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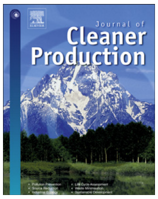

Effect of silicone rubber based impact modifier on mechanical and flammability properties of plastics recovered from waste mobile phones

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ABSTRACT

The plastics recovered from electronic waste have huge potential to be recycled into new products. However, several earlier works have indicated that the toughness properties of the recovered plastics are significantly low. An impact modifier for such plastics was developed in the current study using silicone rubber waste from mobile phone keypads. The silicone rubber keypads were partially de-vulcanized by a thermo-mechanical process and were further grafted with methyl methacrylate to improve its compatibility with the recovered plastics, also from mobile phone waste. The effect of the silicone rubber based impact modifier on mechanical properties, particularly toughness under room temperature and cryogenic temperatures were analyzed. The effect of silicone impact modifier on visco-elastic properties and flammability of the plastics recovered from mobile phone waste was studied. The results revealed that the addition of silicone rubber based impact modifiers improves the toughness of the recovered plastics to a great extent and also that the improvement in toughness is maintained at cryogenic temperatures. The flame retardancy of the recovered plastics improved tremendously on addition of silicone rubber-impact modifier.

1. Introduction

Electronic wastes are among the largest and fastest growing waste stream in the world (Goodship and Stevels, 2012; Pariatamby and Victor, 2013; Wang and Xu, 2014). Associated with this rapid growth, a relatively new waste stream, termed as electronic waste or e-waste has become an important concern globally (Stenvall et al., 2013). Out of the different categories of WEEE mentioned in the EU Directive (2002) mobile phones come under category 3, which includes all kind of IT and Telecom devices. The International Telecommunication Union's (ITU) latest reports estimates that more than 7 billion mobile phone subscriptions were present at the end of 2015, with a population-wise penetration rate of 97% (ICT Facts and Figures, 2015). The fast advancement in the technology, providing better models regularly, forces the consumer to change their phones more frequently. This in turn results in very short service life of mobile phones and thereby generating large amount of phones ending up in waste stream (Li et al., 2015). The use phase of a mobile phone is less than 3 years in developing countries and less than 2 years in developed countries.

India is the fifth largest e-waste producing nation globally and the quantity of e-waste is estimated to increase at a rate of approximately 21% per year. Developing countries like India also face the problem of accumulation of e-waste through illegal trading routes. Recent reports on Indian e-waste scenario suggests that the generation of computer waste may achieve a saturation point in the near future, whereas the quantity of mobile phone waste is expected to grow continuously over the coming years. It is observed that eco-friendly recycling techniques for such waste materials are quite costly and the local recyclers in India are not generally aware of such techniques, resulting in recovery of waste materials through crude techniques, which subsequently results in serious hazards to environment and life. To address such concerns, India recently introduced several legislations for effective management and recycling of e-waste, which triggered a move among recyclers to move towards organized recycling, but such initiatives are yet to be

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realized. Currently the ratio between formal to informal recycling ratio is around 10:90 only, which should be reversed to achieve best results (Pathak et al., 2017).

It is predicted that most of the mobile phones entering into waste streams still have value (in terms of performance and strength). Hence these can be recovered and reused or recycled if properly sorted and segregated (Soo and Doolan, 2014). Mobile phones are very complex products when it comes to dismantling and recycling, due to the large variety of materials present in them such as plastics, metals, glass, ceramics etc. A typical mobile phone consists of several parts such as display unit, battery, front and back cases and printed circuit boards (PCBs). Mobile phones contain about 50% plastics and the rest is formed by other materials (Palmieri et al., 2014). Recovery of polymers from mobile phone waste has gained considerable attention globally in the recent times than ever before (Wang and Xu, 2014). The share of polymers that contribute to the making of mobile phones is around 30%–50%, which is higher than the polymer content in most of the other electronic devices (Sarath et al., 2015). Several reports on polymer recovery indicate that the plastics that form part of mobile phones are mostly engineering plastics such as polycarbonate (PC) and Acrylonitrile Butadiene Styrene (ABS) or their blends. Studies reveal that the mechanical properties of such recovered plastics are comparable to that of new materials; however, they lack sufficient impact toughness (Palmieri et al., 2014; Monteiro et al., 2007).

It is widely known from previous research that impact toughness of plastics may be improved by addition of impact modifiers. Impact modifiers are usually rubbery materials that can take up sudden loads efficiently and effectively owing to their long and flexible chain backbone. One of the most common rubber matrix used for this purpose are butadiene rubber matrices and acrylic rubber matrices. It is known in the art of rubber technology that silicone rubber is superior to butadiene rubber in terms of weatherability and superior to acrylic rubber in low temperature properties. Previous research also shows that silicone rubber based impact modifiers can significantly improve the toughness of engineering plastics (Wu et al., 2008; Yanagase and Ito, 2004). However, simply mixing a rubber and plastic may not create the desired product. The key to success in rubber plastic blending is achieving sufficient compatibility between the two components, resulting in useful properties. Such compatibility may be induced by methods like interfacial modification, compatibilization and rheological optimization.

The silicone rubber keypads taken from mobile phone waste stream were considered as a potential source of impact modifier in the current study. The problem associated with present work was that the available silicone rubber waste is in vulcanized state, which cannot be melt-mixed with recovered plastics. Rubber recycling industry uses a process called ‘de-vulcanization’, which is one of the solutions to the present problem. De-vulcanization is defined as either partially of fully cleaving the cross-links formed during vulcanization. Several de-vulcanization methods have been developed in the industry such as thermal, chemical, mechanical, chemo-mechanical and thermo-mechanical techniques. Out of these, thermo-mechanical de-vulcanization method was employed in the current study owing to several factors. Firstly, since material recycling is the primary objective, the cost of process is to be kept as low as possible. This is achieved by eliminating the need of any external chemicals to enhance de-vulcanization rate and also by using in-house equipments. Secondly, different extents of de-vulcanization can be achieved by varying the process parameters (Mangaraj, 2005).

In the present work, the silicone rubber keypads taken from mobile phone waste stream were shredded to small particles and were subjected to thermo-mechanical de-vulcanization process followed by grafting with methyl methacrylate to improve their interaction with plastics. The grafted-partially-de-vulcanized-silicone-rubber is referred to as the silicone impact modifier (SIM) in the current study. The effect of SIM in plastics recovered from waste mobile phones was analyzed by mechanical property analysis, low temperature toughness, visco-elastic property analysis and flammability. The process flow employed in the current study I schematically represented in Fig. 1.

2. Materials and methods

2.1. Materials

Polymeric components from waste mobile phones for this study were supplied by M/s E-Parisaraa Pvt. Ltd., a certified recycler from Bengaluru, Karnataka, India. All recovered plastics are denoted by a letter “r” prefixed to them in the current study; i.e., recovered PC is indicated as r-PC, recovered PC/ABS material as r-PC/ABS, recovered PS/PC material as r-PS/PC and recovered ABS material as r-ABS. Virgin Polycarbonate (v-PC) with trade name Makralon 1837 was supplied by Bayer Material Science Pvt. Ltd., Mumbai, India. Methyl Methacrylate (MMA) with molecular weight of 100.12 g/mol and purity of 98.5% was supplied by Himedia Laboratories Pvt. Ltd, Mumbai, India. Dicumyl Peroxide (DCP) was supplied by M/s Sigma Aldrich, Japan (Purity–98%).

2.2. Methods

2.2.1. Preparation of silicone impact modifier (SIM) and blending with plastics

The silicone rubber keypads as received from mobile phone waste were cut into small parts (size less than 0.5 mm) and fed into Xplore DSM Micro-compounder and partially de-vulcanized up to 5 min. To achieve better compatibility with the recovered plastics, the partially de-vulcanized silicone rubber was grafted with an acrylic monomer, MMA in the presence of DCP. The rubber was fed into DSM micro-compounder along with 10% MMA and a tinge of DCP at 180 °C for 5 min. At the end of the reaction time, the outlet of

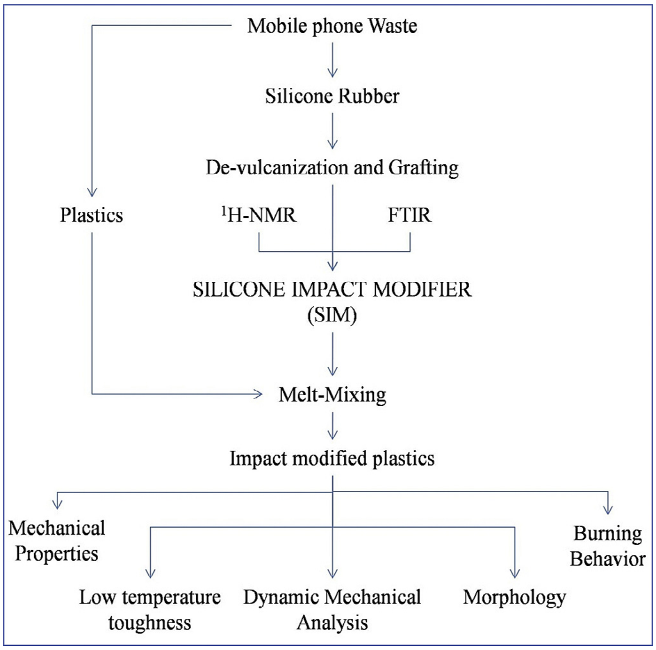

Fig. 1. Process Flow of the current study.