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Rapid Prototyping and Evaluation for Green Manufacturing

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Abstract—**With global awareness of environmental risk and the pressing needs to improve efficiency, manufacturing systems are growing into new concept. Green manufacturing is reflected to employ various green strategies and technique to produce with eco-efficient. Green manufacturing aspects on the machine level were studied in various machining process. On this paper presentsthe green manufacturing review of Rapid Prototyping process. The objective is to evaluate the factors involved in green process of RP.Several comparative RP process respect to green manufacturing criteria are described.**

Rapid Prototyping process uses three dimensional CAD files to fabricate a physical model. Models are usually made from variety of material such as ABS, rubber and specific metals. Each material has the environment impact during the process and recycling.RP process are known as process not suitable for making direct product. However, lates technology makes it suitableto produce the parts with reasonable cost. For near the future, the utilization of this technology is becoming increasing and green manufacturing effect should be considered.Based on study conducted, several type of RP process is eco-efficient due to amount of waste material produced and environment impact during the process.

Keywords— **Green Process, Rapid Prototyping, Rapid Tooling,sustainability manufacturing, eco-manufacturing**

I. INTRODUCTION

Green manufacturing is the term categories as subset of sustainability in which considering the environment impact by adjusting the process within acceptable level. Green manufacturing deals with technologies and solution to transfer from business as usual to a sustainable level of consumption. Interest in Green Manufacturing is increasing from time to time meaning that make the issue is becoming more essential. Strategy and technique to become more eco-efficient include creating product that consumes less material and energy, substituting input materials reducing unwanted outputs and converting output to input (recycling). Green manufacturing should able to prevent pollution and save energy through the discovery and development of technology that eliminates and reduce the use of hazardous substances starting from design, manufacture and application.Green manufacturing approach is also a strategy reducing the energy usage and material intensiveness at the manufacturing process. Conventionally, many of decision manufacturers are based on cost, function and quality. Currently another dimension, environmental sustainability have to be considered. Considering the eco-efficiency, eco-friendly product and process are being motivated by saving the energy cost, concern about non-renewable resources and reducing carbon emission. Rapid Prototyping is one of technologies that make the product more eco-efficient.

Rapid Prototyping (RP) is the process of producing physical objects using additive manufacturing technique. With computer technology, the designed part from 3D computer models is produced by stacking material layer by layer. The process utilizes computer numerical controlled (CNC) machine tools and rapid software tool. Today, RP are used for manufacture with wider range of product even used to produce quality part in relative small number.

Rapid Prototyping has been introduced on 1987 and that was only capable of producing brittle parts. For the time being, there has been much improvement in both machinery and materials. This has led to improved part quality, enhanced material properties, lower manufacturing costs and produce green process. Today Rapid Prototyping is used in variety different applications and becoming a viable manufacturing solution.

RP machines uses of adhesives, lasers or even plasma to fabricate parts. Material choices vary from plaster to titanium dependent on the technology used. Material and process will lead to produce pollution and consumes variety amount of electricity.

Rapid prototyping is commonly used to manufacture visual prototypes of product for evaluation process. Visual prototypes are usually used for market research, executive review, and photo shoots for sales literature. Visual prototypes have also been utilized for medical application[1]. Intricate 3D models is created from CT scan data allowing for better understanding of internal structures as guidance to surgical actions.

Current technology of Rapid Prototyping is even possible to manufacture end-use parts. The use of RP in mass production referred to as Rapid Manufacturing due to variety advantage of the process. Application of Rapid Prototyping technologies enable to reduce utilization of expensive tools, moulds and die the need for expensive re-tooling can be eliminated. Rapid Manufacturing is able to be combined for the low cost of mass production.

II. Review on Green Manufacturing

There are several available work could be found in the context on green manufacturing. The review work deals with the concept of green manufacturing, analytical tools to realize technology developed on green manufacturing.
Green productivity is defined in all activities attempting to decrease wastes during manufacturing process. The importance of green productivity as a competitive edge was highlighted [2]. Several case studies are shown on waste elimination practices to improve the potential green productivity on the manufacturing performance.

Environmental frame work on green manufacturing was proposes to tied waste management through the elimination of causal factors[3]. The framework incorporated environmental and social costs and values into economic activities to support the decisions of the management. The methodology was suggested to help decision makers to arrange green manufacturing plans.

Another framework based on studies of achievement of SME manufacturers on ISO 14001 certification for sustainability to realize green manufacturing was presented[4]. Green MRP tool modified from conventional Material Requirements Planning system was proposed[5]. The tool includes environmental considerations when converting the Master Production Schedule into the component schedules.
Analytical tools includes Life Cycle Analysis (LCA), Design for the Environment (DfE), screening methods and risk analysisthat emerged from process design for green manufacturing was proposed[6]. A model to assess environmental hazards in manufacturing was proposed[7]. The network analytic method was employed to analyze the potential of each impact category created by different kinds of waste in manufacturing processes. Fuzzy set theory was used to find a numeric fuzzy weighting factor of each impact category contributing to ecosystem. present Clean-ability and burr reduction in aerospace manufacturing was also presented by researchers [8].

Interest in Green Manufacturing is increasing from time to time meaning that the term is becoming more essential. Strategy and technique to become more eco-efficient include creating product that consumes less material and energy, substituting input materials reducing unwanted outputs and converting output to input (recycling).

Evaluation of RP as Green process has been done on various aspects. The evaluation based on electrical consumption was presented[9]. Various manufacturing parameters have been tested on three rapid prototyping systems to select sets of parameters for reduction of electrical energy consumption. Finding of this research is important to minimize the manufacturing time but there is no general rule for optimization of electrical energy consumption. Each RP system has been be tested with energy consumption considerations.The manufacturing time is minimized by optimization of electrical energy consumption. By consideration of the complete life-cycle of a rapid prototyped part.

Green manufacturing aspect has to be put in all activities on product development. The activities as shown in Fig.1 are starting from design, procurement, manufacturing, packaging, customer use and remanufacture.

Fig.1 Green manufacturing product life cycle

III. Technology of RP Process

RP process basically are developed not respect to the term of green manufacturing. The objective was increasing speed on design step to produce prototype model. Many steps of process and equipments were eliminated by RP technology. Saving the tools is one of aspect that this process is green.

Vol.1, No.1, April 2013, p.15-20

Generally, manufacturing process is grouped into three categories; subtractive, formative and additive. RP technology belongs to the additive production processes. The part is fabricated by deposition of layers by layer contoured in a two dimensionalplane. The height results from single layers being stacked up on top of each other. Characteristic of RP product is that they are not continuous shape, but have stair-stepping effect in height (z-direction). Smooth model can be fabricated if model is deposited with very fine layers, i.e., smaller z-stepping.

There are two fundamental steps to completely make a part namely generation of mathematical layer information and generation of physical layer model.

The process starts with 3D modeling of the product using any 3D capable CAD software. The 3D model is exported into triangulated surface known as STL (Stereo lithography) format.

In tessellation various surfaces of a CAD model are piecewise approximated by a series of triangles and co-ordinate of vertices of triangles. The number and size of triangles are decided by facet deviation or chorale error. STL files are used as an input to various slicing softwares.

The determination of part deposition orientation is the most important factor to achieve the minimum building time, good surface quality, amount of support.

Once part deposition orientation is determined and slice thickness is selected, tessellated model is sliced and the data in standard data formats like SLC (stereo lithography contour) or CLI (common layer interface) is generated.

The sliced data is used to generation of physical model.The software that operates RP systems generates the path depend on type of process. Generally there are four basic deposition principle of RP machine; laser-scanning (Stereo lithography), Selective Laser Sintering , material deposition and Fused Deposition Modeling).

The final step in the process chain is the post-processing task. At this stage, some manual operations are necessary that done by skilled operator. In cleaning process, the excess elements adhered with the part or support structures are removed. For certain models, the surface of the model is finished by sanding, polishing or painting for better surface finish or aesthetic appearance.

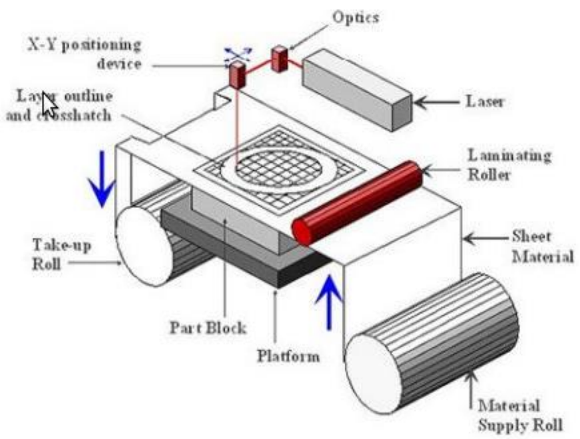

Fig. 2 Laminated Object manufacturing schematic

Fig.2 shows a typical example of RP machine called Laminated Object Manufacturing (LOM). Rolled material is cur by laser follows the contour layer of the model. Every cut sheet material is laminated pressed by a roller.

A. Advantage of RP Technology

RP process have some advantages over other manufacturing process. Many problems facing on Subtractive and formative manufacturing possible to be eliminated. Starting from design stage, feature based design are not necessary because the use of feature information is not necessary. Blank geometry usually defined on subtractive process is also not necessary. Defining of complex sequences is not necessary because the part is produced in one process.

Supporting equipments like clamping, jig, fixture or designing mold and die are not required for Rapid Prototyping process. Even many advantages are achieved, limitation of the process have to be take care. Rapid prototyping is less accurate. Part volume is generally limited to less than one quater cubic meters, depending on the RP machine. Metal prototypes are difficult to make, though this should change in the near future. For metal parts, large production runs, or simple objects, conventional manufacturing techniques are usually more economical. These limitations aside, rapid prototyping is a remarkable technology that is revolutionizing the manufacturing process. Currently, final products are possible to be produced by RP machines.The number is increasing as metals and other materials more widely available. Rapid Manufacturing can not completely replace other manufacturing techniques, especially in large production runs where mass-production is more economical.

B. Environmental weighting effect

Weighting method for environmental effects that damage ecosystem and human health has been defined as Eco indicator. Eco indicator was expansion of Life cycle Assessment management (LCA) to include an extra weighting factor that are environmental properties(Fig.3).

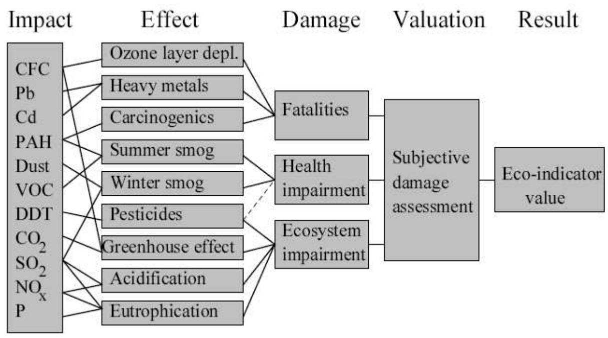

Fig. 3 Methodology of eco indicator value assignment [10]

Vol.1, No.1, April 2013, p.15-20

LCA is the most suitable methods for determining the environmental impact. However, LCAs are to time-consuming and complex. Environmental properties are new properties of materials instead of mechanical and physical properties. Table 2 below shows several weighting factors respect to environmental effect. There are about 80 materials and processes were drawn up.

TABLE I
WEIGHTING FACTOR VALUE[10]

Effect	Classification	Weighting factor
1. Greenhouse effect	NOH LCA manual (IPCC)	2.5
2. Ozone layer depletion	NOH LCA manual (IPCC)	100
3. Acidification	NOH LCA manual	10
4. Eutrophication	NOH LCA manual	5
5. Summer smog	NOH LCA manual	2.5
6. Winter smog	WHO Air Quality Guidelines	5
7. Pesticides	Active ingredient	25
8. Heavy metals	WHO Air Quality Guidelines; Quality Guidelines for Drinking Water	5
9. Carcinogenic substances	WHO Air Quality Guidelines	10

The factor scaled from 0 to 100. Weighting factor for common ABS material used by RP machine is 2.81 while as for comparison, weighting factor for cast iron is 1.26.

IV. REGULATION AND GOVERNMENT SUPPORT

Government & Community pressure to evolve into green manufacturing is increasing. Reducing the environment impact on green manufacturing should deals with concept, tools and technology. Indonesia agree to reduce greenhouse gas emission by year 2020 as much as 26% from business-as-usual by national domestic efforts. This emission reduction will further be improved as much as 41% from business-as-usual by international supports. To achieve this target, the Government of Indonesia issued a national action plan to reduce greenhouse gases emission. It is the guidance to plan, execute, monitor and evaluate the reduction of greenhouse gas emission from sectors of agriculture, forestry, energy and transportation, industry and waste management.

TABLE II
MATERIAL OF RP MACHINE

	1 = Excellent		2 = Good		3 = Average
Technology/ Material Family	Accurate	Fine Feature Detail	Strong	Smooth Surface	Funct Testing
FDM					
ABS	1	2	2	3	1
ABSi	1	2	2	3	1
Polycarbonate - ISO	1	3	1	3	1
PJET					
Clear	1	1	2	1	2
Vero	1	1	2	1	2
Tango	1	1	3	1	1
ZCorp					
Plastic Powder	1	2	3	2	3
SLA					
Accura 50 White	1	1	3	1	2
Somos 10120 WtrClear	1	1	3	1	2
Somos 9920	1	1	3	1	2
SLS					
DuraForm GF	2	3	1	3	1
DuraForm PA	2	3	1	3	1

European country and Australia were implementing the carbonprice by establishing an authority. The Climate Change Authority is an independent body to provide advice on the Government's policies for reducing carbon pollution. The Authority is established to ensure the public is fully informed now and into the future. The carbon price is the element of the Government’s plan for a clean energy future: it will trigger a broad transformation of the economy[11].

A price on carbon is the most environmentally effective and economically efficient way to reduce pollution. This creates a powerful incentive for all businesses to cut their pollution, by investing in clean technology or finding more efficient ways of operating.

In Australia, there's a raft of carbon tax-related initiatives that have been factored into the budget estimates but the one to watch is the so-called "carbon price" of $23per tonne and will be increase 2.5 percent in a year.Around 500 of the biggest polluters will pay for the pollution they emit. Revenue from carbon price will be used by the government to assist households, support job and invest in clean energy and climate change programs.

V. GREEN EVALUATION

Rapid prototyping inherently is a green technology as it is an additive process where no material is wasted in constructing the part layer by layer. Compared this additive fabrication process to subtractive operations like machining and grinding, where all removed material is likely to be wasted, almost no material is wasted. Rapid prototyping uses fewer raw materials since all material to be converted to the product. SLS is can be categorized non wasted RP process. No support structured is used during building part layer by layer. Upper layer is supported when it immersed inside powder. However some RP process is producing small amount waste that used for support structure as shown in Fig.4. Overhangs or cantilever walls need support structures as a green layer has relatively low stability and strength. These overhangs and cantilever geometry are supported if they exceed a certain size.

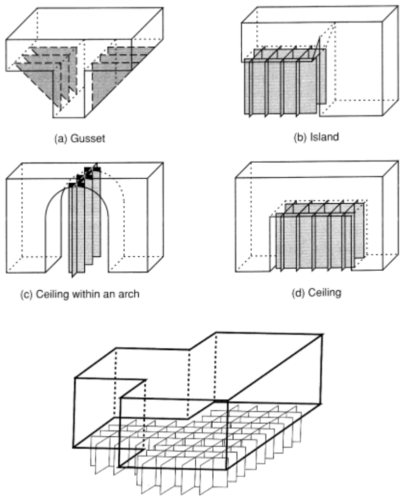

Fig. 4 Support structure used on constructing RP component[12].

The main functions of these structures are to support projecting parts and also to pull other parts down which due to shrinkage tends to curl up[13]. FDM and SLA are typical examples of RP process needs the support structure during construction.These support structures are generated during data processing and due to these data grows heavily specially with STL files.

Even RP is additive process, thewaste material is occurs instead of used for support structure. For stereolithography, the cumulative exposure to UV can cause an entire vat of resin to become unusable. With SLS, waste is generated with each build, because the process requires a ratio of 20% to 50% virgin material to recycled powder. A typical prototype will have a volume of 15% of its volumetric (bounding box) extents.

Scrap material is also generated through bad builds and damaged parts. With so many variables in the art of producing a good prototype, it is unreasonable to expect 100% performance. Although the scrap rate will vary, it would be wise to plan for 10% loss. With all of these factors, 20% to 30% of the prototype cost is to materials.

Rapid prototyping (and additive manufacturing to create final production parts) doesn't require tooling, which also means that less material and fewer resources are used in the manufacturing process.

Rapid prototyping is green because it streamlines the product development process so resources of all kinds aren't wasted, including human resources, energy, time and cost.Many of Rapid Prototyping like FDM and SLA generates substances such as smoke, dust, hazardous chemical, etc. which harmful to human health and the environment. Rapid Freeze manufacturing is introduce as clean process.

Rapid Freeze (RPF) manufacturing is essential to create new model that are fast, clean and low cost using water as raw material. Part is made by freezing the water. RPF makes three dimensional of ice parts layer by layer by freezing of water droplets.No smoke is produced during constructing the part. The part produced by the kind of material can be used as a pattern. Fig.5 shows the time saving for casting process using RP technology[12].

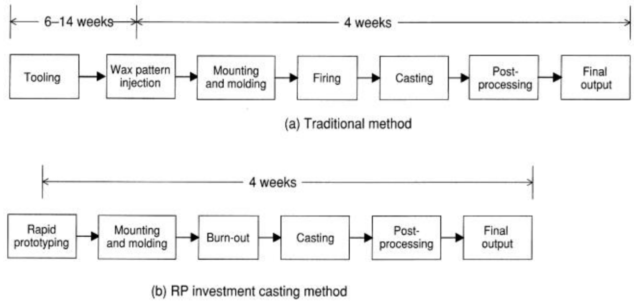

Fig. 5Casting process reduction using Rapid Prototyping Technology

The experiments had shown the feasibility to make silicone molds with the ice patterns. The advantage using ice patterns are easier to remove and no demolding step is needed before injecting urethane or plastic parts. Application of RFP on investment casting is a promising. Investment casting with mold ice patterns demonstrated several advantages over wax investment including low cost (35%-65% reduction), high quality, fine surface finish, no shell creaking and faster run cycle. In term of green manufacturing, no smoke and smells isproduce in investment casting using ice patterns from RFP.Producing pattern from ice is significantly reducing the waste material and pollution generated.

VI. Conclusions

Green manufacturing is factors that have to be considered to responds the global awareness of climate change. Reducing environment impact on green manufacturing should deals with concept, tools and technology.

RP as relatively new technology in Manufacturing have varieties impact on green manufacturing. Rapid prototyping is a green technology where almost no materials are wasted. Depending on type of material used for product, ABS has the level 2.3 of the echo indicator. Invention on Rapid Freeze manufacturing is able to reduce overall casting cost about 35% to 65 % and increase the eco-efficiency.

VII. Acknowledgment

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