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Plastic Recycling Assessment Tool Based On Plastic Part Material And Disassembly Orientation

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Abstract: Improper plastic waste management and disposal is a global issue and yet still unsolved in many countries. The problem becomes worse when the recycler needs to deal with complex plastic products that could disable their initiatives to recycling. This study aims to conceptualize three main factors to influence plastic product recycling such as plastics grade, disassembly orientation, and different color into an assessment tool to evaluate the plastic product recycling performance. The data collection of this study was conducted based on Analytical Hierarchy Process (AHP) methodology before it was used for assessment tool development. The assessment tool has been reviewed and validated by two field experts in product design and green product field. The developed plastic recycling assessment tool could assist the industry practitioners especially the product designers in rethinking of their conceptual design that could ease the recycling activities.

Keywords: Plastic Recycling, Assessment Tool, Product Disassembly, Sustainable Product Design

1. Introduction

Plastic waste is a global issue faced by both developed and developing country including Malaysia [1]. Environmental problems related to plastic waste have become a major problem in Malaysia, particularly due to mismanaged of the plastic wastes [2]. In addition, this problem caused by the high demands of plastics based products, resulting plastic waste generation is too fast than its recycling rate. Therefore, unsurprisingly, many advanced countries are exporting their plastics waste to developing countries for recycling or landfilling [3].

Although much researches were done on product recycling, however, limited research is found to focus on product recycling assessment tool, particularly with consideration of material grades, product's

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colour and product disassembly orientation. For that reason, an investigation was conducted on plastics part disassembly orientation, material type and colour factor towards plastics recycling performance. A plastics recycling assessment tool was developed in the end of this study.

2. Factors that influence the plastics recycling process

In this study, three categories of factors to influence plastics recycling have been considered namely plastics materials, product disassembly orientation, and product colour.

2.1 Plastic Materials

In general, plastic materials for recycling can be simplified into four (4) categories [4]. Firstly, plastic that easy to recycle which is the easiest and most common plastics polyethylene terephthalate (PETE) code 1 and High-Density Polyethylene (HDPE) code 2. Second is plastics that are less commonly recycled the Polyvinyl Chloride (V or PVC) code 3, Low-Density Polyethylene (LDPE) code 4, Polypropylene (PP) code 5 products. The third category is useful plastics to recycle, Polystyrene (PS) code 6 products. Lastly, the hardest plastics to recycle is categories in code 7 characteristic products. According to the Malaysia National Solid Waste Management Department, there are more than 100 types of plastic available and applied in various industries. Given that the characteristics of the plastics often required to be recycled differently but only 6 (six) types of plastic are commonly used. These can be classified with a number that used to facilitate their classification for recycling which also means the characteristic of plastics is required for a certain stage.

2.2 Product Disassembly Orientation

In reverse engineering, disassembly is an important process to ensure all the sub-components can be dismantled for service, re-use, etc. During product development phase, the disassembly process needs to be considered by the designer especially for end of life management purposes [5]. Product disassembly is affected by many factors and criteria. For example, according to Srinivasan et al. [6], in selecting an appropriate disassembly method, first is by optimized the disassembly sequence, second by evaluating the disassembly sequence cost, lastly able to produce design change recommendations in consideration that can make a product easier to disassemble and at the same time have potential benefit to the environment.

2.3 Product’s Colour

Product’s colour has often played a primary role in product ecstatic performance. Colour element is also used to convey information about how the commodity is meant for or how it is created. During recycling, coloured particles can be sorted by form of polymer and colour and coloured particles can be reprocessed into other coloured components as by-products for other purpose [7]. For colour particles, they can be categorized in two which is bright and dark. Although the highest value of plastic recycle is colourless, in nowadays technologies a range of innovations is used for colouring plastic packaging goods with coatings that offering the possibility of colour removal during recycling. For clear plastics, it still favoured on the highest recycled materials market because of their highest material performance. For instance, clear or transparent plastic are most suitable for recycling, color plastic is less suitable for plastic recycle while the coating is least suitable for recycling due to its high cost. This is due to the fact that transparent plastic can be coloured and will be reused in other colours with greater flexibility. Different from the opaque or black colour plastic that allows a high rate of recycled material since any recycled coloured plastic can only be turned black. As a result, transparent plastics still have a high reputation relative compare to the dark colour of plastics that owing to easy recycling [8].

3. Methodology

This study was conducted based on three phase of methodology. Firstly, details background studies on plastics part material recycling is conducted. Review of past studies was conducted thoroughly to identify the factors and parameters to influence plastic product recycling performance. In the second phase, data collection using Analytic Hierarchy Process (AHP) approach is chosen to determine the priority weightage of the recycling criteria [9]. In the third phase, the data obtained from the AHP approach were then being analyzed the factors importance weight, before it was used to development recycling performance assessment tool. The assessment tool was tested and validated by two experts in the field to finalize its feasibility to be used by practitioners or for future research purpose.

4. Results and Discussion

In this section, discussion on the result obtained from the AHP data collection, and validation results of the plastic recycling assessment tool are presented. In AHP framework, three criteria have been categorized such as material type, disassembly orientation, and colour. Each of these criteria can be separated into a few sub-criteria. For the criteria of the material of plastic, it can be separated into Polyethylene Terephthalate (PET), High-Density Polyethylene (HDPE), Low-density polyethylene (LDPE), Polypropylene (PP), Polyvinyl chloride (PVC), Polystyrene (PS), and Mix Polymers. In the disassembly orientation aspect, there are eight pairs of samples of orientation were generated. As for the colour of plastics parts, it was split into sub-criteria such as transparent, bright, opaque, and coating. There are twenty plastic experts from industry and government sectors were participated in the AHP data collection.

In AHP results analysis, a total of twenty sets of data were obtained and transferred from the matrix pairwise comparison of AHP to structure the judgment consistency for the criteria and sub-criteria. These data were obtained from the industry practitioner such as manager, designer, engineer, material specialist, and etc. Next, these data were gone through priority comparison analysis using Expert Choice Software. Table 1 below shows the ranking of analyzed criteria and sub-criteria that influence the recycling performance for plastic product. It can be found that color is ranked as the most important part in plastic recycling, followed by the materials, and last the disassembly orientation.

Table 1. Ranking of criteria to influence plastic product recycling performance

Criteria	Local weight	Sub-criteria	Sub-criteria weight	Global weight	Global weight Rank
Material	0.580	Polyethylene Terephthalate (PET)	0.344	0.069	**3**
		Density Polyethylene (HDPE)	0.202	0.024	**19**
		Polyvinyl chloride (PVC)	0.101	0.005	**23**
		High Low-density polyethylene (LDPE)	0.132	0.010	**21**
		Polypropylene (PP)	0.126	0.010	**21**
		Polystyrene (PS)	0.052	0.017	**20**
		Mix Polymer (Other)	0.042	0.001	**26**
Disassembly Orientation	0.209	1A	0.598	0.075	**2**
		1B	0.402	0.034	**18**
		2A	0.491	0.051	**12**
		2B	0.509	0.054	**8**
		3A	0.502	0.053	**10**

		3B	0.498	0.052	**11**
		4A	0.506	0.054	**8**
		4B	0.494	0.051	**12**
		5A	0.456	0.043	**16**
		5B	0.544	0.062	**5**
		6A	0.490	0.050	**14**
		6B	0.510	0.055	**7**
Color	0.211	Transparent	0.649	0.089	**1**
		Bright	0.133	0.004	**24**
		Opaque	0.145	0.004	**24**
		Coating	0.072	0.001	**26**

4.1 Assessment tool

From the AHP analysis, the obtained priority weightages from all the criteria were used to develop an online based plastic recycling assessment tool as shown in Figure 1.0 below, and Figure 2.0 shows the example results generated using the plastic recycling assessment tool.

Figure 1: Online based Assessment Tool for Plastic Recycling Performance

Figure 2: Online based Assessment Tool for Plastic Recycling Performance

In term of the assessment tool score evaluation, it was based on the submission score obtained from the AHP weightages to determine the level of plastic product recycling performance. The scoring formula used in this assessment tool is shown below:

$$SO = Scr + Icr + Sma + Ima + Sdo + Ido + Sco + Ico \qquad \text{Eq. 1}$$

where, *SO* = Score obtained from all factors, *Scr* = Score obtained in the main criteria, *Icr* = Score obtained from the main criteria, *Sma* = Score obtained in sub-criteria of material, *Ima* = Specific weight for selected sub-criteria of material aspect, *Sdo* = Score obtained in sub-criteria of disassembly orientation aspect, *Ido* = Specific weight for selected sub-criteria of disassembly orientation aspect, *Sco* = Score obtained in sub-criteria of colour aspect and *Ico* = Specific weight for selected sub-criteria of colour aspect.

The developed assessment tool was validated and be reviewed by two university experts in the aspects of user interface, graphical modeling, quality results estimation, flexibility, and knowledge-based system. Overall, both of the experts are agreed with the functionality and the assessment approaches of the assessment tool.

5. Conclusion

In conclusion, this study is designed to provide a better understanding of plastic product recycling through an assessment tool for recycling decision. Three main factors to influence product recycling have been considered in the assessment tool namely plastic part materials, disassembly orientation, and the base colour of the plastics. The assessment tool has obtained positive feedbacks from the experts in the field to confirm it usefulness to the industry practitioners. With the presence of the assessment tool, it enables industry practitioner to perform assessment during in the product design and development phase, particularly to relate their design to the recycling performance

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