An Intelligent Approach to Recyclability Evaluation In Automobile Design

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Abstract. *An automobile comprises of thousands of parts of which 74-75% is composed of ferrous and non-ferrous material and 8-10% are from plastics, and typically only less than 75% of weight can be recycled and the rest cannot. As a result this leads to an increasing number of landfill required. Unfortunately, there is no more space available. With the importance of environmental protection and sustainable development; recyclability of materials is now becoming increasingly important in automobile design. Recyclability measures the efficiency of material recycling. Due to environmental regulation, automobile manufacturers are working to improve recyclability as well as reducing amount of recycle material to be used in new vehicles. One approach to evaluating recyclability during automobile design is mandatory needed to asses and give consideration whether the design has meet certain recyclability level. Although many approaches have been proposed by several authors, there is still a need for an intelligent solution that combines CAD system with recyclability evaluation in a single application. The purpose is to incorporate environmental consideration during the design phase. This paper attempts to propose an approach for recyclability evaluation using fuzzy method. A case study on an automobile's side mirror parts is presented to give clear figure how recyclability evaluation works.*

Keywords: *environmental protection, automobile design, recycling, recyclability*

1. INTRODUCTION

Environmental awareness and the pressure of more stringent regulations such as The EU Directive, give pressure on automobile manufacturers to produce a more environmental friendly products. Automobile products comprise of thousand parts of which 74-75% is composed of ferrous and non-ferrous material and 8-10% are plastics. Typically only less than 75% the weights can be recycled and the rest cannot. This leads to the increasing number of landfill required. Unfortunately, there is no more space available. According to Williams, et. al (2007), the automotive recycling infrastructure successfully recovers 75% of the material weight in end-of-life vehicles mainly through ferrous metal separation. However, this industry faces significant challenges as automotive manufacturers increase the use of nonferrous and non metallic materials. Vehicle composition has been shifting toward light material such as aluminum and polymer with a consequence of higher impact on the environment. A vehicle affects the environment through its entire life cycle in terms of energy consumption, waste generation, green house gases, hazardous substances emissions and disposal at the end of its life (Kanari, 2003).

To overcome this problem, The European Union has established The EU Direction for end of life vehicle and underlined that in 2015, recyclability rate of automobile must reach 85%. According to The EU Directive, recyclability means the potential for recycling of component parts or materials diverted from an end of life vehicle. Vehicle manufacturers and their supplier are requested to include this aspect at the earlier stage of the development of a new vehicle, in order to facilitate the treatment of a vehicle at the time when it reaches its end of life. Many countries are now refer to the EU legislation and try to formulate a strategy to fulfill this requirement by using less of non-recyclable material in their products,

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calculating for energy usage, limit waste stream, etc.

Recyclability means the potential for recycling of component parts or materials diverted from an end-of life vehicle. Improving recyclability must be addressed in the design process. The challenge of the designer is to maintain and even improve previous level of recyclability either by using less material, substitute recyclable materials or other design approaches that will satisfy certain recyclability level.

This paper proposes an approach for recyclability evaluation using the fuzzy method. A case study on an automobile's side mirror is presented to give a clear picture of how recyclability evaluation works.

2. RECYCLABILITY EVALUATION

There are several methods that have been developed to evaluate recyclability of a product. Tsuji (2006) proposed The Recyclability and Toxicity Score. This method attempts to calculate recyclability target of automobile in percentage and value of toxicity by using the toxic equivalency potential (TEP). TEP metric materials used in a car design is an equivalent value with toxic substances. The recyclability is determined by summing the masses of

$$R = \frac{mmrm + mrep + mf + mnf}{mv} * 100 \quad (1)$$

where:

mmrm = mass of mandatory removed material
mrep = mass of reusable parts
mf = mass of ferrous metals
mnf = mass of non-ferrous metals
mv = mass of vehicle

The mass of mandatory removed material consists of mass of tires (mt), mass of batteries (mb), and fluids (mfl), shown as :

$$m_{mrm} = m_t + m_b + m_{fl} \quad (2)$$

The mass of reusable parts consists of body panels and engines. The terms m_f and m_{nf} represent mass of ferrous and non ferrous metals in the automobile. The next step in the scoring process is to determine toxicity score by using Toxic Equivalency Potential (TEP). TEP system is a metric that compare the mass of heavy metal with the mass of benzene or toluene. The toxicity of benzene or toluene is based on cancer risks. Heavy metals that are considered as toxic metals are lead, mercury, hexavalent chromium, cadmium. The amount of toxic metal in the automobile is calculated as a deduction of

Another approach developed by Hiroshige, et. Al (2001) uses Recyclability Evaluation Methods (REM). The methods the recyclable materials and dividing by ELV weight. Recyclability is measured as:

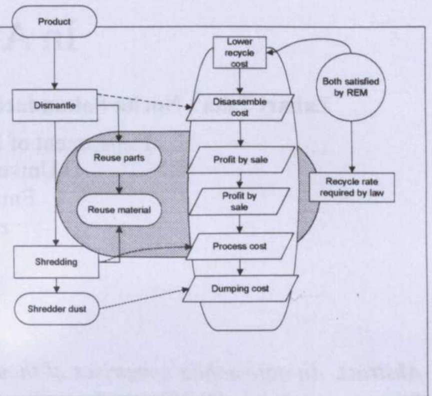

Figure 2: Area covered by Recyclability Evaluation Method (REM)

determine product's ease of recycling in advance, without complex product prototyping and the experimentation and it is desired at the early stage of design. The REM is based on 100 point scale that indexed on the ease of recycling and cost. The score decreases from 100 as the cost value becomes larger. Two variable used in REM are recyclability evaluation score (E) to access design quality in terms of difficulty of recycling, and estimated recycling cost (K) to project recycling cost. In this way, design improvement is also taken into consideration.

Recyclability Evaluation Score evaluate recyclability as well as recycling cost based on 100 scale. The calculation formula is based on these principles:

- Recyclability evaluation score is basically calculated using recycling cost estimate.
- The score decreases from 100 as the cost value becomes larger. Figure 2 and Figure 3 illustrates the area that covered by REM and the concept of recyclability evaluation respectively.

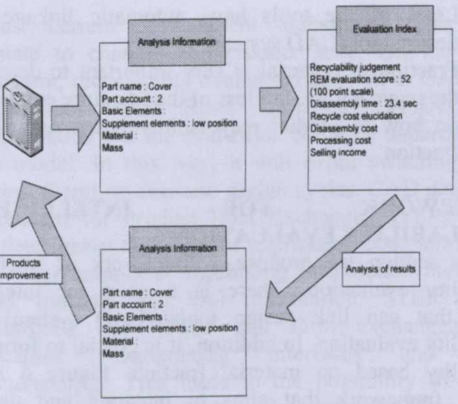

Fig 3. Concept of Recyclability Evaluation

Putting recycling expenses components as well as recyclability target is an innovative approach that is very useful to guide design engineer in selecting materials used. However, the method does not clarify sensitivity analysis to adjust the changing of recycling expenses. Estimated value of cost is only based on the actual or historical data.

To obtain recyclability score, Zettier, et al, (2000) developed Suitability for Recycling (KE). The score compare cost components arising from materials that are not recycled with cost that occur in the material recycling process chain. The formulation is as follow:

$$KE\ (\%) = \frac{\text{cost of equivalent new material + disposal}}{\text{cost of dismantling + reprocessing+logistics}} \quad (3)$$

Recycling class are set as shown in Table 1. R1 and R2 are defined as "green" components.

Table 1: Recycling class

Recycling class	Criteria for suitability for recycling	Problem materials
R1	>100%	none
R2	80-100%	none
R3	<80%	existing

In this research, dismantling time is a crucial factor to calculate suitability of recycling. The current method computes suitability of recycling as an overall value for each complete and finished work step, and not for individual components. In order to determine suitability of recycling, the sum of all expenditure for the components in work step is compared with the earnings as follow:

$$KEeconomical = \frac{\sum \text{proceeds}}{\sum \text{costs}} \geq 100\% \quad (4)$$

This method proposes for an approach for cost optimization as well suitability of recycling derived from dismantling analysis. However, the scale for suitability for recycling (KE) does not give exact value. This makes it difficult to determine whether materials are classified as R1, R2 or R3. A more simplified method to classify is needed. Another method introduced by Huisman, et. al (2001) presents a new approach in calculating recycling quotes. The general idea of EWRQ is to replace conventional weight-based recyclability that only address weight factor for material fraction and does not represent the actual environmental value. In EWRQ method, recyclability is reflected from environmental impact, since various type of material has different environment load.

The EWRQ calculation is weighted using eco-indicators 95, eco-indicator 99 and Toxic Potential Indicator (TPI). Then, the result is transferred to a 0% to 100% scale by using normalization step. There are three steps to generate EWRQ:

a. Quantification of the actual impact of a product by using several data as follows:
b. The product's overall material composition
c. The percentages (and grades) in which every material appears in every fraction for each end-of life treatment

An environmental assessment model to obtain environmental score by using eco-indicator 95, eco-indicator 99 and TPI define the reference values for a minimum and maximum environmental impact. In this case, maximum environment impact is the highest environmental damage, with all materials ending up in the environment (water, soil and air).

The environmental impact contribution from material fraction is then positioned in the scale between 0% - 100% using normalization step as illustrate in Fig. 4.

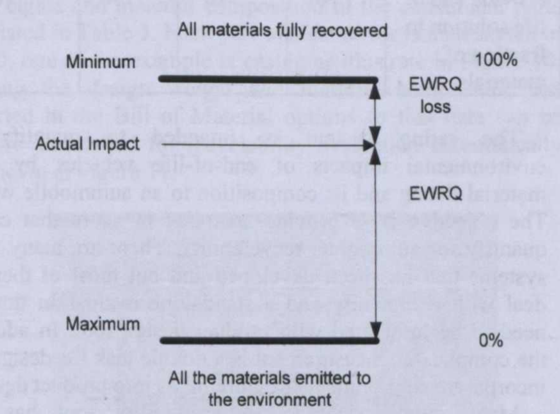

Figure 4: Normalization step

To achieve recyclability score, EWRQ is very useful to give insight what environmental impacts for the use of each material. The model is based on end point score that use subjective weighting steps; therefore detailed information for specific fractions of material to specific environmental problem is needed.

A vehicle, particularly automobile, comprise from thousand of material components that give significant impact to environment throughout its life cycle in terms of energy consumption, waste generation, green house gases, hazardous substances emission and disposal at the end of their life. Enforcement of ELV regulation has strong focus on reuse and recycling target that in 2015 should achieve 85% by average weight per vehicle. This regulation has shift full responsibility to manufacturer to facilitate end of life treatment. Thus, it is obvious to strategically develop a way that can reduce environmental burden, by improving recyclability of vehicle.

Comparison of existing research on recyclability evaluations are described in Table 2.

Table 2: Comparison of existing recyclability evaluation

Feature	Methods/tools			
	RTS	REM	KE	EWRQ
Estimation of recyclability score	Yes	Yes	Yes	Yes
CAD based recyclability evaluation	No	Yes	No	No
The model consider cost optimization	No	Yes	Yes	No
Provide end of life solution to fraction of materials	No	No	No	Yes

The rating system is intended to quantify the environmental impacts of end-of-life vehicles by using material listing and its composition to an automobile weight. The objective is to provide an index or score that can be quantify for automobile recyclability. There are many rating systems that has been developed and but most of them are deal with complexity and a standalone evaluation that still need to be integrated with product design tool. In addition, the complicated measurement is a double task for designer to incorporate environmental requirements into product design.

Many studies regard to recyclability tool has well demonstrated, but several obstacles detectable:

a. The evaluation is not incorporate with the product development phase that makes design correction more complicated.
b. Some methods found are not simply understandable, thus it makes double task for design engineer
c. Least of the tools have automatic linkage with design tool (CAD system).
d. Fraction of material is very important to determine the recyclability, but less of the literature emphasizes on how to predict recyclability based on material fraction.

3.FRAMEWORK FOR INTELLIGENCE RECYCLABILITY EVALUATION

In this section we propose a framework of intelligent recyclability evaluation. There is a need for integrated solution that can link design tools (CAD system) with recyclability evaluation. In addition, it is crucial to formulize recyclability based on material fraction. Figure 6 is the proposed framework that aims to integrate and develop connectivity between design tools and end-of-life strategies of automobile, particularly its recyclability.

The framework proposed for a linkage between design tools with recyclability evaluation and make design correction during product design regards with environmental recommendation.

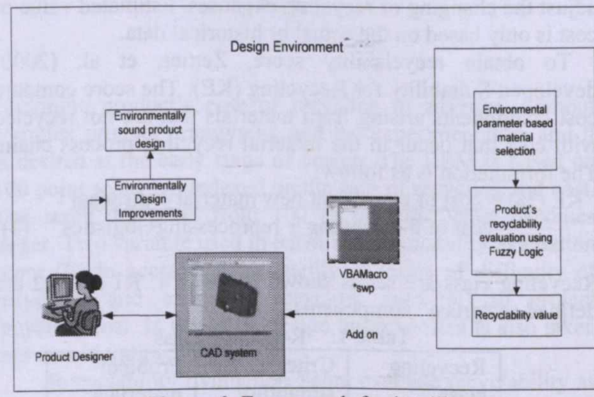

Figure 6: Framework for intelligence Recyclability evaluation

Design activity for many products is carried out using 3D (three dimensional) software tools. The software tool is equipped with virtual prototyping platforms, where a product can have virtual geometric properties such as size, volume, features, weight, and material composition which generated from product design database. Current availability of design tool software integrated with environmental tool is very limited; therefore designer who runs this application is not prepared with environmental knowledge. Design tool significantly modify geometric form of a product and does not included design guidance on material selection and its recyclability. On the other hand, ELV regulation called out for recyclability target that must be fulfilled. Thus, in design environment, product designer will determine part and material that compose a product then use the CAD data as an input to recyclability evaluation.

Most current environment assessment tools did not automate to changes the product state. On the proposed framework, recyclability evaluation adds-on in CAD systems using Macro Visual Basic Application (VBA), so data transformation and the evaluation could be undertaken in the same model. In this way, it will avoid switching to other systems, therefore decrease design cycles. CAD data are store in Standard for Product Data Exchange (STEP) format, a complete format that most of application compatible and can carry large amount of machining information including the model, material and tool information. STEP format is standardized ISO 10303 that form exchangeable files, application programming interfaces and database implementation. This leads to the possibility of using the same standard data throughout the system and avoiding data losses.

Recyclability module add-on in the CAD system aims to provide estimation of a product's ability to be recycled. This tool is connected with design tool application using object library that available in CAD system. Thus, from this point of view, designer can easily make prediction to meet recyclability target.

The first step to determine recyclability value is to get data from CAD system. Data that needed in recyclability evaluation is material fraction and mass for every part. Then, parameter that significantly influenced recyclability is set according Eco Indicator (EI) data to determine environmental impact. Once parameter is set then recyclability evaluation is then formulized using clustering method to determine recyclability region based on material composition of parts that has been inputted by design engineer as described in Fig. 7.

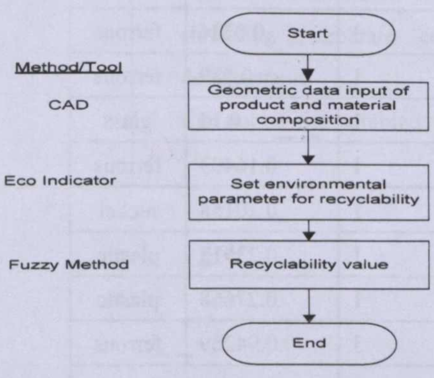

Figure 7: Steps in determining recyclability

In Figure 6, material database is added in the tool so that designer can easily track which material that has environmental warning.

With this proposed system, designer can eliminate time that used to gather both environmental data with technical data. The framework can allow designer to make optimal decision during product design as well as meet environmental requirements.

4.CASE STUDY

Many environmental assessment tools can be applied to products but less are practically easy to use by the product designer. This section aims to establishing how recyclability evaluation can be used by product designer to improve their design as well as meet environmental requirement.

A case study a side mirror of a car has been conducted. Initially, a side mirror of a car is manually disassembled (Figure 9).

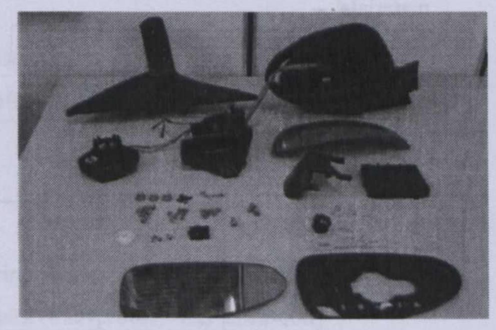

Figure 9: Disassembled side mirror

Weights and material composition of the constituent parts are listed in Table 3. Each part of side mirror is then sketch in CAD, one of the example is casing as illustrate in Figure 10. During the design weight and material composition are inserted in the Bill of Material options so that data can be restore and called for recyclability evaluation automatically as shown at Figure 11.

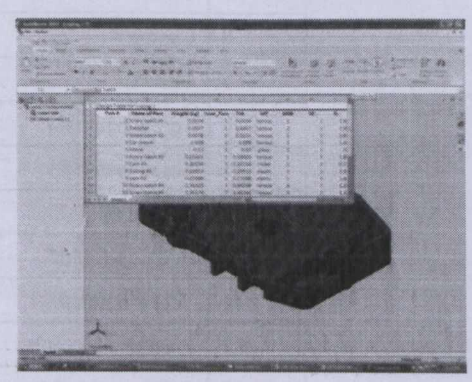

Figure 10. Casing draw in CAD systems and Bill of Material each part

To achieve certain level of recyclability, automobile designer must calculate recyclability value for each part. According to Mattieux et. al (2008) recyclability of a product is not only influence by fastening, architecture and material choice, but also on the combination of material and joints among them. In addition, recyclability also considers many other aspects such as economic value of virgin material and secondary materials, the availability of technology and environmental impacts of materials.

To calculate recyclability, all of the variable that influenced recyclability should be add in the model. Recyclability should have three aspects:

- To increase quantity of recyclable components and materials
- To increase economic benefit (is not consider on this paper)
- To decrease environmental impact

Table 4 shows variable that considered for recyclability evaluation. Parts that constituent's car components (side mirror) are then evaluated using fuzzy tool box in MatLab. In this case, a membership function should be determined first for each variable. The next is constructing If-Then rule for recyclability according to given variable. Data then inserted to MatLab for computation and it yield to recyclability value at Table 5.

Table 3: Weight and material composition of car's side mirror

Part #	Name of Part	Weight (kg)	Number Of part	Total weight	Material Type
1	Screw batch #1	0.0034	1	0.0034	ferrous
2	Retainer	0.0067	1	0.0067	ferrous
3	Screw batch #2	0.0078	3	0.0234	ferrous
4	Car mount	0.089	1	0.089	ferrous
5	Mirror	0.15	1	0.15	glass
6	Screw batch #3	0.16403	1	0.16403	ferrous
7	Cam #1	0.20158	1	0.20158	nickel
8	Casing #1	0.23913	1	0.23913	plastic
9	cam #2	0.27668	1	0.27668	plastic
10	Screw batch #4	0.31423	3	0.94269	ferrous
11	Screw batch #5	0.35178	7	2.46246	ferrous
12	Casing #2	0.38933	1	0.38933	plastic
13	Plastic Mould	0.42688	1	0.42688	plastic
14	Screw batch #6	0.46443	2	0.92886	ferrous
15	Plastic	0.00012	1	0.00012	plastic
16	Subassembly Motor	0.0077	1	0.0077	ferrous

17	Screw batch #7	0.0056	2	0.0112	ferrous
18	Casing #2	0.045	1	0.045	plastic
19	Main Case	0.23	1	0.23	plastic

Table 4: Variable consider for recyclability evaluation

Variable	**Approach use**
Environmental Impact (EI)	Based on Eco-Indicator. Parts weight are multiply with Eco indicator to determine environmental impact
Technical possibility (TP)	Rating: 1 Technical possibility of recycling material is high, infrastructure is available 2 Technical possibility of recycling material is medium, infrastructure is rare 3 Technical possibility to recycling material, no infrastructure is available
Material Separation Rating (MSR) [18]	Rating : 1 may be disassembled easily manually 2 may be disassembled with effort manually 3 may be disassembled with effort requiring some mechanical means or shredding to separate component materials. The process has been fully proven. 4 may be disassembled with effort requiring some mechanical separator shredding to separate component material. The process currently under development. 5 Can not be disassembled. There is no known process for separation

Table 5. Recyclability value for each part

Part #	Name of Part	Recyclability Value
1	Screw batch #1	2.50
2	Retainer	3.26
3	Screw batch #2	3.04
4	Car mount	3.49
5	Mirror	3.50
6	Screw batch #3	2.10
7	Cam #1	3.50
8	Casing #1	3.50
9	cam #2	3.50
10	Screw batch #4	3.50
11	Screw batch #5	1.33
12	Casing #2	1.41
13	Plastic Mould	3.51
14	Screw batch #6	3.51
15	Plastic	3.51
16	Subassembly Motor	3.51
17	Screw batch #7	3.51
18	Casing #2	3.51
19	Main case	2.09

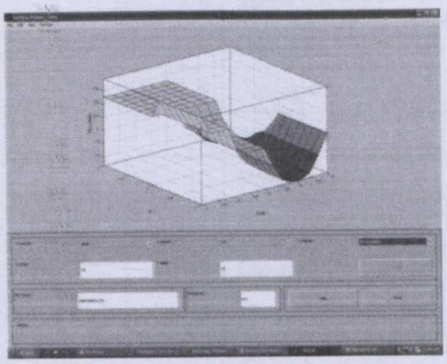

Figure 12. Surface graph for recyclability with input MSR

and TP

Figure 12 give explanation that the lower TP and MSR will raise the recyclability value.

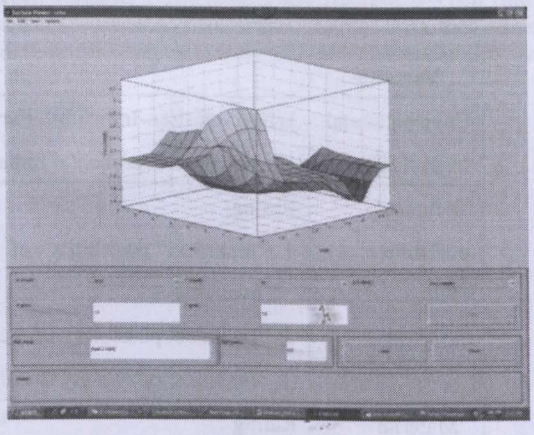

Figure 13. Surface graph for recyclability with input EI and MSR

Surface graph in Fig 13 shows that the lower MSR and EI will give higher recyclability value. So the higher EI will decrease recyclability value.

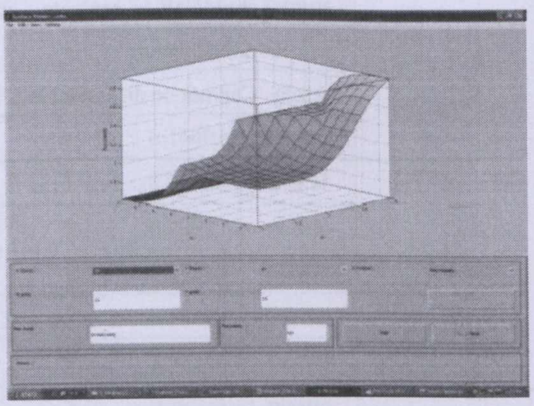

Figure 14. Surface graph for recyclability with input TP and EI

Surface graph in Fig 14 shows that the lower TP and EI will give higher recyclability value.

In Table 5 can be shown that part number 11 and 12 have lowest recyclability value, 1.33 and 1.41. It is proof that these parts potentially have lowest level of recyclability regards to EI, MSR and TP. Therefore, it is necessary to evaluate these parts and explore for some design improvement.

After recyclability value has been achieved, parts that have lowest recyclability value should have analyzed. Here, the design team has to be able to draw up each criterion for design improvement. Table 5 shows recyclability values, and it can be concluded that only part number 11 (screw batch #5) is on the lowest recyclability value. This means that there is the need for redesign or make another scenario for this part.

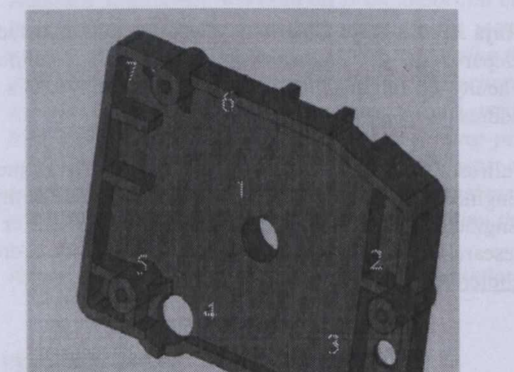

Figure 15: Casing #2 with seven srew batch#5

Possible scenarios for redesign according with the result of recyclability evaluation are:

1. Reduces number of screw batch
   It can be explained that seven screw batch #5 composing casing #2, makes it difficult and time consuming for material separation and give longer disassembly time. Therefore the design should not use too many screw. However designer need consider that joint strength between casing and other part may reduce. An experiment of redesign has been done with reducing 4 screw and recyclability is recalculated, yield to the value of 2.08 that is much higher that before (1.33).
2. Change material for fastener
   Using the same material between fastener and casing will increase material separation rank; therefore it will raise recyclability value. Using this scenario, we recalculate recyclability and the value was 3.47, a 2.06 higher than before.

Based on two scenarios, the designer can select second scenario which has higher recyclability value.

5. CONCLUSION AND FURTHER WORK

An intelligent approach to recyclability evaluation is proposed. A case study on an automobile side mirror was introduced. It was found that recyclability evaluation of a product is highly dependent on the scenario being considered. The designer has to carefully define the scenario for design improvement. A list of possible scenarios has to be developed to assist the designer in improving recyclability.

On the future method has to be systematically transform into single application that will allow the designer to automatically store and call data directly from and to CAD system. Currently the approach comprises two steps: retrieve data from CAD system and submitting to a fuzzy based recyclability evaluation.

A more variable can be added to influence recyclability such as incorporate economic benefit of recycling and minimizing Automotive Shredder Residue (ASR).

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