International Journal of Environmental Engineering– IJEE
Volume 2: Issue 2 [ISSN: 2374-1724]
Publication Date: 30 October, 2015

Evaluation of Recyclability of Waste Mobile Phone Plastics

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***Abstract* — Plastic components from waste mobile phones were sorted and characterized using visual, spectroscopic and thermal methods. The mechanical properties of the recovered plastics were investigated by comparing with commercially used reference materials. The results revealed the practical feasibility of these recovered plastics to make new products through mechanical recycling. The samples were also tested for brominated flame retardants (BFRs) using gas chromatography-mass spectrometry (GC/MS) technique and the results indicated the absence of BFR in recovered plastics, hence these can be processed without any risk of BFR toxicity.**

Keywords— Mobile Phone Waste Valorisation, Plastics identification, Estimation of Recyclability, Plastics Recycling

I. Introduction

The fast growth in electrical and electronic equipment industry generated a relatively new kind of waste stream, termed as Waste Electronic and Electrical Equipment (WEEE) or simply, e-waste and it has become a major area of concern throughout the globe due to the vast amount of e-waste disposed every year [1]. Among WEEE, mobile phone waste has gained considerable attention in the recent years. According to latest Gartner reports, mobile phones have contributed to more than 50% of total sales of electronic products (in numbers), out of which smart phones hold a major share. But surprisingly, mobile phones are one of the least recovered and recycled products of electronic wastes [2].

India stands second in the global telecom network having more than 750 million mobile subscribers [3]. The mobile phone waste volume is accordingly escalating at a fast pace owing to their very short life cycles. India, being a developing nation, reusing or recycling mobile phone materials is an efficient way to reduce and manage the mobile phone wastes. But mobile phones contain a large number of materials and components making them highly complex and difficult to segregate for further recycling. Even though many researchers and industries have developed many processes for quick dismantling and segregation of mobile phone wastes, the recycling rate is still quite low owing to the very limited awareness of the customer [4].

From the various mobile phone waste management literatures, it is clear that plastics are the prime constituents in mobile phones, which are easily acquirable for recycling and contributes up to 40%-60% of all materials used in mobile phones. Also, such articles indicate that major share of plastics used in mobile phones is made up by engineering grade plastics such as PC, PC/ABS blends, HIPS and ABS, which may still possess high value in terms of performance and economy, making them ideal for reuse and recycling [5].

In the present work, plastic components dismantled from waste mobile phones, collected from recycling plants, have been categorized using conventional identification methods such as generic marking of plastic products supported by advanced characterization techniques such as FTIR and Differential Scanning Calorimetry (DSC). Thermal and mechanical properties of these recovered waste plastics were evaluated and the data has been corroborated with reference materials to assess their reusability and sustainability towards application sector. The present work also highlights the presence of brominated flame retardants on the selected mobile phone components. The plastics from 2nd and 3rd generation mobile phones have been considered in the present study.

II. Material and Methods

Plastic components from waste mobile phones for current study was collected from a local recycling facility. The work was divided into different stages. Initially, the plastic components from mobile phone waste were segregated for identification. These parts were then segregated based on the polymeric markings (as per ISO 1043) during the second stage, and were sub-divided into parts with and without marking and also as per the type of polymer, as shown in Table 1. The parts with no generic markings (F-NC, B-NC and Key-P) were melt-mixed during third stage, using a twin screw extruder (M/s Thermo Fisher, USA, Haake Rheomex OS PTW 16) to get a uniform composition for better FTIR identification studies [18]. The parts that had markings were directly sent to FTIR analysis (M/s Thermo Scientific, USA, Nicolet 6700, 4000cm-1 to 400cm-1) in fourth stage.

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TABLE 1. TYPES OF MATERIALS IN CURRENT WORK WITH SUB-CATEGORIES AND CODES

No	Category	Sub Category	Assigned Code
1	Front Casing	With marking	-
2		Without marking	F-NC
3	Back casing	With marking	-
4		Without marking	B-|NC
5	Keypad	Plastic	Key-P
6		Elastomeric	Key-E

Differential Scanning Calorimetry (DSC) measurements were carried out using a M/s TA Instruments, USA, Q20 under nitrogen using a heating rate of 10°C/min, from -70°C to 250°C. Thermogravimetric analysis (TGA) was carried out in a M/s TA Instruments, USA, Q50 under nitrogen with a heating rate of 10°C/min, from room temperature to 700°C. Also a GC/MS analysis was done to ensure the samples are BFR-free (Thermotrace GC Ultra – Thermo DSQ II GC-MS system under electron ionization model). Tensile and flexural (3-point bend mode) testing was carried out using an Universal Testing Machine (M/s Instron, UK, Instron 3382 UTM) machine fitted with a 100kN load cell operated at a cross-head speed of 5mm/min. Test specimens for tensile testing (165X19X3.2mm, as per ASTM D638) and flexural testing (127X13.5X3.2mm, as per ASTM D790) were preconditioned for 24 hours under standard conditions prior to testing. Combination of Tinius Olsen IT 504 Plastic impact tester with Tinius Olsen 899 Notch cutting machine was used for Izod impact testing in accordance with ASTM D 256 samples with and without notch. Heat Deflection Temperature (HDT) of the samples was also measured as per ASTM D648 (M/s Gotech, Taiwan, HV-2000-C3) at a heating rate of 2°C/min.

III. Results and Discussion

A. *Sorting and Identification*

After preliminary identification, around four thousand numbers of mobile components were sorted according to the product type. markings. Fig. 3 represents the quantitative data of sorting process.

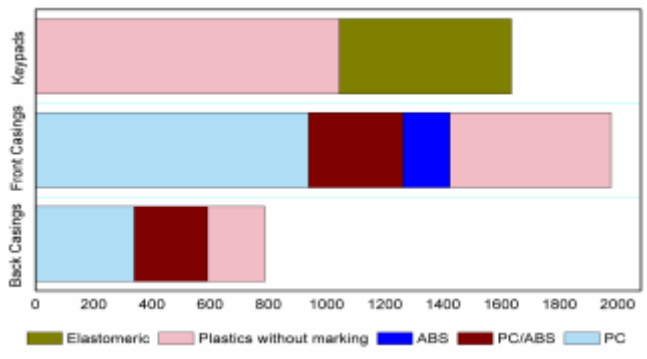

FIGURE 1. PRELIMINARY SORTING RESULTS OF PLASTICS RECOVERED FROM MOBILE PHONE WASTE (VOLUME IN NUMBERS)

Among these components, back casings were high in volume followed by keypads, whereas front casings were relatively low. This may be due to rapid growth in touch screen phone sales. Also, it is important to note that a major share of plastics had no generic markings. For further identification of these parts, FTIR analysis was adopted.

B. *FTIR Analysis*

Fig. 2 shows the FTIR spectra of the products recovered (F-NC, B-NC and Key-P) from mobile phone waste that had no marking.

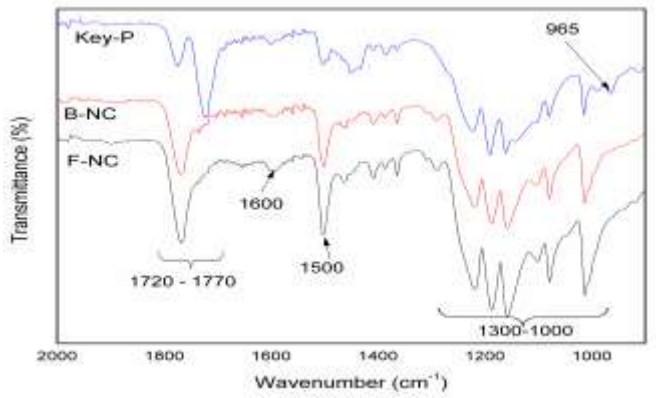

FIGURE 2. FTIR SPECTRA COMPARISON of F-NC, B-NC, Key-P

The observed multiple sharp peaks at (1300–1000) cm^{-1} and 1768cm^{-1} are indicative of carbonyl stretching and confirms the presence of polycarbonate in all three materials. Further, minor peaks were observed around 1600cm^{-1} and 1500cm^{-1} indicating the aromatic in-ring vibration which might be due to the possible presence of styrene from ABS, indicating that these materials might be also a blend of PC/ABS [6]. The FTIR spectra of Key-P also showed significant vibrations at 1600cm^{-1} and 965cm^{-1} indicating K-P might be a mix of high impact polystyrene and polycarbonate. The spectral peaks identified from Fig. 3, such as; 2966cm-1 (Si-OCH3), 1258cm-1, 862cm-1 and 785cm-1 (Si-CH3) and 1005cm-1 (Si-O-Si) positively identified Key-E as silicone rubber [7].

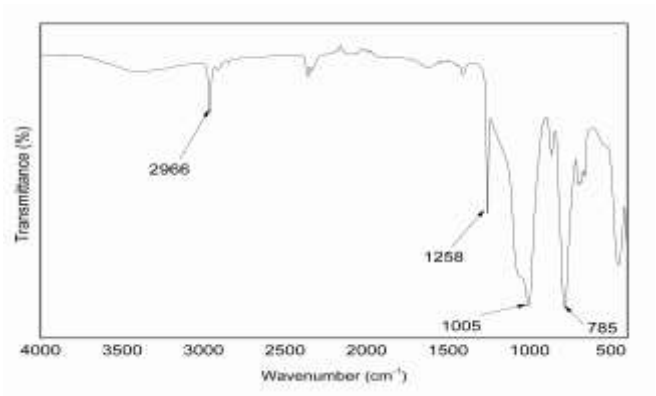

FIGURE 3. FTIR SPECTRA of Key-E

The products with generic markings were also checked with FTIR analysis and it was found that products were in complete conformance with their respective markings. Thus it is clear that together with generic markings and FTIR analysis, a complete identification for the plastics in mobile waste stream is possible.

C. Thermal Analysis

For detailed identification of recovered plastic parts, DSC and TGA studies were conducted and are represented in Fig. 4 (a) and (b).

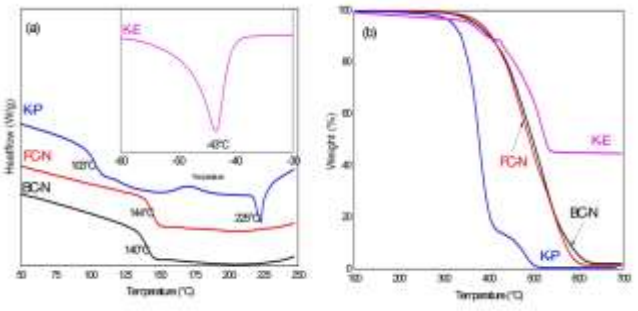

FIGURE 4. (A) DSC THERMOGRAMS (B) TGA WEIGHT LOSS CURVES FOR B-NC, F-NC, KEY-P, AND KEY-E

It can be understood from the DSC thermograms, shown in Fig. 4(a), that both F-NC and B-NC show single glass transition (Tg 140°C – 145°C, which is close to the Tg value of polycarbonate material (140°C - 150°C) [8]. This interpretation is also in line with FTIR spectra, which indicated these two materials consist of significant polycarbonate peaks.

The DSC of K-P shows a Tg around 100°C and a sharp Tm around 225°C, both indicating the possible presence of polystyrene. Thus it can be assumed that K-P is a blend of PC with PS or HIPS. The calorimetric study of K-E was performed over -70°C to 0°C (Figure 4 (a) inset) and a broad melting peak has been observed at -43°C, which is typical of filled silicone rubber material [9].

Fig. 4(b) shows the weight loss curves of F-NC, B-NC, Key-P and Key-E. It is observed that both F-NC and B-NC had degradation temperatures between 470°C and 500°C, supporting the FTIR and DSC results. The weight loss curve of K-P showed two-step degradation as it is a blend of different components which has been predicted by DSC and FTIR results. These two degradations of K-P can be attributed to polystyrene (300°C to 450°C) and polycarbonate (450°C to 550°C). TGA results of K-E showed around 55% of residue at 600°C, which is a typical observation of silicone rubber materials containing inorganic fillers.

D. GC/MS Analysis

GC/MS analysis of the samples was conducted to ensure that the recovered plastics were free from any kind of brominated flame retardants. The parts with generic markings can reveal the information regarding flame retardants type and quantity. It was observed in the current study that the parts which had generic markings showed no sign of BFRs. To ensure the absence of BFRs in the parts without, they were analyzed using GC/MS.

Fig. 5 shows the ion chromatograms obtained for the different samples. The results were matched with mass spectral reference library (NIST2011.L) for brominated flame retardants. The search was run for all brominated compounds from di-bromo to deca-bromo compositions.

Although several peaks were observed, none of them corresponded to any of the known BFR compounds. These results are synonymous with an earlier work done by Chen et al. (2012) [10] on their mobile phone housings.

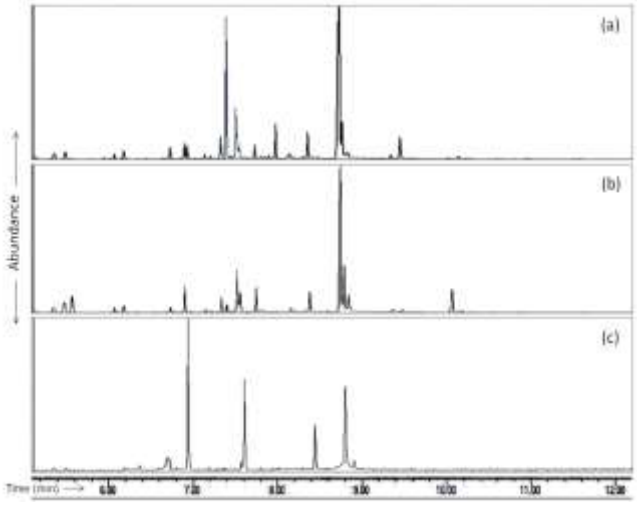

FIGURE 5. ION CHROMATOGRAMS OBTAINED FROM GC/MS ANALYSIS OF DIFFERENT SAMPLES; (A) FC-N, (B) BC-N AND (C) K-P

Hence, the non-existence of BFRs in the parts which are recovered from the mobile waste streams in the current study suggests that the materials can be recycled without any toxic concerns.

E. Mechanical Properties of Recovered Plastics

The mechanical properties of plastics recovered from mobile waste were studied to see how effectively they can be recycled into new products. The properties of parts were compared with a PC/ABS alloy (Cycoloy 1200HF), which is widely used in electrical and electronic equipment (EEE) manufacturing with reference to product datasheet.

The mechanical properties of PC/ABS based FC-N and BC-N were compared with commercial reference material data sheet and is shown in Fig. 6. It is observed that the flexural (strength and modulus) properties are at par with the reference data within the standard deviation limits.

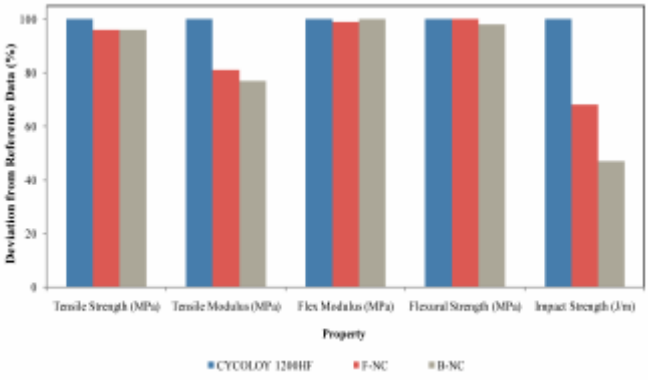

FIGURE 6. PROPERTIES OF RECOVERED PLASTICS (WITHOUT GENERIC MARKING) IN COMPARISON WITH REFERENCE MATERIAL DATA

Whereas, a decrease in tensile strength, tensile modulus and impact strength have been observed compared to reference material. This might be indication of some amount of degradation to the parts during its service life. The unsaturated sites such as polybutadiene (PBD) in ABS and carbonyl groups in polycarbonate are susceptible to

degradation under ageing process, resulting in strength properties. The reported data is also in line with the various related earlier works [6, 8]. From the Fig. 1, one can understand polycarbonate is also used solely to make the mobile phone components. Therefore a comparative report on mechanical and thermal properties of PC based products with a standard PC reference material has been presented in Fig. 7.

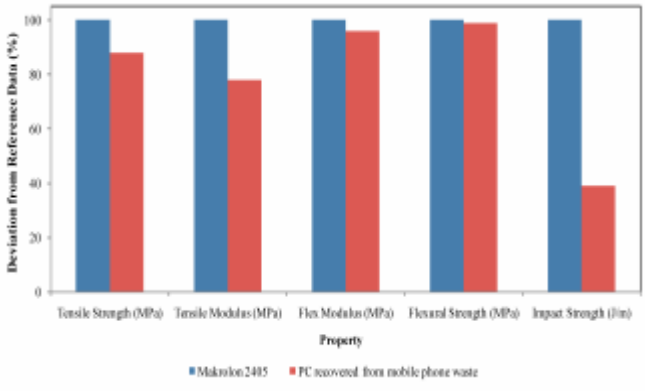

FIGURE 7. PROPERTIES OF RECOVERED PC IN COMPARISON WITH REFERENCE MATERIAL DATA

It is also understood from the data that only tensile and impact properties are significantly lower compared to the reference material, which is mostly due to the possible chain scission resulting from ageing during service life of the products.

The comparison data of mechanical strongly suggest the potential use of recovered plastics to tailor the needs of application sectors. The low impact strength can be effectively improved with the incorporation of rubber particles. As a futuristic work, one can grind the elastomeric components recovered from mobile phones, such as elastomeric keypads, to a fine powder and can be incorporated as a toughening agent within the recovered plastics in order to improve their impact strength.

IV. Conclusion

The polymeric parts from waste mobile phones were identified by combining visual, spectroscopic and thermal techniques. The polymeric marking was greatly effective in identifying a major share of the mobile plastic components. The parts that had no polymeric markings were identified by FTIR and thermal analysis methods. The collected polymers were found to have no kind of brominated flame retardants as per GCMS analysis and therefore can be reprocessed without any environmental toxicity concerns. The comparison of mechanical properties of recovered plastics with reference materials revealed that most of the properties are at par with the reference materials even after its service life. The short life of mobile phones can generate waste materials having good properties, which can be recycled with/without further modifications to tailor the industrial needs. Hence, the present work suggests that the plastics from mobile phone waste has sufficient potential for being recycled into new products.

Acknowledgment

The authors would like to thank Department of Chemicals and Petrochemicals, Government of India for the financial support.

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