production of the specimens using the injection moulding process. Also, the maximum tensile stress and tensile modulus at different temperature are shown in Figures 4 and 5 respectively. These figures show that at elevated temperature, the tensile strength and modulus of the recycled mixed plastics have significantly decreased but the increment of temperature does not produce a linear decrement of tensile properties. There was a significant decrease of 75% and 80% in tensile strength and modulus when the temperature was increased from 23°C to 100°C, respectively. It is due to that fact that the glass transition temperature of HDPE, LDPE and PP is -120°C, -120°C and -18°C (Abdel-Bary 2003). Above the glass transition temperature, the molecules possess sufficient thermal mobility to move completely past one another which further increases with the rise in temperature (Daniels 1989). This has resulted in the sharp reduction of the material properties at the elevated temperature. The results from the test performed at 40°C simulating summer conditions shows that recycled mixed plastic has much less tensile properties than at room temperature such that the tensile modulus drops from 906.2 MPa to 575.6 MPa. Furthermore, Figure 6 shows a comparison of tensile strength (TS) and tensile modulus (TM) of mixed recycled plastics (MRP) which shows that there is a higher reduction of TM than TS at elevated temperature. The low modulus at higher temperature means it increases the deflections within the structure when it is loaded, which may make this product unacceptable in serviceability limit requirements. Thus, the designers shall consider the design data at a higher temperature as the most critical situation. Future research should focus on the use of thermal stabiliser and/or thermal coating to prevent the decrement of mechanical properties at the elevated temperature.

Table 1. Summary of results

Temperature (^oC)	Maximum Stress (MPa)			Modulus of Elasticity (MPa)		
	Ave	Std. dev.	COV (%)	Ave	Std. dev.	COV (%)
23	14.828	0.66	4.4	906.2	87	8.3
30	13.08	0.29	2.2	789.2	72.24	9.1
40	10.89	0.26	2.4	575.6	60.23	10.4
60	7.65	0.17	2.1	351.6	22.91	6.5
80	5.5	0.06	6.2	235.8	12.83	5.4
100	3.69	0.15	4.2	179.4	14.07	7.8

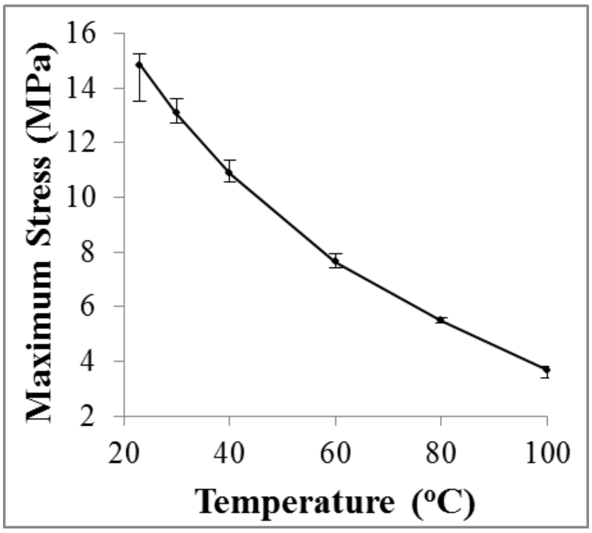


Figure 4. Tensile strength of the specimen

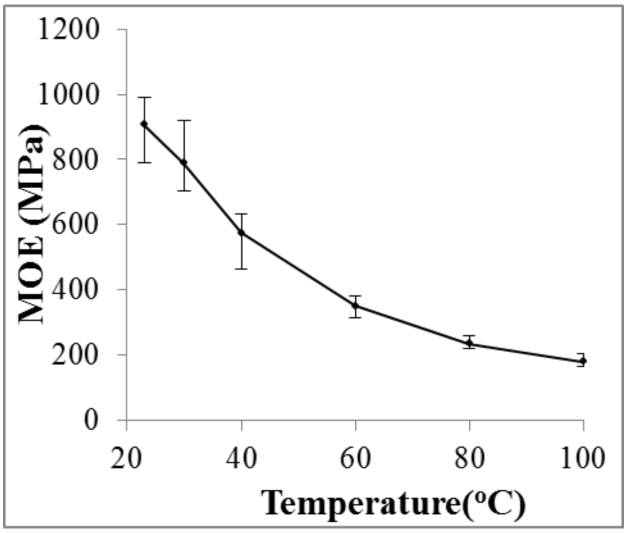


Figure 5. Tensile modulus of the specimen

A comparison of the effect of the temperature on virgin polypropylene (PP) based on Gupta et al. (1989) and mixed recycled plastic (MRP) based on this study is shown in Figure 6. Since these are different materials, the data were normalised by dividing the data of the specimens at higher temperature to that of the data at lowest temperature. From Figure 6, it can be seen that in case of tensile strength (TS) of PP and MRP the overall trend is similar. However, at around 60^oC the reduction of tensile strength of PP is minimal as compared to that of MRP. One of the reasons of the continuing decrement of the strength of MRP is that it is a mixture of PP, HDPE and LDPE out of which LDPE has a lower melting temperature than that of PP. This can be a critical for design as the reduction of strength at higher temperature will be more than that of virgin plastics.

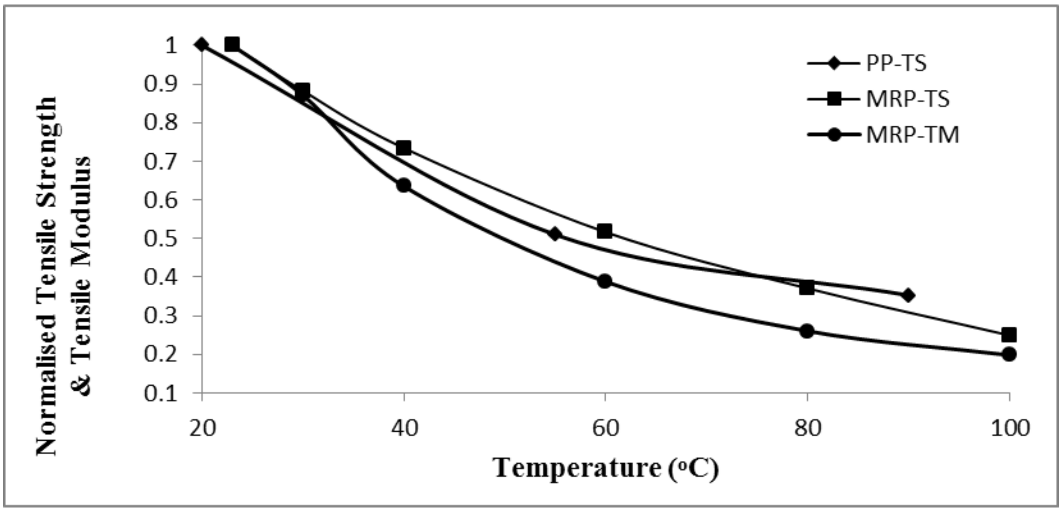


Figure 6. Comparison of different thermoplastic at elevated temperature

CONCLUSION

The following conclusion can be drawn from this work:

- When the temperature increases from 23°C to 100°C, the tensile strength and modulus reduced from 14.8 MPa and 906.2 MPa to 3.7 MPa and 179.4 MPa, respectively,
- There is a higher reduction of the tensile modulus than tensile strength at elevated temperature,
- The thermal stability of the mixed recycled plastics is similar to that of virgin plastics,
- This result emphasises to use thermal stabiliser and/or thermal coating to prevent the decrement of mechanical properties.

ACKNOWLEDGEMENTS

The authors would like to thank Replas Pty Ltd for providing the recycled mixed plastic used in this study. The authors would also like to acknowledge PARTEC for providing the equipment during the preparation of the test specimens.

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