Polymeric feedstock from post-consumer and post-industrial plastic wastes for automotive interior applications

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Abstract: In this study, an economically-viable methodology is discussed where a blend of post-consumer recycled (PCR) plastics and post-industrial scrap (PIS) polymers is refined and used as the feedstock for manufacturing of interior structural products for automotive industry. A comprehensive thermo-mechanical characterisation suggest that feedstock obtained using a melt-filtering based refining process, offers performance on par with the virgin materials with reduced cost and environmental impact. Using both lab-scale prototyping and pilot plant trials, interior trim parts have successfully been produced to demonstrate the viability of using this new feedstock in mainstream polymer production processes such as injection moulding and thermoforming for automotive applications.

1. Introduction

Often component suppliers of today’s highly competitive automotive manufacturing sector face with very demanding and competing requirements. This can include the production of components of high strength/weight ratio, lower prices, higher fuel efficiency and greater comfort together with a push towards a more sustainable, and low-pollution level industry. Increasing use of polymers and polymeric composites in automotive applications (currently up to 20%) [1, 2], on the other hand, draws a special attention to re-use and recycling of polymeric components and their manufacturing wastes. The objective is not only to reduce the cost but also to help the industry become more sustainable by minimisation of its waste and use of post-consumer recycled plastics in manufacturing of, at least, some low-end (non-structural and non-visible) interior components to start with.

Despite the development of various recycling methods and complex sorting and classification techniques [3,4], the lack of infrastructure and the access to sophisticated characterisation equipment is, in the first place, often the major bottleneck hampering the take-up of such routes by the small & medium manufacturing businesses. Previously we have reported [5] on the performance of recovered polymers from the waste electrical and electronic equipment (WEE) with minimum sorting using compression moulding & thermoforming as the two low melt-flow-index (MFI) processes. In this work, an enviable waste recovery method is investigated with which some products have been produced by blending post-consumer recycled (PCR) plastics and post-industrial scrap (PIS) polymer wastes. While PCR plastics
suffer from a variety of contaminants, PIS wastes in contrast enjoy much lower degree of contamination and offer direct re-use or minimal recovery effort such as classification, sorting, sizing etc.

In this paper, a methodology is proposed for a combined use of refined PCR plastics and PIS waste to offset the difficulties faced with re-manufacturing of such polymeric wastes into feedstock of acceptable quality for end-use products. This will pave the way for the use of more recycled plastics and as a result avoiding landfilling such wastes and minimising environmental impact. Mechanical as well as thermorheological tests have been conducted to characterise this new recycled feedstock, and physical prototypes have been made to demonstrate its manufacturability on industrial scale.

2. Materials & Methods

Materials used in this work were a combination of post-consumer recycled (PCR) plastics and post-industrial scrap (PIS) polymers. PCR plastics comprised of various olefins and non-olefin based polymeric constituents contaminated with metallic and non-metallic (such as papers and thermoset foam) inclusions sourced from a printer cartridge collection program. The post-industrial scrap polymers were supplied from an industry partner’s plastic manufacturing processes, which were a composite of Ethylene Vinyl Acetate (EVA) with 75 vol% ceramic powder, abbreviated here as EVACOMP. Fourier Transform Infrared (FTIR) spectroscopy was used, on random basis, to identify the spectra of various polymeric constituents in the supplied PCR material, returning a wide range of thermoplastics including Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), PC/ABS, Polyethylene (PE), Polypropylene (PP) and Polystyrene (PS). Commingle of these thermoplastic polymers, denoted as CTPCOMP here, were shredded into 2 groups of small (3-8 mm) and large (8-20 mm) flake size.

Due to a large volume of contaminants present in the post-consumer recycled plastics, decontamination was an imperative before trialling of any production process. Also, in order to prevent the bridging in the hopper of injection moulding machine as well as blockage in screw’s solid-conveying zones, the materials were required to be in a form of regularly shaped and relatively small pellets. This was achieved with the help of the appropriate extruder pelletiser. Using the following steps, an industrial grade twin screw extruder was employed to re-extrude the as-received stocks:

1. Various volume fractions of post-industrial EVACOMP was mixed mechanically with pelletised PCR wastes. During pelletising main metallic contamination were separated.

2. During the preliminary trials, an initial temperature setting was figured out using a laboratory scale extruder. Such temperature setting would have to fall within the working temperature window with its lower bound being the glass transition temperature of the amorphous plastics or melting point for semi crystalline plastics, and upper bound being the highest degradation temperature of the constituent polymer in the stock.

3. Magnetic separators were used in the hopper of extruder to remove ferromagnetic contaminants.

4. A manually-rotating melt-screening mechanism was employed, which was mounted in-line with twin-screw extruder. Given the average size metallic contaminants, metal meshes of two sizes were inserted at desired time interval to make sure the resultant melt is contamination-free. This was checked both visually and using a Thermogravimetric analyser (TGA). TGA was employed to verify that no contaminants with high decomposition temperature (metals or ceramic) were present in the refined feedstock.

5. A suitable screw compression ratio was then used according to literature [6]. Then speed of pelletiser was adjusted to achieve the desirable size for pellets. A maximum processing temperature of 245°C was
used for melt filtration.

**Figure 1(a)** shows a blend of PCR plastics shredded mechanically before processing and Figure 1(b) shows the resultant regular-shaped granules produced from a refined feedstock in an industrial twin screw extruder.

![Figure 1. (a) Shredded PCR flakes](image1a.png) ![Figure 1. (b) Refined PCR+PIS granules](image1b.png)

**Table 1** shows a list of composites (Composite A, Composite B and Composite C) of EVACOMP and CTPCOMP, which were made with different proportions (CTPCOMP/EVACOMP ratios of 89/11, 78/22, 67/33). Their properties were compared with those of EVACOMP and CTPCOMP of both large and small flakes.

| Material       | CTPCOMP | EVACOMP |
|----------------|---------|---------|
| Composite A    | 89 %    | 11 %    |
| Composite B    | 78 %    | 22 %    |
| Composite C    | 67 %    | 33 %    |
| CTPCOMP        | 100 %   | -       |
| Large Flake    | 100 %   | -       |
| CTPCOMP        | 100 %   | -       |
| Small Flake    | 100 %   | -       |
| EVACOMP        | 0 %     | 100 %   |

**Table 1**: Composite Materials and respective filler volume fractions

Quasi static tensile and impact mechanical properties of these composites as received and post-filtered were investigated by fabricating test specimen using compression moulding and injection moulding processes. In addition, thermo-rheological properties of the materials were tested to obtain experimental parameters required to run a numerical-based computer analysis for optimisation of flow in injection moulding process. *Autodesk Mouldflow Insight* plastic flow simulation software was used to achieve such optimisation for pilot plant trials of this new PCR and PIS blended feedstock.

3. Results & Discussion

Tensile, impact and flexural strength of the as-received and refined PCR-PIS composites are shown in Figure 2 to Figure 4. Graphs on the left are that of test specimen produced by compression moulding, and the graphs on the right are that of specimens produced by injection moulding.
Compression-moulded samples: EVACOMP exhibits the lowest tensile strength (0.92 MPa) in comparison with CTPCOMP and other composite materials whereas CTPCOMP Small Flake exhibits the highest tensile strength. Amongst the composite materials (A, B and C) having EVA as the filler, the composite B shows the highest tensile strength (18.94 MPa). The incorporation of EVA into CTP resulted in the reduction of tensile strength. There is a general decrease in impact energy when the weight fraction of EVA into CTP is increased. This is in contrast to what was expected. EVA with its high viscoelastic properties was expected to have a synergistic effect of increasing elongation and overall impact energy of the composites. But it was observed that during compression moulding process, EVA was present as a completely separate phase with poor bonding to the main matrix. This is believed to be due to poor processability of compression moulding process whereby the flow of materials is heavily restricted even at temperatures substantially above the glass transition temperature or melting point of the composite components.

**Figure 2.** Tensile strength of composite materials, CTPCOMP and EVACOMP produced by compression moulding process (left), and injection moulding process (right).

**Figure 3.** Impact strength of composite materials, CTPCOMP and EVACOMP produced by compression moulding process (left), and injection moulding process (right).
Figure 4. Flexural strength of composite materials, CTPCOMP and EVACOMP produced by compression moulding process (left), and injection moulding process (right).

Injection moulded samples: CTPCOMP samples exhibit the highest strength in both tensile and flexural test regimes. However, the highest impact energy was produced by composite A containing 11% of EVACOMP. Injection moulding process, as expected, produced specimens of much higher consistency than the compression moulding process. As a result, EVA fraction was homogenously mixed within CTPCOMP, which increased the toughness or equivalently the impact energy required to break the samples. Overall melt-filtered feedstock processed through injection moulding process had a significantly higher tensile and flexural strength than the as-received shredded materials processed through compression moulding.

Figure 5. Measuring loss of weight over the temperature scans indicate thermal stability of the refined feedstock near processing temperatures.
As evident from the TGA results of various polymeric resins, shown in figure 5, the refined feedstock experiences no thermal degradation (indicated by weight loss on the graph) at temperatures close to the processing (injection or compression moulding) temperatures. It is also demonstrated, by graphs in Figure 6, that the refined feedstock and neat ABS exhibit similar force versus deflection behaviors.

**Table 2(a). Statistical analysis of the properties for refined feedstock**

| Series | n = 10 | Emod GPa | Fmax MPa | dL at Fmax % | Fbreak MPa | dL at break % | W to Fmax Nmm | W to break Nmm |
|--------|--------|----------|----------|--------------|------------|---------------|--------------|---------------|
|        |        |          |          |              |            |               |              |               |
| x      | 1.33   | 41.2     | 3.5      | 40.7         | 3.5        | 1466.31       | 1497.59      |
| s      | 0.0671 | 1.23     | 0.3      | 1.51         | 0.3        | 190.00        | 229.93       |
| v      | 5.04   | 2.98     | 7.8      | 3.72         | 9.06       | 12.96         | 15.35        |

**Table 2(b). Statistical analysis of the properties for refined feedstock**

| Series | n = 10 | Emod GPa | Fmax MPa | dL at Fmax % | Fbreak MPa | dL at break % | W to Fmax Nmm | W to break Nmm |
|--------|--------|----------|----------|--------------|------------|---------------|--------------|---------------|
|        |        |          |          |              |            |               |              |               |
| x      | 1.27   | 42.8     | 3.7      | 30.7         | 15.7       | 1629.85       | 9529.04      |
| s      | 0.0295 | 0.528    | 0.1      | 1.14         | 5.2        | 56.52         | 3316.08      |
| v      | 2.32   | 1.23     | 1.47     | 3.72         | 32.98      | 3.47          | 34.80        |
6 and statistical analysis in Tables 2(a) & 2(b), that the post-filtered PCR and PIS blends have similar tensile strength and deformation at maximum force to that of neat ABS with higher stiffness. It is understood that the polymeric fractions with higher melting temperature than 245°C (such as nylon 6 & nylon 6.6 denoted as PA in the TGA graph) remain un-melted during melt-filtration process and perform as reinforcement in the rest of the polymeric matrix upon solidification.

Figure 7. Preserved shear-thinning behaviour of decontaminated PCR feedstock (left) and best injection-gate location analysis (right).

Figure 8. Interior automotive trim and a tray-base produced from post-consumer recycled plastics by injection moulding process.

The refined feedstock maintained its pseudo-plasticity as is evident from the rheological results shown in Figure 7. Figure 8 shows two types of products produced from the refined polymeric feedstock recovered from post-consumer waste during pilot plant trials in a polymer processing factory in South Australia. A gate location analysis using Autodesk Moldflow Insight software and the rheological studies of the blends revealed the best location of injection gates, which were paramount to the successful production of complex geometry of the products shown in Figure 8.
4. Conclusion
A new composite material has been processed from a blend of post-consumer recycled printer cartridges and post-industrial polymer wastes, and refined as the feedstock for injection moulding of automotive parts. During pilot plant trials, successful prototyping of a representative automotive trim part has been demonstrated. Injection moulded parts were superior to those produced by compression moulding. An approximate cost analysis of using post-consumer and post-industrial recycled polymers shows an average 40% reduction in cost compared to virgin materials while retaining a tensile strength on par with that of virgin polymers and with a higher stiffness. Significant reduction in landfiling of polymer waste, through re-use and re-manufacturing by melt-filtration, offers an obvious solution to an environmentally friendly and suitable manufacturing methods for production of non-visual and non-structural automotive components. Thermogravimetric and rheological analyses show the thermal stability and retained shear thinning behaviour of the recovered polymeric waste having gone through the melt filtration, thus making it viable feedstock for further mainstream plastic processing technologies.

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