LIFE CYCLE ASSESSMENT (LCA) OF POWDER METALLURGY

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Abstract – Two major environmental advantages with powder metallurgy are high utilisation of material and low energy consumption. A disadvantage as compared to most low-alloyed wrought steels is the use of other alloying elements such as copper and nickel. It is also common to use higher alloying contents. The systematic approach of LCA has been used to compare the PM process with other manufacturing methods. The paper also presents how LCA can be used to evaluate different powder metallurgical processing steps and alloys for the manufacture of components as a means to quantify the environmental influence.
KEYWORDS: LCA, LIFE CYCLE ASSESSMENT, ENVIRONMENT, ECOLOGIC, POWDER METALLURGY, ALLOYING ELEMENT

I. INTRODUCTION

A major issue to consider for industries in the modern society is the environment and the influence of the companies activities on the ecological system both for existing and future generations. Environmental aspects have become important for decision making besides other such as economical, political etc. A problem, however, is the lack of knowledge regarding the ecological effect of industrial activities and especially difficulties in quantifying these effects. Many companies and organisations active within powder metallurgy are today developing systems according to ISO 14000 which is the international standard for environmental matters [1, 2, 3].

Life Cycle Assessment (LCA) is a systematic method which has been used for many years and describes the environmental influence of a specific process or product during its whole life cycle [4,5].

This paper uses LCA to compare the environmental effect of powder metallurgy components and components made of wrought steel as well as comparing different low alloyed PM-steels. It shows that LCA is a useful tool to describe the PM process and that parts made of sintered steel have a smaller negative environmental effect than parts made of wrought steel.

II. THE METHOD LCA

A life cycle assessment (LCA) is a compilation of inputs, outputs and potential environmental impacts of a product system and its whole life cycle. Inputs and outputs refer to the use of natural resources, emissions to air, water and soil, and solid waste. The life cycle consists of the processes and transports involved in raw material, production, use and waste management. LCA is sometimes called "cradle-to-grave" assessment (fig. 1).

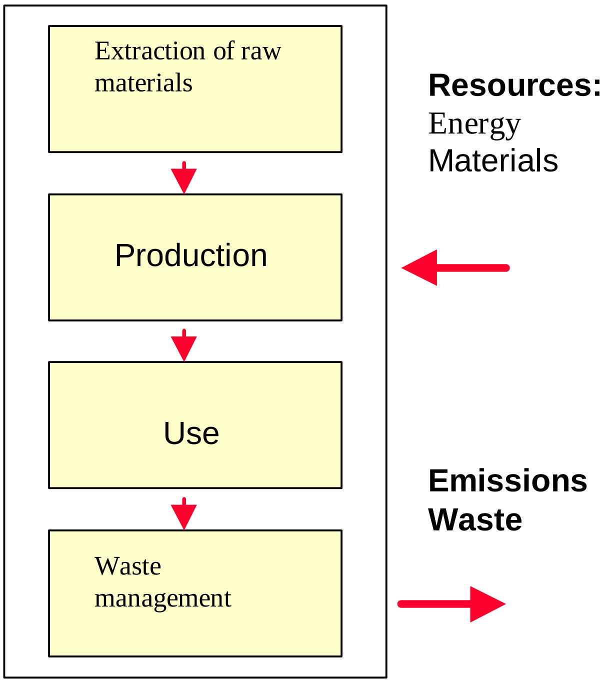

Fig. 1. LCA – the "cradle-to-grave" concept.

The phases of LCA are described in ISO 14040 [4, 6] and consists of 1) definition of the case, product or process to be evaluated, 2) collecting data for the environmental loading involved and 3) calculating the impact on the environment of the involved loadings (impact assessment).

In the last phase, impact assessment, the environmental effect is classified into different categories such as resource depletion, global warming, human toxicity etc. Finally a "weighting" of data is performed where the total environmental impact of the life cycle is assessed.

After the characterisation, a normalisation of the data may be performed during which the contribution to each impact category is normalised by dividing it by the total contribution to the impact category from a given geographical area during a defined time period. In this way it is possible to compare the relative contribution from the studied product to an environmental problem for a country during one year with the relative contribution to the other impact categories.

There are a number of different systems to define impact categories but the definitions used in ISO 14040 can be regarded as the internationally approved system. In this standard impact categories are defined as in table 1.

Table 1. List of impact categories included in this study, the equivalence factors and the units for characterisation factors.

Impact category	Equivalence factor*	Units for characterisation factors
Abiotic depletion	ADP	(kg reserves)$^{-1}$/kg
Global warming	GWP	kg CO_2-equivalents/kg
Photo-oxidant creation	POCP	kg ethene-equivalents/kg
Acidification	AP	kg SO_2-equivalents/kg
Eutrophication	EP	kg PO_4^{3-}-equivalents/kg
Human toxicity, air emissions	HCA	kg/kg

* This column defines the equivalence factor used in this study.

Abiotic depletion means depletion of natural resources which are not renewable such as oil and minerals. It is measured as 1/kg which means 1 kg of a non-renewable resource is used and is related to the total known available amount of the particular resource possible to utilise according to current production practices and technologies.

Global warming concerns substances which contribute to the greenhouse effect. The characterisation factor stands for the extent to which a mass unit of a given substance can absorb infrared radiation compared to a mass unit of CO_2.

Photo-oxidant creaction reflects the problem of creation of substances such as ozone by photo-chemical reactions in the air (close to the ground). The smog in big cities is an effect of these kinds of reactions. The POCP of a substance is a measure of the extent to which a mass unit of the substance forms oxidants compared to the oxidant formation from a mass unit of ethene.

Acidification is a measure of the ability of a substance to acidify soil and lakes. The acidification potential is the ability of 1 gram of substance to release H^+ ions compared to that of 1 gram of SO_2.

Eutrophication [7] is a measure of imbalance of the nutrition in soil and water (too much nutrition). The Eutrophication Potential is the capacity of a substance to favour biomass formation compared to that of 1 gram of phosphate (PO_4^{3-}).

Human toxicity concerns substances emitted to air, water and soil which are toxic to human beings. There is no consensus on how to include human health in LCA. The human toxicological factor for air, HCA is calculated by methods defined by RIVM and WHO [8]. It includes tolerable concentration in air, tolerable daily intake etc.

III. PM VERSUS WROUGHT STEEL

A LCA study was carried out with the objective of comparing the environmental impact when producing a component either by machining of forged steel or by powder metallurgy. The chosen component had a weight of 130 grams and is used in an automotive engine. The composition of the two materials and their respective material utilisation is shown in table 2.

Table 2. Component data (130 g)

	Composition, %				Material utilisation*
	Cr	Ni	Cu	C	
Wrought steel (forged)	1.0	0.9	-	0.2	62 %
PM-steel	-	-	3	0.5	95 %

* Scrap is recycled.

The process tree for production of a component by powder metallurgy is shown in fig. 2.

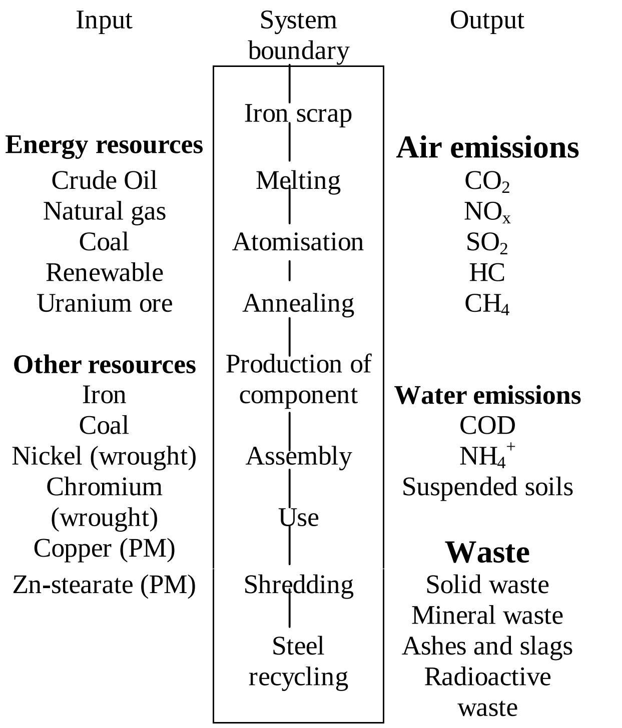

Fig. 2. Process tree for manufacture, use and recycling of a PM-component.

The process for the machined component is similar but instead of the steps atomisation and annealing, casting and forging is utilised. Figure 2 shows the system boundary. On the left side of the system natural resources such as energy and raw material necessary for the production of the component are listed and on the right side of the system emissions and waste are listed.

The primary energy used for a component made by powder metallurgy is less than half of that used for the wrought material (fig. 3). Even if the scrap from machining of the wrought component is recycled the energy demand for the production of the part is much higher than for PM. Energy demand for raw material production is similar for the two methods and the energy recovery (saving) when re-using the materials is identical.

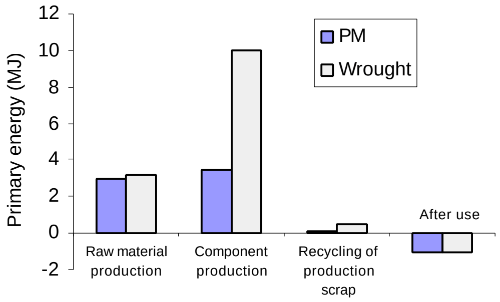

Fig. 3. Comparison of the primary energy demand in different parts of the life cycle.

In order to compare the two manufacturing methods concerning environmental impact categories the collected data were normalised. These impact values (fig. 4) show that PM for each category has a smaller environmental influence than the wrought steel. Especially the Abiotic depletion, Acidification and Human toxicity are substantially lower.

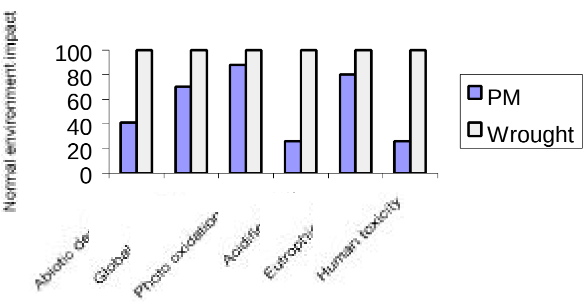

Fig. 4. Comparison of the normalisation results.

IV. COMPARISON OF FOUR PM ALLOYS

Four PM alloys were analysed by utilising the LCA-method. The base for the comparison was the same component as described earlier in this paper with a weight of 130 g. The investigated alloys are given in table 3.

Table 3. Evaluated PM alloys

Alloy	Composition, %				
	Cu	Ni	Cr	Mo	C
A	2	0	0	0	0.5
B	0	0	1.5	0.2	0.5
C	0	0	3.0	0.5	0.3
C	1.5	4.0	0	0.5	0.5

The first two alloys (A and B) result in medium strength after sintering whereas the two last alloys (C and D) are primarily suitable for high strength components.

The environmental impact of these alloys for the production and re-use of a PM-component is shown in fig. 5.

The high figures for material D depends on the content of Ni. Even though the background data used for calculating the environmental effect of Ni is uncertain it is obvious that this element has the strongest influence on the ecological system. The largest effect of Ni originates from the refining of Ni-rich ore to metallic Ni. Major effects are high electricity demand, emission of sulphur dioxide and the limited amount of natural resources.

Abiotic depletion gets a large contribution from alloys C and D because of the content of Mo. The higher figures for D depends on alloying with nickel instead of chromium due to the fact that nickel is a more scarce resource.

The contribution to *global warming* is highest for material D but the difference to A and C is not that large. The reason for the difference is mainly caused by the use of fossil fuels in the production of the elements nickel and molybdenum. The emissions contributing to global warming are mainly carbon dioxide and to some extent methane. For this impact category alloy B has the smallest effect. The contribution to global warming is low for the production of chromium and the possibility to recycle the components after use also has a positive effect to reduce the global warming effect.

The *photo-oxidant creation* is a local environmental issue and is primarily associated with the production of the alloying elements. No major differences between the alloys can be seen.

Only alloy D has a large influence on the *acidification* related to the formation of sulphur dioxide emissions when producing nickel from sulphur-containing ore. As SO_2 is spread by the air and precipitates to soil and water by rain and humidity this ecological effect is considered to be regional (compared to global and local).

The *eutrophication* is similar for all alloys and also rather small. The effect is regional and the contributing emissions are primarily nitrogen oxides and ammonia.

As described earlier the *human toxicity* is not well defined and is therefore impossible to quantify. In this case both toxicity from air and water is evaluated. The impact from material D is based on air pollution of sulphur-dioxide formed during production of nickel as

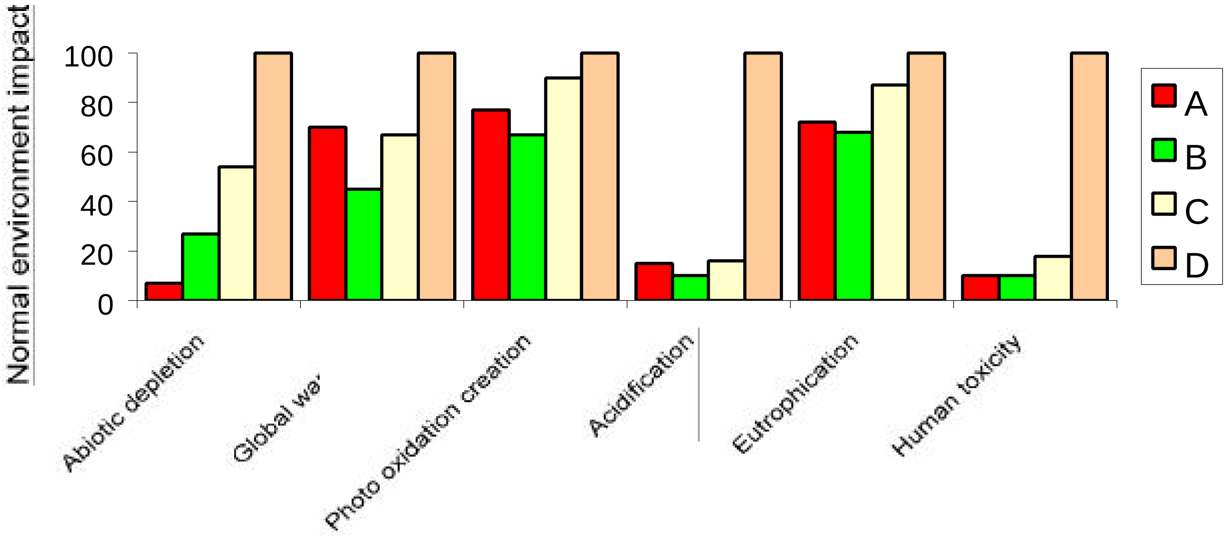

Fig. 5. Environmental impact of four different PM alloys.

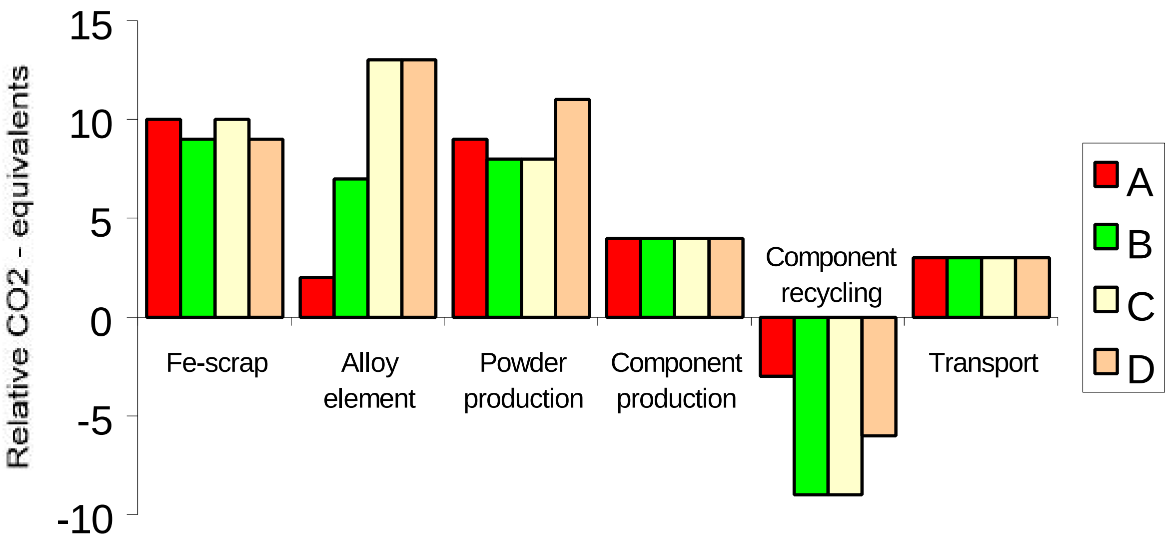

Fig. 6. Global warming effect of processing steps for manufacturing of a PM component using different alloys.

well as fluorides and iron giving rise to water emission originating from molybdenum production.

V. GLOBAL WARMING

All environmental impacts have an influence on the life of people. Depending on geographical area, financial situation, political circumstances etc. the type of impact is considered more or less difficult or problematic. The issue of global warming is influencing people all over the world and might be the impact on which it would be possible to reach a consensus among all nations. This is already well on the way by for example Agenda 21.

A comparison of global warming effect when producing PM components from the four alloys A-D (table 3) is shown in fig. 6.

The dominating steps are Fe-scrap, alloying elements and powder production. The influence of alloying elements is less for the materials with copper and low contents of chromium and molybdenum (A and B) than materials C and D, whereas the other processing steps have almost the same impact on the CO_2-equivalent independent of alloy composition. A major advantage of the two chromium containing alloys is the possibility to recycle. Their contributing effect to reduce global warming through recyclability is three times that of the copper-containing alloy. The problem with copper is the negative influence on formability of steel. This is a major concern when using scrap for steel to be cold rolled.

VI. ELECTRICITY CONSUMPTION

The choice of electricity production data is an important factor for the results. In this study data representative for Europe have been used even if part of the raw materials and processing steps are performed outside Europe. For the data related to iron powder production Swedish average electricity production has been used (about 50 % hydropower/50 % nuclear power).

An example of the environmental impact related to the production of electricity and other factors is shown in fig. 7 for manufacturing of a PM component based on material C (table 3). Results for the other materials (A, B and D) show similar relations.

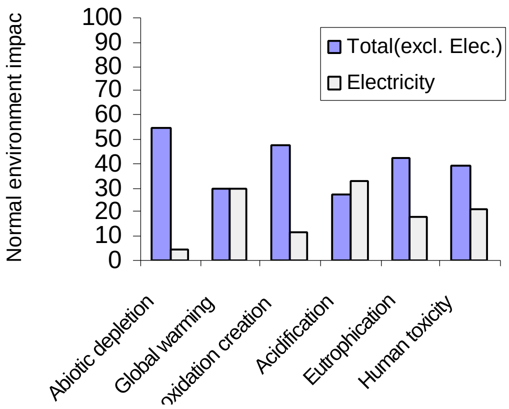

Fig. 7. Environmental impact related to electricity production and total excluding electricity for a PM component made of Fe + 3% Cr + 0.5% Mo + 0.3% C (material C).

The impact from electricity is mainly a consequence of powder and component production and less an effect of the different alloying elements. Both global warming and acidification are to a great extent influenced by the production of electricity.

VII. ENVIRONMENTAL IMPACT FROM THE USE PHASE

An experience from many LCAs is that the “use phase” of the studied product many times dominates the life cycle’s total environmental impact. Since the main goal of this study is to analyse and compare two different manufacturing techniques and different PM alloys, the use phase of the component, i.e. the use of the car, is not included in the life cycle. However, the following calculation from the use phase gives the total environmental impact.

The fuel consumption of the car is dependent on weight, rolling friction, air resistance, movable parts and actual load. The following was done:

The fuel consumption of the car is distributed to a PM component with respect to each component’s share of the total weight of the car. Only 37 % of the fuel consumption is proportional to the weight of the car. Other fuel consumption originates from air resistance etc. The calculation of emissions of CO_2 is 174 g/km, the life time of the car is estimated to 200 000 km, the car weight is 1 400 kg and the weight of the PM component is 0.130 kg.

174 [g/km]*200 000 [km/component]*(0.131/1400)*0.37 = 1205 g CO_2/component

The environmental load for using a car, i.e. the fuel consumption and the emissions to air, is given in literature [9].

The emission of CO_2 and the resource depletion due to fuel consumption is substantially higher than these values for the production of the PM component. The CO_2 emission is for example almost 10 times higher than the weight of the component. However this study focuses on the production and recycling of automotive components rather than the use.

VIII. SUMMARY

LCA is a useful method to assess the environmental impact of PM part production. Lack of background data and uncertainty of the validity of existing data however must be considered when evaluating the result of a LCA. By understanding the origin of the used information the deviation of the result can be judged.

This LCA clearly demonstrates the lower environmental influence of the powder metallurgy process compared to machining of wrought steel for the manufacture and recycling of automotive components. This advantage is primarily a result of the lower use of energy. Environmental impacts such as depletion of natural resources, acidification and human toxicity are between 26 % and 41 % compared to the figures for machined components.

The comparison between PM materials shows that the alloying elements chromium and copper have a smaller environmental impact than nickel and molybdenum. Concerning abiotic depletion the material with 2 % Cu is the least detrimental whereas the material with 1.5 % Cr + 0.2 % Mo has the smallest influence on global warming, photo-oxidant creation and acidification.

The global warming is primarily dependent on the production of steel and powder and less influenced by the type of alloying element used. The higher amount of CO_2 formation for the production of chromium and nickel is compensated for by the potential of recycling materials with these elements whereas copper containing steel in future will be difficult to recycle because of the reduction of ductility of steel with impurities of copper.

IX. ACKNOWLEDGEMENT

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