SUSTAINABLE MANUFACTURING: EFFECT OF MATERIAL SELECTION AND DESIGN TO THE ENVIRONMENTAL IMPACT IN THE MANUFACTURING PROCESS

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ABSTRACT

The environmental impact of a manufacturing process is also dependent on the selection of the material and design of a product. This is because the manufacturing of a product is directly connected to the amount of carbon emitted in consuming the electrical energy for that manufacturing process. The difference in the general properties of materials such as strength, hardness and impact will have significant effect on the power consumption of the machine used to complete the product. In addition the environmental impact can also be reduced if the proposed designs use less material. In this study, an LCA tool called Eco-It is used. Evaluate the environmental impact caused by manufacturing simple jig. A simple jig with 4 parts was used as a case study. Two experiments were carried out. The first experiment was to study the environmental effects of different material, and the second experiment was to study the environmental impact of different design. The materials used for the jig are Aluminium and mild steel. The results showed a decrease in the rate of carbon emissions by 60% when Aluminium is use instead from mild steel, and a decrease of 26% when the-design is modified.

Keywords: Sustainable manufacturing; production tooling; environmental impact; milling; Life Cycle Analysis (LCA); Eco-Tools.

INTRODUCTION

The increasing world population has created a greater demand for production goods. The resulting increase in productivity has resulted in more pollution (Franci, 2009). From a manufacturing point of view, an increase in production is good because it reduces manufacturing cost, but in terms of environmental impact, the increase in energy consumption leads to increase in carbon dioxide emission. Energy generation as driven by consumption demand is a key contributor to carbon dioxide and climate change. Nicholas, 2006 said in the year 2000, energy related carbon dioxide equivalent (CO_e2) emissions represented about 65% of the global greenhouse gas emissions. Due to this problem, an increase in awareness by the community to reduce pollution on the environment and a more sustainable production has been proposed. Sustainable production is an approach to improving environmental performance in manufacturing production. Sustainable production means that products are designed, produced, distributed, used and disposed with minimal (or none) environmental and occupational health damages, and with minimal use of resources (materials and energy), (Leo, 1993). This approach is primarily driven by rapidly increasing problems concerning environmental damages, huge amounts of waste, occupational health

damages and increasing use of non-renewable resources. These problems coupled with expected exponential growth in world consumption during the next 50 years where the world population will grow to about 12 billion people, requires prompt solutions.

There are many methods to improve sustainability in manufacturing. Some of them as suggested by Pusavec in 2010 include:

- Reduce machining processes energy consumption,
- Minimize waste (generate less waste and increase waste re-usage or recycling),
- Use resources efficiently,
- Use recyclable materials or reuse machine-tool components,
- Improve the management of metalworking fluids, swarf, lubricating oils, and hydraulic oils (improved environmental, health, and safety performance,) and
- Adopt life cycle assessment methods.

In this paper the reduction of machining processes energy consumption is studied. A key element of sustainability is the prudent use of natural resources, such as energy. Energy generation as driven by consumption demand is a key contributor to carbon dioxide emissions and climate change. In the year 2000, energy related carbon dioxide equivalent (CO_2e) emissions represented about 65% of the global greenhouse gas emissions, from this percentage, about 24% and 14% of CO_2e emissions were attributed to power generation and industrial activity,(Nicholas, 2006). Hence reducing energy consumed by machining processes is one of the strategies to improve the performance sustainability by reducing the energy footprint, (Rajemi, 2010).

Life Cycle Assesment(LCA)

According to G.Martinopoulos in 2006, the simplest LCA tool that is available in market today is Eco-It. Eco-It or Eco-Indicator tool is a simple tool for Eco-design. It works with Eco-Indicators, these are single scores that express the seriousness of the environmental load of a process or material. The higher the score, the more serious is the impact. Eco-It allows a designer to model a complex product and most of its life cycle in a few minutes. It calculates the environmental load, and shows which parts of the product's life cycle contribute most. With this information user can target own creativity to improve the environmental performance of product. The program structure is simple. There is a Main window with four pages (Figure 3):

- Life cycle page, which is allows the user to describe the product life cycle under investigation.
- Production page, in which the user needs to enter the hierarchical structure of the product, and specify the materials and production processes per part.
- Use page, where user needs to enter the energy and transport components that use during jigs manufacture process.
- Disposal page, where the user needs to specify the waste scenario for the product or for different parts and materials.

The working philosophy of Eco-It is based on Eco-Indicator 95 and 99, which is are earlier Eco design tools before Eco-It. The first step in any further interpretation consists of comparing the scores with another value. In LCA terminology this is called the normalisation step, and the values are normalised to the average European. A weighting step is therefore necessary to achieve an overall result. After detailed analysis of the options the so-called Distance-to-Target principle is chosen for determining the weight factors.

The evaluation method used for calculating the Eco-Indicator99 is in "three steps". These three steps are

1. Inventory of all relevant emissions, resource extractions and land-use in all processes that form the life cycle of a product. This is a standard procedure in Life Cycle Assessment (LCA)
2. Calculation of the damages these flows cause to Human Health, Ecosystem Quality and Resources
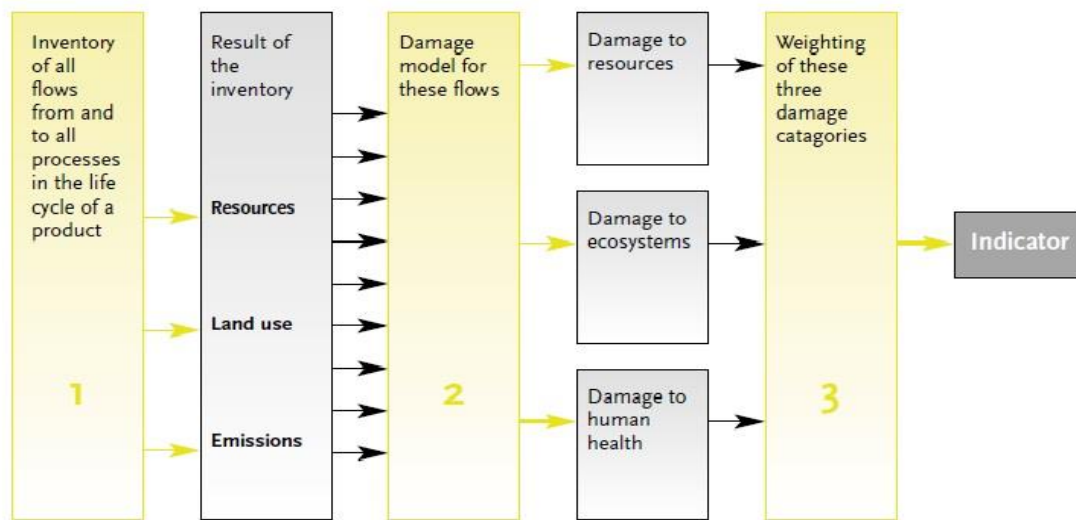3. Weighting of these three damage categories.

The above steps are illustrated in figure 2.

Figure 2. General procedure for the calculation of Eco-indicators. The light coloured boxes refer to procedures, the dark coloured boxes refer to intermediate results
Source: ECO-it 1.3 manual, Pre Consultants, the Netherlands, www.pre.nl

Figure 3. Eco-It interface

In this study, the jig data were taken from the experiment such as data of power consumption of the machine and is analysed by Eco-It in order to get the rate of carbon emissions.

CASE STUDY OF A JIG

In order to study the environmental impact in production tooling, the manufacturing of a simple jig is used as a case study. Two experiments were conducted which are different material and different design of the jig. The two different materials used are mild steel and aluminium. The main objective is the calculation of the environmental impact due to different materials and designs

The jig is made up of four parts, two parts form the body holder and other two parts are for clamping. In the first design, five holes are drilled in the sides of the body holder surface. Two holes on the left and right of the body holder are through holes to tie the parts together. The other three holes are for locator pins. The dimension of the holder body is 150 mm x 60 mm, with a thickness of 30 mm. While for the clamping parts is 150mm x 60 mm with a thickness of 10mm. While for the second design for the body holder is 150 mm x 60 mm, with a thickness of 20 mm. While for the clamping parts is 150mm x 60 mm with a thickness of 10mm. This design uses two pin locating holes and two through holes.

The jig manufacturing processes starts with facing the surface of the material by using a milling machine. The inserts use for both materials is Carbide coated with a cutting speed use of 800 m/min depth of cut of 0.20mm and feed rate of 0.20mm/tooth. After surface facing, the process continues with drilling. The process starts with setting the coordinate edge finder and the speed of the edge finder at 200rpm. Next, a center drill is used to drill five holes for design 1 and four holes for design 2 at a speed 1000rpm. The drill diameter is 10mm for the through holes and 8mm with 10mm depth for the 3 holes of design 1 and 2 holes for design 2. The speed use for drilling is 800rpm. The energy used by the milling machine was recorded by a three phase power analyzer. Data obtained from the experiments is included in Eco-It for the calculation of the rate of carbon emissions. Figure 4 below shows design 2 of the simple jig.
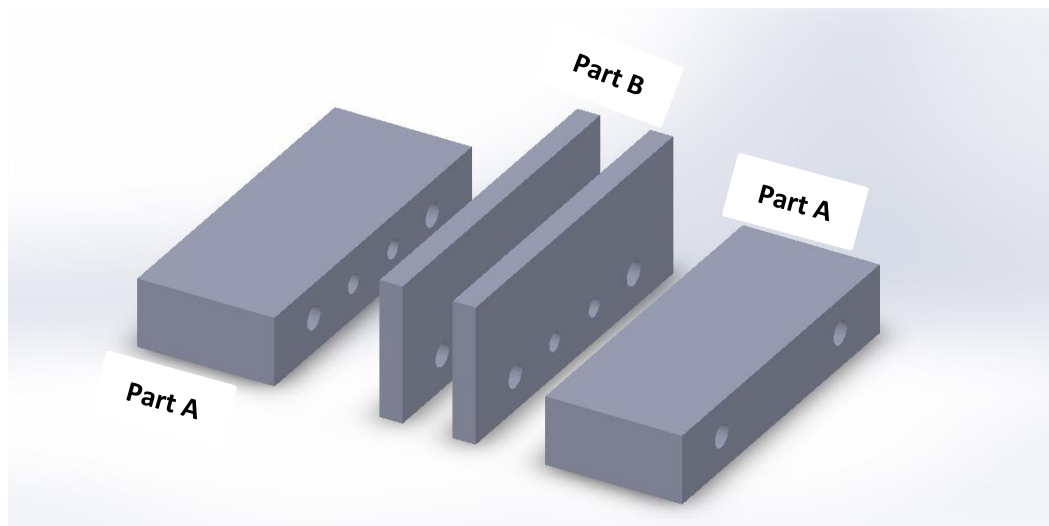

Figure 4. Design of simple jig

RESULTS AND DISCUSSION

This section presents the results of the experiments. Table 2 and table 3 below shows the total power consumption for each process and the total weight of material and weight of material that have been removed for both experiments. The data are entered into Eco-It to generate the amount of carbon emissions produced for each material.

Table 2. Total power consumption for each process used for both experiment.

Power consumption for each process.	Design 1		Design 2	
Processes	Mild steel	Aluminium	Mild Steel	Aluminium
Tool Setup and facing for part A plate	0.267 kWh	0.379 kWh	0.263 kWh	0.375 kWh
Total of drilling operation part A plate	0.530 kWh	0.424 kWh	0.495 kWh	0.399 kWh
Facing part B plate	0.228 kWh	0.296 kWh	0.228 kWh	0.296 kWh
Total of drilling operation part B plate	0.302 kWh	0.104 kWh	0.277 kWh	0.089 kWh

Table 3. Total weight of material and material removed after specific process

Weight	Design 1		Design 2	
	Mild steel	Aluminium	Mild Steel	Aluminium
Part A plate	3850 gram	1320 gram	2360 gram	840 gram
Part B plate	1180 gram	420 gram	1180 gram	420 gram
Facing part A plate	125 gram	40 gram	121 gram	40 gram
Facing part B plate	80 gram	20 gram	80 gram	20 gram
Drilling operation for part A plate	190 gram	70 gram	160 gram	60 gram
Drilling operation for part B plate	40 gram	10 gram	30 gram	7 gram

For design 1, the results indicate that mild steel has a high rate of carbon emissions by 60% compared to aluminium. (figures 5 (a) and (b)).
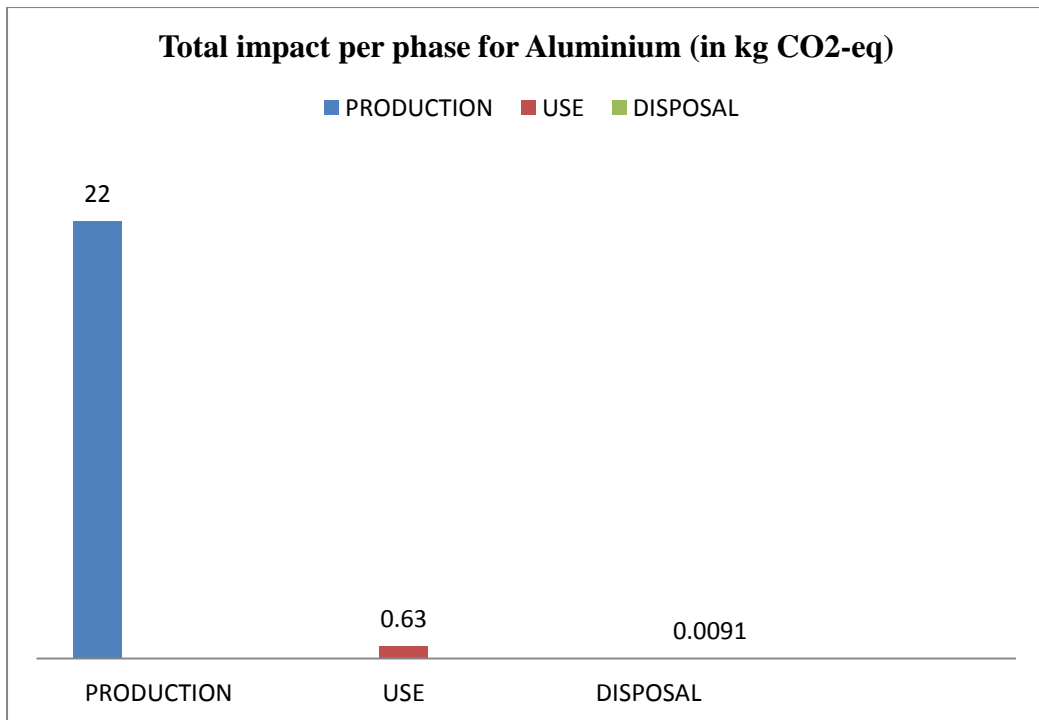
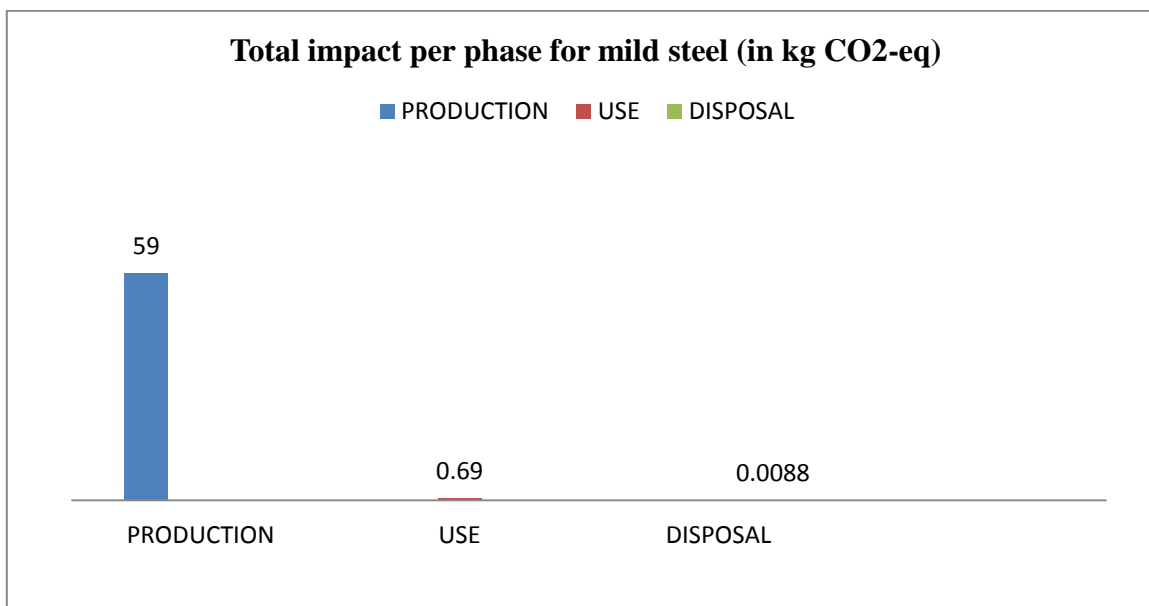Figure 5(a): Total impact per phase for Aluminium of design 1

Figure **5**(b): Total impact per phase for Mild Steel of design 2

With design 2 there is a decrease of 26% of the carbon emission rate. For both materials as shown in Table 4

Table 4. Summary of Comparison

Material/ Phase	DESIGN 1		DESIGN 2	
	Mild Steel (in kg CO2-eq)	Aluminium (in kg CO2-eq)	Mild steel (in kg C02-eq)	Aluminium (in kg CO2-eq)
Life Cycle	60	23	43	17
Production	59	22	42	16
Use	0.69	0.63	0.66	0.61
Disposal	0.0088	0.0091	0.0062	0.0066

The life cycle and production carbon emission is higher for mild steel than Aluminium because of the higher carbon content in mild steel. Mild steel contains 0.16% to0.29% carbon. There is not much difference in term of electrical consumption Mild steel and Aluminum jigs the material hardness.

The small changes in the design, in this case reducing 5 holes to four and reducing the thickness of the material of the holder body from 30 mm to 20 mm, have resulted in a reduction of the carbon emission by 28.33% for mild steel and 26.09% for aluminium. This clearly shows that design has a significant impact on the carbon emissions.

CONCLUSION

It can be concluded that the use of the appropriate material and design for a product has a profound impact on carbon emissions. Future works includes the use of meta heuristics approaches such as genetic algorithm to optimize the material and design of a product

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REFERENCES

Cristiano A. da Silva, Paulo M.C. Ferrao, Manuel Freitas, "Using Life Cycle Assessments on environmental management projects: a case study of a Brazilian vehicle development",2008

ECO-it 1.3 manual, Pre Consultants, the Netherlands, www.pre.nl

Franci Pusavec,Peter Krajnik and Janez kopac "Transitioning to sustainable production- Part 1: application on machining technologies", Cleaner Production,2009.

Franci Pusavec,Peter Krajnik and Janez kopac "Transitioning to sustainable production- Part 11: evaluation of sustainable machining technologies", Cleaner Production,2009.

Flore Vallet, Benoit Eynard and Stephanie Glatard, "Using eco-design tools: An overview of experts' practices", journal of Manufacturing Technology, 2012

G. Martinopoulos, G. Tsilingiridis and N.Kyriakis. "Three Eco-Tool comparisons with the example of the environmental performance of domestic Solar Flat Plate hot water systems", 2007

J.Jeswiet, and S. Kara, "Carbon emissions and CES[TM] in manufacturing." CIRP annals-Manufacturing Technology, 2008.

Kalpakjian s, Schimid s, Manufacturing Engineering Technology, 6th edition, 2010 Pearson Prentice Hall, Upper Saddle River, NJ.

Leo Alting, Jorgen Jorgensen," The life cycle as a basis for sustainable industrial production", 1993.

M.F Rajemi, P.T Mativenga and A.Aramcharoen,"Sustainable machining: selection of optimum turning conditions based on minimum energy considerations", Journal of cleaner Production,2010.

Nicholas, s., 2006. Stern Review: The Economic of Climate Change. Office of Climate Change, UK.

P.T Mativenga and M.F Rajemi, "Calculation of optimum parameters based on minimum energy footprint", journal of Manufacturing Technology", 2011.

VanLoon G, Duffy SJ, Environmental Chemistry: A Global Perspective. 2000 Gary vanLoon and Steven J. Duffy, Oxford University Press, oxford, UK

Wenzel H, Hauschild M, Alting L, Environmental Assesment of Products, Methodology Tolls and Case Studies in Product Development, institute for Product Development, Chapman & Hall, vol 1: pp. 244-247