Wide-range Profiling of WEEE-Derived Polypropylene Using Multi-Technique Analytical Methods

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INTRODUCTION

E-waste, also known as waste electronic and electrical equipment (WEEE), is among the sources of waste with the fastest rate of growth in the world and a very big market size (Islam, Dias and Huda 2020). The global waste generation is anticipated to reach 53.9 metric tons by 2025, leading to challenges with their recycling (Alassali et al. 2020). Most out-of-use electrical and electronic devices (e.g., televisions, printers, household equipment, etc.) have recently been landfilled or burned, both of which have negative ecological effects (Alassali et al. 2020); the release of microplastics to soils, water bodies, and the inhalation of toxic fumes (Ferreira-Filipe et al., 2024; Odnevall et al., 2023).

Mechanical recycling is the cheapest means of recycling thermoplastics, but the sorting of the plastics for improved secondary products has always been the major challenge (Vogt et al., 2021; Lamtai et al., 2023; Huang et al., 2022). Sorting is necessary to achieve interesting properties for secondary raw materials with high purity (Maris et al., 2018), particularly in comparison with virgin materials. Colour sorting of mixed plastics has been used to study brominated flame retardants (BFRs) concentrations in heavy plastic fractions (Stubbings et al., 2021). Studies on the comprehensive or forensic analysis of such colour-sorted plastics, amongst PP grades, have not been reported, especially the interactions and effects of the various additives on the physicochemical properties.

The primary goal of this research is to develop an efficient and sustainable method of mechanically recycling Waste Electrical and Electronic Equipment (WEEE)-derived polypropylene (PP) by colour and evaluating its physicochemical properties using advanced characterization techniques. This approach is expected to optimize recycling processes and enhance the quality of recovered PP for reuse in various industries, aligning with sustainability goals.

MATERIALS AND METHOD

The research involved the collection of WEEE-derived PP from Enva Plastics Limited, sourced from the casings of household electronic devices, and manually sorted by colour (white, grey, black, and red). The sorted samples were then characterized using several advanced techniques. Thermogravimetric Analysis (TGA) assessed thermal stability and decomposition behaviour. Fourier Transform Infrared Spectroscopy (FTIR) identified chemical functional groups present in the recycled PP and helped detect contamination from additives, fillers, or other polymers. X-ray Diffraction (XRD) determined the crystalline structure and phase composition of the PP samples, useful for assessing differences in crystallinity among colour-sorted PP materials. Energy Dispersive X-ray Analysis (EDXA), used in conjunction with Scanning Electron Microscopy (SEM), analyzed the elemental composition and identified impurities and additives. Differential Scanning Calorimetry (DSC) measured the melting temperature, crystallization behaviour, and thermal transitions, helping compare thermal properties of different colour-sorted PP fractions. The data obtained from these analyses were compared across different colours to determine variations in properties and assess the recyclability potential of each WEEE PP fraction.

RESULTS AND DISCUSSION

The FTIR analysis confirmed the polymer as polypropylene (Figure 1a), with match percentages between 86-88% for mixed thermoplastics and 90% for white-sorted PP. Variations in absorption peaks were influenced by the molecular structure, the type, and concentration of dyes or pigments.

The DSC analysis (Figure 1b) revealed that the melting temperature for PP thermoplastics was between 163°C and 165°C but higher for sorted samples, with mixed PP having a higher recrystallization temperature (119°C) compared to white (115°C) and other colour-sorted plastics (117°C).

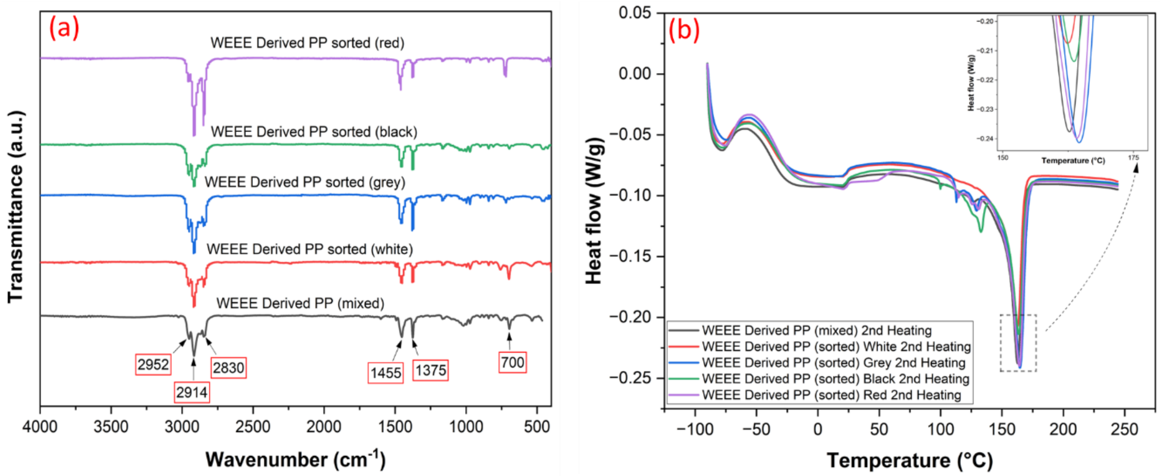

Figure 1: Combined (a) FTIR spectra and (b) DSC curves of mixed and sorted PP thermoplastics

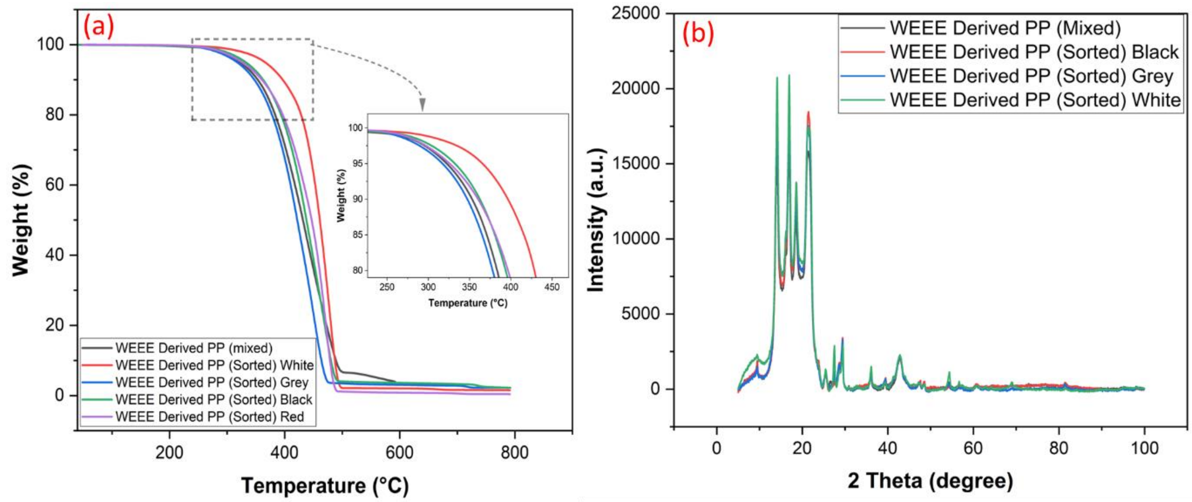

Figure 2: Combined (a) TGA thermograms and (b) XRD spectra for mixed and sorted PP thermoplastics

The TGA results showed that mixed PP had the lowest onset of degradation (233.6°C), while colour-sorted samples had higher values (300°C for white, 262.8°C for grey, 269°C for black, and 257°C for red). Mixed PP exhibited a 94.5% mass loss, indicating lower thermal stability and incomplete decomposition compared to colour-sorted PP, which had up to 99% mass loss.

The measured intensities and corresponding crystallinity percentages indicate variations in the crystalline content of different PP fractions. white PP exhibited the highest crystallinity at 71.4% and intensity of 20,844 counts, suggesting a more ordered crystalline phase than others fractions.

Different elements have been found in the recycled plastics in different weight and atomic percentages, showing the presence of different additives. Most of the additives can be narrowed down speculatively based on the regular ones used for industrial production.

CONCLUSION AND RECOMMENDATIONS

The colour-sorted plastics gave improved properties within the PP polymer type, revealing the possibility of reductions in the variations of PP grades within a batch and the different effects of colour additives. This research enhanced recycling efficiency by promoting efficient sorting and characterization. Additionally, it provided novel data on the behaviour of different coloured PP fractions in recycling processes, offering practical recommendations for waste managers and policymakers. This will enable industries such as automotive, construction, and packaging to incorporate high-quality recycled PP into new products, reducing dependence on virgin plastics and expanding the market potential for upcycled WEEE polypropylene. Advanced sorting technologies such as AI-powered optical sorting is therefore recommended, to improve the precision of polypropylene sorting from WEEE waste.

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