Developing Multi Criteria Decision Making Model in Procurement Chains for Sustainable Products

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***Abstract*— The manufacturing organizations have recognised the importance of sustainability with increasing government regulations and concern of sustainable products among customers. The environmental impact, economical advantage and social performance are the three dimensions of product sustainability and it's often termed as triple bottom line concept of sustainability.**

For improving sustainability at product level, product design, material selection and manufacturing process are the important orientations needed to be considered. To achieve sustainability the material used for product or product part plays an important role. To meet the triple bottom line concept of sustainable material selection the multiple criteria related to the physical nature of the product and its production scenario are to be considered.

This work developed a Multi Criteria Decision Making (MCDM) model and weighted the criteria and sub criteria for material selection for the front mudguard part of two-wheeler. The commonly available and used material for manufacturing the part is polymer. The material alternatives selected for the part are Acrylonitrile Butadiene Styrene (ABS), Polypropylene, Nylon (PA), Polyethylene (PE), Polypropylene (PP), Polyethylene terephthalate (PET), Acrylic (PMMA), polystyrene (PS) and Poly Vinyl Chloride (PVC) based on k-mean cluster analysis on a data set collected of thirty polymers. These criteria included in the work are physical properties and other factors which includes density, specific stiffness, young's modulus, strength, cost, elongation, toughness, recyclability, maximum temperature limit and energy of the polymer. MCDM methodology of Analytical Hierarchy Process is used for selection of the best alternative from the available choices.

***Keywords*— Sustainability; Material Selection; Multi Criteria Decision Making**

I. INTRODUCTION

Sustainability is a significant enabler to race in the global scenario. Sustainability concept focus on three dimensions: environmental, economic and social performance. Rapid growth in Indian economy in the past two decades procured tremendous benefits, yet it has also highlighted the demand for energy and natural resources. Between 1980 and 2010, India mark it a growth of 6.2% while the world as whole pick up a growth rate of 3.3%. India's share in global GDP more than doubled from 2.5% in 1980 to 5.5% in 2010. For India, eradication of poverty and inclusive growth should be the governing objectives of the activities in the post 2015 development agenda.

While sustained growth is vital for further rising living standards, convening India's poverty reduction objectives, as well as food and energy needs, it ought to be made greener and sustainable. Attempts are therefore needed to increase energy and resource efficiency, especially through lower fossil fuel consumption, acceptance of clean technologies, sustainable agriculture, effective waste management, sustainable logistics management, etc. [Rajesh Kumar, (2012)].

For improving sustainability at the product level, three courses required to be considered; Product design, material and manufacturing process. Raw material used for product development plays an important role in environmental impact minimization and economical performance improvement and thereby achieving sustainability. In recent years, several systematic methods have been proposed to help the designer in the selection of materials and processes [Charles J (1996), Farag M. (1997)]. Of the more commonly used quantitative selection methods, that of Ashby is based on the definition of material indices, consisting of sets of physical–mechanical properties which, when maximise some performance aspects of the component under examination [Ashby M,(1995)]. Defining these indices, it is possible to compile selection charts summarising the relations between properties of materials and engineering requirements [Ashby M (1992)]. Usually taking into consideration the physical–mechanical properties of materials, these selection charts can be extended to introduce some environmental properties [Navin-Chandra D(1991)].

Sustainable material selection involves multiple criteria, to meet the product requirement and triple bottom line concept sustainability. Multiple-Criteria Decision-Making (MCDM) method has been utilized to solve material selection problem. MCDM is concerned with structuring and solving decision and planning problems involving multiple criteria. The ever increasing variety of materials is available today, with each having its own characteristics, applications, advantages, and limitations. In choosing the right material, there is not always a single definite attribute of selection and the designers and engineers have to take into account a large number of material selection attributes. The selection of an optimal material for an engineering design from among two or more alternative materials on the basis of two or more attributes is a multiple attribute decision making (MADM) problem. The selection decisions are complex, as material selection is more challenging today. There is a need for simple, systematic, and logical methods or mathematical tools to guide decision makers in considering a number of selection attributes and their interrelations and in making right decisions.

The work tried to develop a MCDM model for a two wheeler fibre part (mudguard). The criteria for us include; social, economic and environmental under which sub criteria such as Toughness, Density, Temperature limit, Specific Stiffness, Fracture toughness, Young's modulus, Strength, Elongation etc. are considered. The alternatives are to be considered are the polymers which can substitute the existing fibre.

The work started with a detailed study on sustainability and MCDM methodologies for material selection and arrived at a selected product. Data collection and analysis on properties of polymers and identify the alternatives and criteria for the material selection problem is arrived on basis of expert opinion and literatures. Thereby reached on a MCDM model with the alternative and criteria. Application of MCDM methodologies to select the best alternative by Analytical Hierarchy Process (AHP) software tool Expert choice 2000.

II. LITERATURE REVIEW

Sustainability is a multilevel attempt which considers product, processes and entire supply chain networks. Its opportunities break through the mass production and consumerist consumption without boundary, signalling for an elevation in the outlining of human wants. Sustainability at all levels will act as a driver for innovation, business growth, environmental protection and social well-being. The posture of zero impact will be substituted by sustainable strategies which will make a positive influence without affecting the triple bottom line criteria [McCool (2004)]. To achieve excellent triple bottom line performance, new modes of economic, social and environmental strategies are essential. Competing organizations must shift from natural agitation to new forms of symbiosis, to grasp areas that none of the partners could hope to achieve on their own.

For even and sustainable pathways, green practices can do miracles in creating social, economic and environmentally sustainable production and consumption modes. By greening or sustaining the natural resources and ecosystem services, the current generation steward's or supports future generations to meet their needs (anoop a. t. (2014)).

A. Role of Material Selection in Sustainability

Sustainability of products greatly depends upon the raw material used to manufacture the products (Changxu 1998). The author studied the role of materials in sustainable development and concluded that the improvement in ecological environment and reduction in adverse environmental impact is directly or indirectly related to the material selected for production. Rydh and Sun (2005) evaluated life cycle inventory data of 17 material groups which includes 214 types of materials used in mechanical design and their contribution to environmental impact is also being discussed. Using the data collected, they conducted multivariate analysis and found that there exist a weak correlation between physical material properties and environmental impact of these materials. Ljungberg (2007) discussed the importance of developing sustainable product. The author pointed out that the material selection and sustainable design have higher impact on development of sustainable product. Vinodh and Jayakrishna (2011) conducted a study to minimize the environmental impact of an automotive assembly through selecting alternative material and alternative manufacturing process for product development. They pointed out that the change in material is more effective in reducing the environmental impact than manufacturing process. Ghadimi et al. (2012) conducted a case study of automotive component and remarked that the replacement of material is effective to make the product more sustainable.

B. Approaches in Sustainable Material Selection

Weaver et al. (1996) introduced a design strategy with selection of material to reduce the adverse impact in the environment. The author pointed out that Environmental impact indicators should be used as selection criteria for the evaluation of sustainable materials. Holloway (1998) introduced air and water pollution indices as environmental attributes to select the material in mechanical design. Ermolaeva et al. (2004) integrated environmental impact assessment with structural optimization to select material for Sustainable Product Development (SPD). Structural optimization is used select light weight material and Life Cycle Assessment (LCA) approach integrated the eco indicators for selection procedure. Giudice et al. (2005) introduced a systematic material selection procedure for life cycle design process.

C. MCDM Approaches in Material Selection

Shanian and Savadogo (2006) used ELECTRE (ELiminationEtChoixTraduisant la REalite) for the material selection process but the procedure will be lengthy and if the number of alternative increases, the computational procedure will become elaborate. Rao (2006) proposed a material suitability index that evaluates and ranks the materials for a given engineering component. The index is obtained from a material selection factors function, obtained from the material selection factors graph. The graph was developed considering material selection factors and their relative importance for the application considered. Using Grey relational analysis, the multi-criteria weighted average was proposed in decision making process to rank the materials with respect to several criteria (Chan and Tong ; 2006). The authors remarked that the methodology will guide the selection process and help a decision maker solve the selection problem. Rao (2008) used VIKOR, compromise ranking method for the material selection problem. The author explained the procedure using two material selection examples and used AHP (Analytic Hierarchy Process) for assigning weights to the criteria. Recently, many traditional materials which have served in engineering applications for a long time are being replaced by the so called „new materials", in order to meet the demand of weight reduction and performance enhancement. The rapid spread of computers and the development of information networks such as the Internet make it easier to construct new databases or use existing databases of material properties [Jee DH (2000)]. When selecting materials for engineering designs, a clear understanding of the functional requirements for each individual component is required and various important criteria or attributes need to be considered. Material selection attribute is defined as a attribute that influences the selection of a material for a given application. These attributes include: physical properties, electrical properties, magnetic properties, mechanical properties, chemical properties, manufacturing properties (machinability, formability, weldability, cast ability, heat treatability, etc.), material cost, product shape, material impact on environment, performance characteristics, availability, fashion, market trends, cultural aspects, aesthetics, recycling, target group, etc.

Rao (2006) presented a material selection model using graph theory and matrix approach. However, the method does not have a provision for checking the consistency made in the judgments of relative importance of the attributes. Further, the method may be difficult to deal with if the number of attributes is more than 20.

Manshadi (2007) proposed a numerical method for materials selection combining non-linear normalization with a modified digital logic method. However, the method does not make a provision for considering the qualitative material selection attributes and weights assigned to various attributes is rather arbitrary. Chan and Tong (2007) proposed weighted average method using grey relational analysis to rank the materials with respect to certain quantitative attributes. A methodology based on an improved compromise ranking method is suggested by R. VenkataRao, which helps in selection of a suitable material from among a large number of available alternative materials for a given engineering application. The proposed method is a general method and can consider any number of quantitative and qualitative material selection attributes simultaneously and offers a more objective and simple material selection approach. The suggested methodology can be used for any type of selection problem involving any number of selection attributes.[R. VenkataRao (2008)].

III. Research Methodology

The methodology followed during this project is shown in Figure 1. The project begins with the literature review on role of material in Sustainable Product Development (SPD) and approaches in sustainable material selection. Problem identified based on the researches. Then the candidate product is selected for the case study. Multi Criteria Decision Making Problem formulation is done by identifying the criteria and alternative material for the case product. Selection of best material is done by AHP methodology.

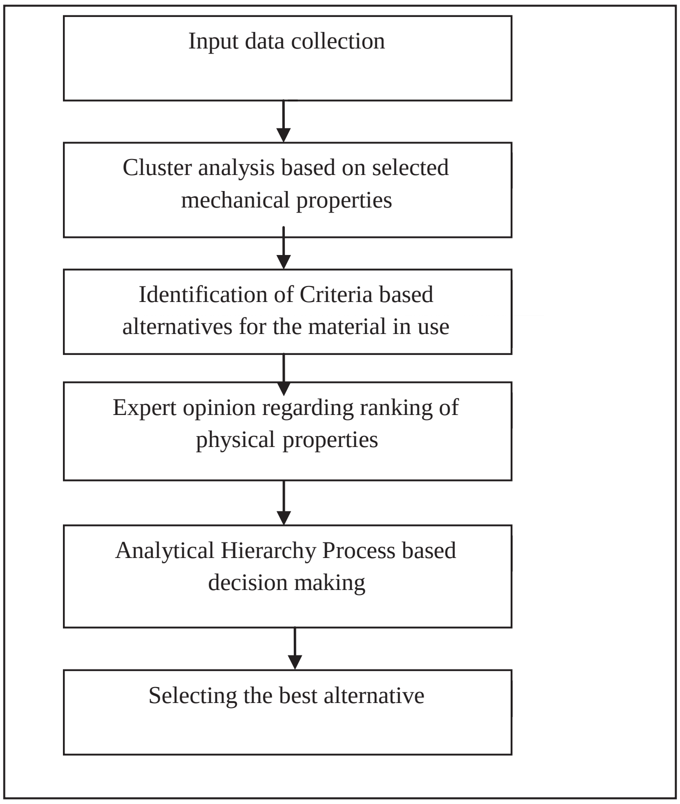

Fig. 1. Flow sequence of the work

IV. SUSTAINABLE MATERIAL SELECTION

A. *Data collection*

The data collected are the properties of the entire polymer such as elastomers, thermoplastics, thermoset and polymer form. All the major sub categories will contain thirty one different polymers in above mentioned four families. For all the polymer materials eleven property ranges are find out and tabulated. The source of data is the materials selection in mechanical design by a Michael F Ashby (3rd edition).

B. *Cluster analysis*

Here cluster analysis is used to identify different alternatives for the material ABS which is mainly used for manufacturing two wheeler mud guards. This was the first step towards replacing this material with a more sustainable material. The analysis was conducted in IBM SPSS Statistics v.21.

As a first step physical properties of 30 alternative polymers where collected along with that of ABS. Cluster analysis where conducted with this data.

A cluster of 8 polymers are grouped on the base common physical properties. These are kept as the replaceable alternative for each other and can be used for the front mudguard.

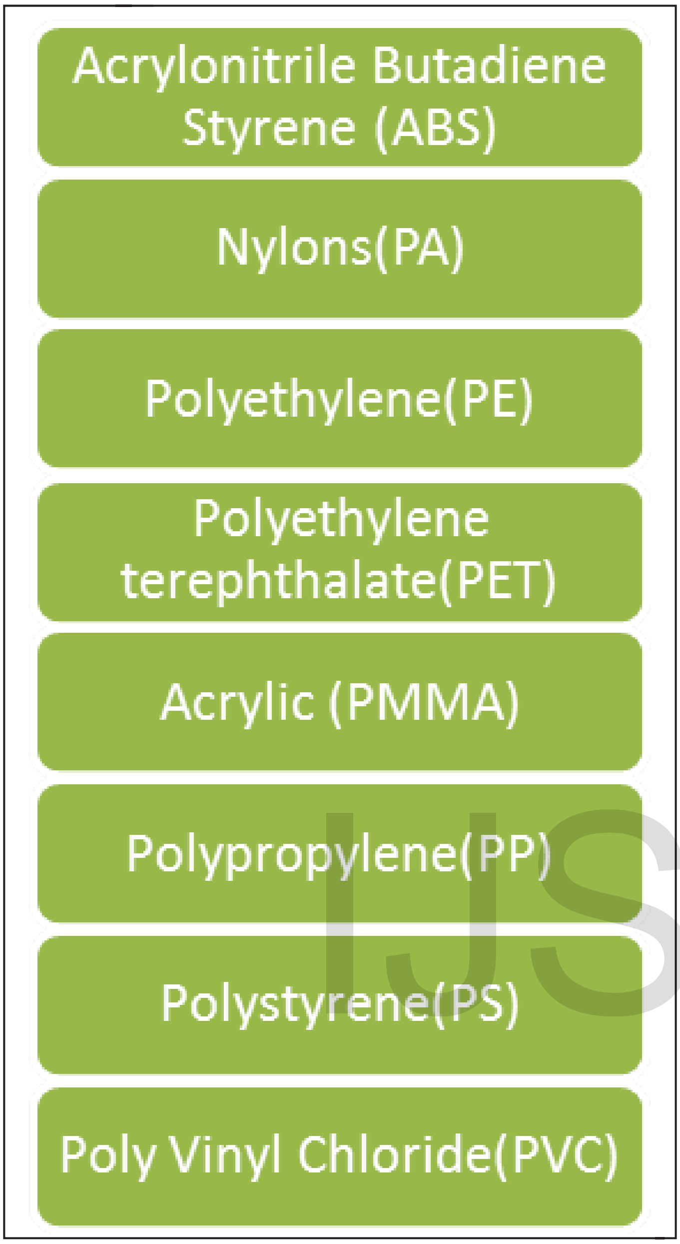

Fig. 2. Alternatives of polymer which can be used for two wheeler mud guard

C. *AHP model for selection of alternatives*

The sustainability is defined as the three legged tool, which is made on the basement of economic, social and environmental and all other terms are to be defined under this main deviation. AHP require a hierarchical model and calculate the priority vector at each level by pair wise comparison. The AHP method is chosen because of its advantage on direct dependency of input data on the priority calculation. The expert opinion have a greater effect on the selection and its easily done through this method.

The sustainability structure is defined under the three leg and the factors for material selection are listed underneath. The structure is defined on the basis of sustainability definition and the design factors are selected on the basis of expert opinion and the availability of data.

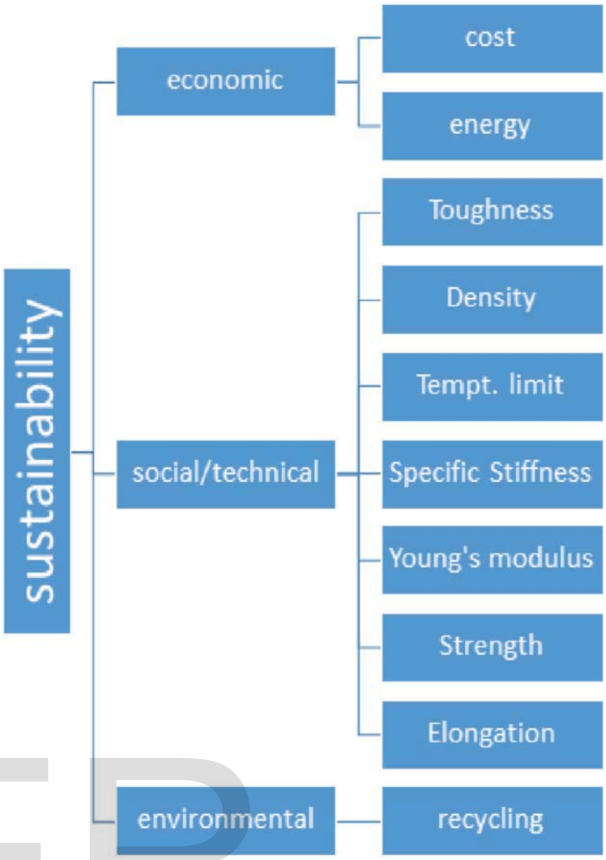

Fig. 3. Criteria and sub criteria forn AHP model.

D. *Expert opinion*

Expert Opinion is the informal technique which can be used to serve a range of purposes, and may be used to support in problem identification, in illustrative the issues relevant to a specific topic, and in the valuation of products. Individual experts can be referred, but it is better to bring clusters of experts together so that a wide range of experience can be taken.

Expert opinion is often used to find potential complications with products before they are released for more comprehensive estimation, but can be used at any stages of design. However it is important to ensure that those experts consulted have no prior connection or concern in the design of the product to be evaluated, as or else it will be difficult to obtain fair views.

The MCDM model should have a goal, criteria sub criteria structure, and alternative. We arrived at the model with the above structure and alternatives, to calculate the preference weight, we need to have the pairwise comparison matrix. For sustainability the three main criteria are to be equally considered and the design physical properties are to be ranked on pairwise, so expert opinion from five experienced managerial staffs in design are taken, three opinion from professors in design are taken. The average of the ranks are taken in a pairwise comparison matrix is made.

V. Result and Discussion

A. AHP Result

Fig. 5.1 shows the screenshot of the result interface of EXPERT CHOICE 2000. The weightages shown in the interface were given by the pair wise comparison of alternatives based on the properties being considered. The three main criteria being considered were given equal weightages for sustainability concern. From this, the properties are ranked on a scale from 1-9.

The weights for these factors were considered equal. The sub criteria of economic factors include cost and energy. The sub criteria for social/technical factors were toughness, strength, elongation, specific stiffness, temperature limit, density and Young's modulus and the same for environmental factors was recyclability. The factors selected were those used for the selection of the material at present.

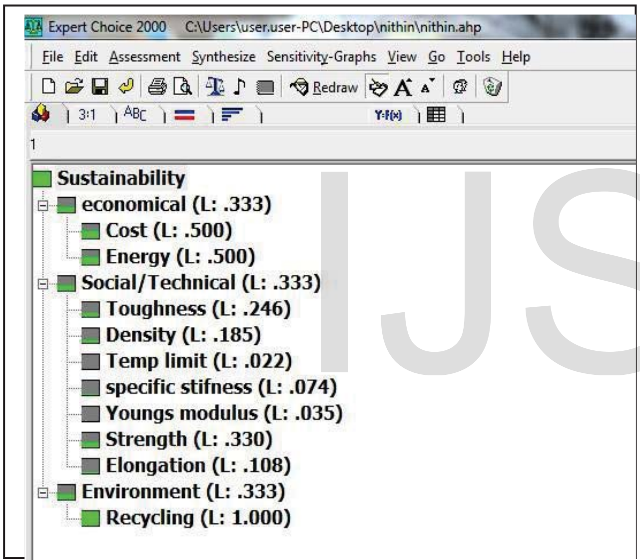

Fig. 4. Screenshot of Expert Choice 2000 interface

High density poly ethylene was found to be the most sustainable alternative considering the economic, social/technical and environmental factors, with a weightage of 0.241 it is shown in Figure 5.

Polyethylene is the most produced plastic in the world, with which everyone daily comes into contact. From its early days it has been considered a real asset in the world of the materials, although at first its value was only proven as insulation of electrical wiring. At present the power of polyethylene is its discrete reliability, its obvious

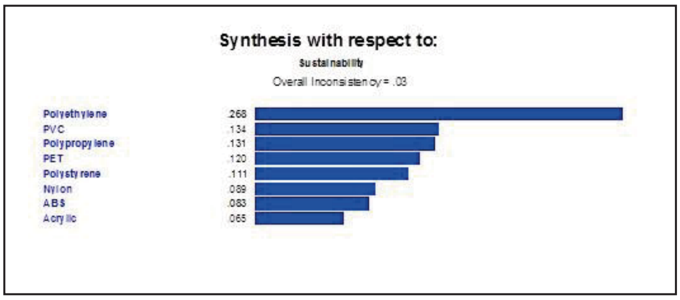

Fig. 5. Output of Expert Choice 2000.

solidity and its almost unlimited uses. We are so used to this modern material, it has become something common and every day, and we tend to take it for granted. Poly ethylene has a very simple polymer structure, so it is easy to process. And it can be drawn to very large elongations, but it is quite expensive. The alternatives ranked next were poly vinyl chloride, poly propylene and PET with weightages of 0.156, 0.141 and 0.114 respectively.

VI. Conclusion

Using the developed model of MCDM an alternative for sustainable material is found out. For the developed model, the AHP tool is used to find the sustainable material, and high density poly ethylene was found to be the most sustainable alternative considering the economic, social/technical and environmental factors, with a weightage of 0.241. The weights for these factors were considered equal. The sub criteria of economic factors include cost and energy. The sub criteria for social/technical factors were toughness, strength, elongation, specific stiffness, temperature limit, density and Young's modulus and the same for environmental factors was recyclability. Poly ethylene has a very simple polymer structure, so it is easy to process, transparent to easily coloured and is tough so can absorb shock, but it is quite expensive.

Data collection and data analysis was done for all polymer family obtained the similar alternatives which could be replaceable, the criteria was selected on the basis of the Expert opinion and the literature survey. The alternatives ranked next to polyethylene are poly vinyl chloride, poly propylene and PET with weightages of 0.156, 0.141 and 0.114 respectively. The work selected a set of polymer which can be widened to metals and alloy compounds, so the material will give a greater sustainability index and can be done as future work. The product scenario is considered, the production procedure and the total supply chain can also be considered to achieve more sustainability towards industrial aspects.

Acknowledgment

If words are considered as symbols of approval and token of acknowledgement, then the words play the heralding role of expressing my gratitude, my salutations and prayers to the **GOD** almighty who is our supreme power.

I am deeply indebted to Dr. Regi Kumar V. Associate Professor, Department of Mechanical Engineering for his excellent guidance, positive criticism and valuable comments.

I would also wish to thank my parents and other faculty members, who stood by me during my tough times. Last but not the least I take this opportunity to thank my dear friends who stood always as a source of encouragement.

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