ISSN 2176-5480

22nd International Congress of Mechanical Engineering (COBEM 2013)
November 3-7, 2013, Ribeirão Preto, SP, Brazil

IDENTIFYING THE MAIN VARIABLES FOR AN EFFECTIVE LIFE CYCLE ANALYSIS IN GRINDING PROCESS

Remo Augusto Padovezi Filleti
Eraldo Jannone da Silva
Escola de Engenharia de São Carlos da Universidade de São Paulo
Address: Av. Trabalhador São-carlense, 400, Pq. Arnold Schimidt – 13566-590 – São Carlos, SP, Brazil
Email: remo.filleti@usp.br; eraldojs@sc.usp.br

Abstract. *During the last decades, the increasing concern of the industrialized countries about the environmental impacts of manufacturing processes resulted in the development of reducing and controlling initiatives of those governments. In this context, the use of environmental management tools as Life Cycle Analysis – LCA, which identifies the manufacture production environment impacts and develops strategies for their control and reduction, are more and more desirable. One of the most current LCA's methodologies is the Unit Process Life Cycle Inventory UPLCI. However, there are few datasets available of its performance in important manufacture processes, such as grinding. The aim of this paper is to increase the availability of these datasets by the development of a framework with the inputs, outputs and most important variables of the grinding unit process, in order to perform a lean and effective UPLCI. The methodology consists on the implementation of the LCA's Objective Description and Scope phase, defined by the ISO 14040 and 14044 standards, to build the framework. The result framework has three types of inputs and outputs (Energy & Fluid Materials, Workpiece and Solid Materials), five processes (Grinding Process, Dressing Process, Fluid & Air Filtering, Fluid Application and Quality Tests) and three most relevant environmental issues (Grinding Time, Cutting Fluid Management and Dressing Interval Strategy). The identified environmental variables, as well the developed framework, creates a solid base to perform the next phases of the grinding UPLCI.*

Keywords: *Grinding, LCA, UPLCI*

1. INTRODUCTION

Since the 90's, there is a growing concern about the environmental impacts of manufacturing production on the most of industrialized countries. This concern about a “greener production” made some countries to perform environmental preservation actions, as the adoption of stronger environmental tax policies, acceptance of global protocols and agreements (like Kyoto's Protocol) and economic stimulus to “green companies” (fee reduction or lower loan interest).

In this context, the implementation of eco-efficiency in manufacturing process becomes a very important (economic) issue. The World Business Council for Sustainable Development - WBCSD (2000) defines eco-efficiency as the ratio of product or service value by its environmental influence, shown by the Eq. (1):

$$eco - efficiency = \frac{Product\ or\ service\ value}{Environmental\ influence} \qquad (1)$$

One way to determine which process parameters aggregates value to the product/service and which parameters has significant environmental influence is by a Life Cycle Analysis (LCA). This environmental management tool has as fundamental goal the identification of improvement opportunities at a product environmental performance, but it can also be used to improve the product economics and social performance. The LCA's structure is divided in four parts, as shown by Fig.1 (ABNT, 2009a) (ABNT, 2009b).

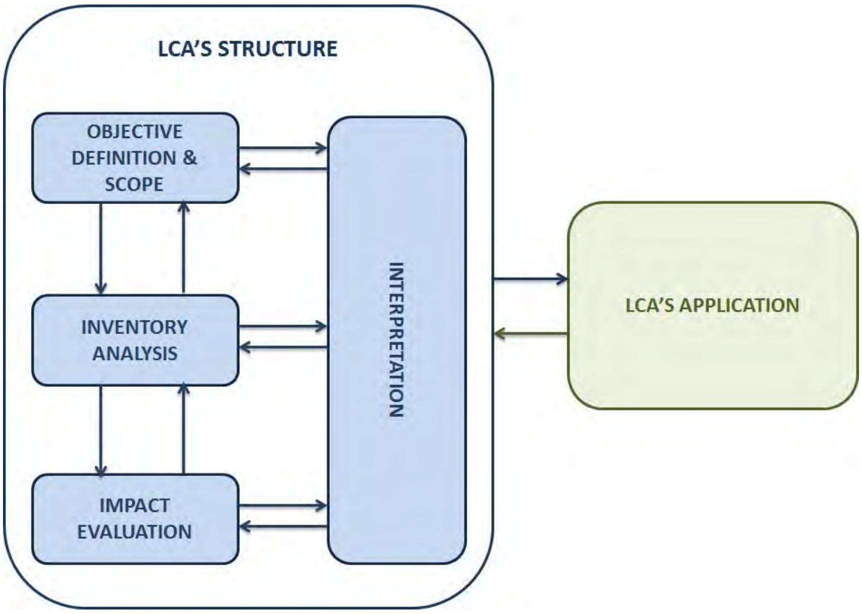

Figure 1. Life Cycle Analysis Structure

According to Machado et al. (2009), grinding has a prominent position among the abrasive processes, providing the production of high dimensional and geometric quality components. These characteristics are desirable for most of the metal-alloy components, and metalworking companies, especially in the automotive and aircraft sectors, where the amount of components with high requirements of tolerances and surface finishing pushes the grinding performance standards to the higher limits (Kopac and Krajnik, 2006).

Machado et al. (2009), however, points out that grinding has a low efficiency in material removal per power consumption, compared with other machining process like turning and milling. Moreover, the process has high levels of heat generation during the material removal and, therefore, the application of cutting fluid is necessary to cool the workpiece and promote the required lubrication in the grinding zone. The cutting fluid, in the most of the cases, is an oil, water-emulsion or water based solution (Linke and Overcash, 2012), and some of its components may be harmful to the environment and/or to the worker health.

Based on the current scenario, the eco-efficiency in grinding is key point to achieve the required environmental compliance and performance in modern manufacturing. Thus, an effective UPLCI of grinding is mandatory.

1.1 Objective

This paper aims to perform, for the Grinding Unit Process, the first phase of the LCA - *Objective Definition and Scope*. It will be identified the most important inputs, outputs, process and flows of the chosen system. Thus, the basis for a lean and effective LCA to improve grinding unit process eco-efficiency will be provided.

2. LCA'S FIRST PHASE – OBJECTIVE DEFINITON AND SCOPE

The definition of the objective and scope is the base of a Life Cycle Analysis and, by this reason, has to be well performed in order to achieve the desirable results at the planned time. In this phase, it is defined which are the borders of the studied system, its inputs, outputs and other relevant information required to build the product's process life cycle framework.

As shown by Fig. 1, all LCA's phases are two-way connected with two or more other phases, what represents the iterative property of this tool. So, besides the importance of a well done definition of the objective and scope for the whole analysis, this first phase, as well the others ones, can be changed, if necessary, at any time during the LCA's performing.

2.1 Objective Definition

This stage must contain the defined application and the reasons of the study's implementation (Alves, 2007). In other words, it has to answer the following question: –Why it is necessary to perform a LCA for this proposed system?". From this answer, it is possible to define which are the desirable outcomes of the study and to forecast how the system will be approached by the analysis.

Once the LCA's Objective is defined, it must be used like a guide for all the other phases of the analysis, serving as reference to ascertain if one system process, input, output, result and/or other information, is relevant or not to its achievement.

2.2 Scope

This stage is based in the identification of all relevant parameters, processes and information and how they are related with each other. The definition of the LCA's scope has to contain: Product System Definition, System Borders, Functional Unit, Allocation Proceedings, Impact Categories and Limitations.

The conclusion of this stage results in the construction of the first product's product system diagram, which will contains the most important inputs, outputs, fluxes, and processes, primordial for the next phases of analysis, not approached in this article.

2.2.1 Product System

The product system consists in the set of process and fluxes (raw materials, products and energy) that molds the product's LCA and characterizes its functions (ABNT, 2009a) (ABNT, 2009b).

The representation of the product system is made by a diagram containing all its related processes and fluxes. Figure 2 shows an example of a product system diagram, its inputs, outputs, inside processes and the fluxes between the processes.

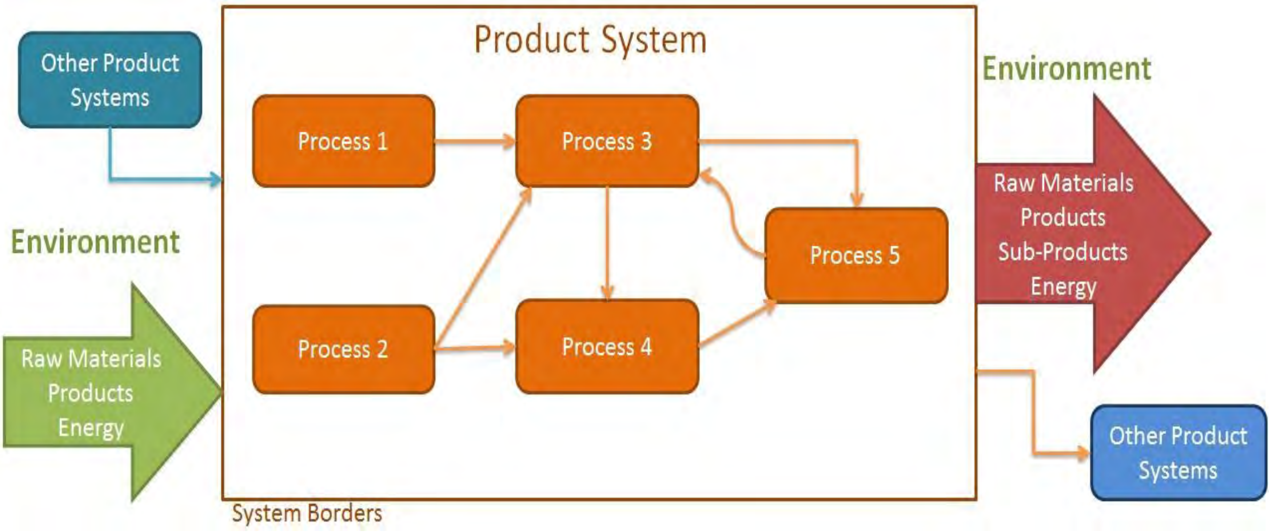

Figure 2. Product system diagram example

2.2.2 System Borders

The borders of the system are the adopted criteria that delimit which processes are parts or not of the product system, as well which are the income and outcome system's fluxes. Its representation can be seen at the product system diagram example in Fig. 2.

All the LCA's steps are based on the information and considerations done to the inside elements (internal processes and fluxes) and to the edge elements (system's inputs and outputs) of the system borders. Therefore, their definition and the cutting requirements for processes and fluxes have to be aligned with the proposed objective, in order to decrease the possibility of excluding important processes/fluxes or including irrelevant ones to the analysis.

2.2.3 Allocation Proceedings

The allocation proceedings are the definition of which income or outcome fluxes (raw material, product or energy) of a studied product system or process are shared to another product system.

An allocation proceeding example can be seen in an alcohol/sugar production plant. Considering this plant as the product system, one of its processes is the heating of the sugarcane juice in a boiler by the combustion of the sugarcane bagasse. The energy (heat) flux, in this case, is divided in two: part of it goes to the boiler and part of it goes to the environment. However, part of this heat that goes to de environment can be used in another product system to produce electric energy. This new part of energy flux, which will be used to produce electric energy, is an energy flux allocation proceeding.

The use of allocation proceedings, nevertheless, usually complicates the LCA performing, because these proceedings can bring some of the others product systems parameters to the analysis. Thus, if the use of allocation proceedings is necessary, they have to be well described and represented in the product system diagram, clearly defining which the allocated fluxes are and, as well as their target product systems.

2.2.4 Impact Categories

This step consists on the definition of which environmental, economic and/or social issues are relevant for the chosen product system. It must be chosen one or more impact indexes for each selected impact category, in order to give magnitude and quantify it. Brino et al. (2012) indicate that the impact categories may vary according to the selected LCA methodology.

Hereafter, there is some of the impact categories used on a LCA

- Human Health;
- Wealth Generation;
- Wealth Distribution;
- Global Warming;
- Ozone’s Layer Depletion;
- Ecotoxicity;
- Eutrophication;
- Acidification and
- Abiotics Resources Depletion.

The choice of the impact categories are related with the kind of impact (environmental, economic and/or social) it will be considered, the objective of the Life Cycle Analysis and the information availability of each impact category or index.

2.2.5 Functional Unit

The functional unit is used as a reference unit to quantify the system performance, in other words, all the impact indexes of the LCA (environmental, economic and/or social) must be couple up to the defined functional unit, to be analyzed by the same metric.

Considering, for instance, a wood chair production as the product system example to be analyzed by the LCA tool, a functional unit for this mentioned system would be “produced chairs”. From this unit, it is possible to identify environmental, economic and social performing rates, like power consumption/produced chair (environmental), average cost/produced chair (economic), work accidents/produced chair (social), etc. These rates allow the comparison of this product system with others similar, as plastic or metal chair production, and the definition of which are more efficient between the LCA’s impact categories.

Each LCA must have only one Functional Unit, to make both interpretation and comparison with other similar product system more clear and objective.

2.2.6 Limitations

The limitations can appear at any time during the LCA performing, occasioning, every time it occurs, the need of an overall review of the analysis in order to verify if it is still possible to reach the proposed objective.

Much of the limitations, however, can be identified at the initial steps of the analysis, what helps to avoid “inconvenient surprises” during the LCA performing. In this context, it is important to spend scope definition time to identify the limitations of the analysis and evaluate the best way of acting: to accept the limitations or to work for overcoming them.

3. GRINDING UNIT LCA’S FIRST PHASE APPLICATION

3.1 Defining the LCA’s Objective

The objective of this Life Cycle Analysis is to propose actions and modifications to improve the eco-efficiency of the standard grinding unit process, by productivity increase associated with waste production, eco-contamination and energy consumption decrease.

3.2 Product System, System Borders and Allocation Proceedings

The LCA’s product system is the grinding process unit for metal alloy pieces, which was divided on five different processes (Grinding Process, Dressing Process, Fluid Application, Quality Tests and Fluid & Air Filtering), three types of inputs (Metal Piece, Solid Materials and Fluid Materials & Energy) and three typed of outputs (Ground Metal Piece, Solid Materials and Fluid Materials & Energy).

The borders of the system were chosen to contain just the main processes of the grinding process unit, disregarding:

- Previous metal alloy pieces production steps, like mining, smelting, and metal conformation;
- Income energy, like electric energy and pressurized air energy, generation steps;
- Production of the auxiliary materials steps, like cutting fluid, air & fluid filters, dressing tool and grinding wheel;
- Destination of the products and sub-products.

The product system was also molded to do not require the use of allocation proceedings, in order to avoid the analysis of parameters from other product systems.

3.3 LCA’s Functional Unit

The chosen LCA’s functional unit was the final product: ―approved ground workpiece”, in other words, the processed workpiece which achieved the desired geometrical and superficial characteristics.

3.4 LCA’s Impact Categories

Table 1 presents the chosen LCA’s impact categories, defined from the objective of eco-efficiency improvement at the grinding process unit.

Table 1. Life Cycle Analysis’ Impact Categories

Impact Category	Type of Impact	Related Objective's Parameter
Wealth Generation	Economic	Productivity
Global Warming(1)	Environmental	Energy Consumption
Ecotoxicity	Environmental	Eco-contamination
Abiotic Resources Depletion	Environmental	Waste Production

(1) The relationship between Energy Consumption with Global Warming is based on the CO2 production during the energy generation, once 81.1% of the global energy generation matrix is based on fossil fuel combustion (IEA, 2012)

3.5 Limitations and considerations

The initial limitations and considerations were defined in order to achieve the final objective, avoiding abrupt changes at the scope. It was listed four main limitations/considerations:

- **Type of ground material:** The grinding process for metal alloy workpieces was chosen just as an example, based on its wide utilization in important sectors of the industries, like automotive and aircraft. However, this study can be used as base for grinding process units of other type of materials;
- **Sub-Products destination:** In order to simplify the product system and provide a lean LCA, all the outputs of the system, besides the ground workpieces, are released or discarded to the environment and will not, in a first moment, be an input to other product system;
- **LCA’s coverage:** The more processes of a product life cycle were included at the product system, more information and actions can be generated to improve the product performance on the LCA’s impact categories. However, the objective of the study is to perform a lean LCA, headed just to the grinding process unit, therefore, processes that are not part of the grinding process unit were not included in the system borders;
- **Processes division:** The processes inside the LCA’s diagram were divided according its processes main goals and in order to guarantee a clean and clear view of energy and material fluxes between them. For these reasons, steps that have direct relationship with one of the five main processes and do not present more than one explicit flux with other processes were incorporated by the related main process.

3.6 Defined Product System Diagram

Figure 3 contains the diagram shaped by the product system definitions.

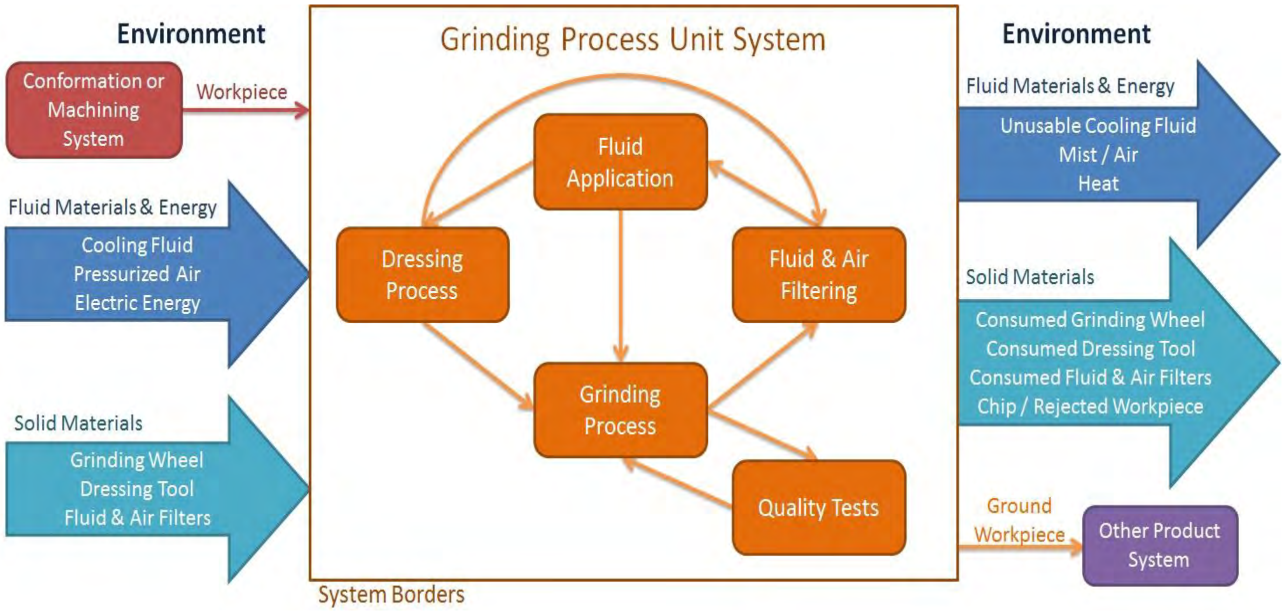

Figure 3. Grinding process unit system diagram

3.6.1 Inputs & Outputs

The inputs and outputs of the product system were grouped, in three different classes, according to their composition and function: Product (Metal Piece Input and Ground Metal Piece Output), Solid Materials and Fluid Materials & Energy.

The first input/output class, Product, consists of metal piece which will become the product system: the final ground workpiece.

The second class, Solid Materials, is formed by the solid auxiliary materials and components: Grinding Wheel (Grinding Process), Dressing Tool (Dressing Process) and Air & Fluid Filters (Air & Fluid Filtering). These materials are consumed by the grinding process unit and have to be changed periodically. After their reposition, the consumed items become the Solid Material output of the system, amongst the Rejected Pieces (ground metal pieces that were not approved by the quality tests and could not be reworked in grinding process) and the chips formed by the abrasive cutting during the grinding process.

The remaining class (Fluid Materials & Energy) is represented by different forms of energy, air and cutting fluid. At the system's input, this class is composed by electric energy, pressurized air and new cutting fluid. The electric energy is the main energy source of the system, responsible for almost all processes energy alimentation. The pressurized air represents a material (air) and energy (air pressure) flux and, together with the cutting fluid, is responsible to create the fluid mist, during fluid application.

The system output is composed by heat, mist & air and waste cutting fluid. The heat is generated at all processes inside the product system, but much of it comes from the grinding process. The air should leave the system by the air filtering system; otherwise, if the air filtering is not working properly, the air will leave the system contaminated with cutting fluid (mist). The waste cutting fluid is the consumed fluid at the product system and cannot be used any more, e.g., lost by evaporation, degradation or by system leakage.

3.6.2 Grinding Process

The grinding process consists of material removal by the cutting action of the abrasive grains of the grinding wheel, providing high quality superficial and geometrical characteristics to the workpiece. This is the main process of the product system, which aggregates value to the product.

Kopac and Krajinik (2006) affirm that the increase of the grinding wheel speed is the main factor of productivity improvement, because it provides the reduction of the cutting time (Wealth Generation); but there is an increase on the power consumption rate (Global Warming). A significant rise on the grinding wheel speed, however, is just possible by the use of superabrasives (cubic Bore Nitride or Diamond) grinding wheels, which are more expensive than the regular ones, but suitable for that operation. Superabrasive wheels have different design characteristics, with core made mostly by steel, with abrasive layer many times thinner than the conventional wheels. In the end of life, superabrasive wheels can have their metal body reused, just replacing the abrasive layer.

Linke and Overcash (2012) highlights the importance of the geometric and superficial quality of the pre-ground workpieces. The lower the stock to be removed in grinding (due to be a better machining characteristic from the previous operation) less working time and less energy from the grinding process unit will be required.

The time management of grinding process is the most important element of eco-efficiency of this product system process. Shorter grinding times will lead to less power (Global Warming) and the fluid/solids material consumption (Abiotic Resources Depletion/Ecotoxicity), and higher productivity (Wealth Generation).

3.6.3 Fluid Application and Fluid & Air Filtering Process

The cutting fluid application process is responsible for cooling the workpiece, flushing the chips away from the grinding zone and promoting the required lubricant action to reduce tool wear and to minimize the plowing and sliding mechanisms during chip formation. During dressing, cutting fluid is used to cool the wheel and the dressing tool, as wheel as flushing the abrasive debris from the contact are between wheel and dressing tool.

Cutting fluid is applied to the process in a closed-loop system: the fluid is pumped from a sump to the application nozzle at the grinding zone. Mist is formed due to the impact of the fluid jet against the workpiece and the wheel. After the application, the recovered fluid and the air mist inside the grinding machine will be clean at the Fluid & Air Filtering Process.

During air filtering step, the mist passes through the air filter, which will remove the suspension cutting fluid and will release clean air to the environment. At fluid filtering step, the recovered cutting fluid passes through the filtering system (paper filter with chips and debris being retained by paper mesh. Then the cleaned cutting fluid returns to the sump in order to become available and being recirculated.

The cutting fluid management has a high impact at grinding eco-efficiency, once it embraces all the LCA’s objective parameters. The type of the cutting fluid interferes at its heat transfers (Wealth Generation), its durability (Abiotic Resources Depletion) and on its environment toxicity (Ecotoxicity). Besides that, an optimized flow rate of cutting fluid at the working surface represents savings in pump’s energy consumption (Global Warming) and cutting fluid reposition (Abiotic Resources Depletion).

Finally, a regular maintenance at the Fluid and Air Filtering system provides the reuse of the cutting fluid (Abiotic Resources Depletion) and avoids uncontrolled losses to the environment by mist and leaks (Ecotoxicity).

3.6.4 Dressing Process

The dressing process consists on the periodically maintenance of the grinding wheel cutting properties, by the removal of a thin layer from the grinding wheel surface through the dressing tool action. This tool is normally a diamond tool which machines the grinding wheel surface in order to remove the consumed abrasives grains, unearthing the new ones located in the interior layers.

The grinding wheel cutting properties maintenance is closely related with the productivity (Wealth Generation), once it avoids chances at grinding process parameters. However, the dressing process is also related with the waste generation (Abiotic Resource Depletion), once it removes debris (worn abrasives and bond material) from the outermost layer from the grinding wheel, as well causes the dressing tool wear during use, requiring the periodically change of the tool. Other important issue from this process is the energy consumption (Global Warming), required to dressing.

There are two dressing process variables that significantly impact the LCA’s objective parameters: the dressing period and the dressing overlap. Chen et al. (1998) demonstrate that the use of a dressing periodicity strategy stabilizes the grinding wheel cutting performance, improving the system’s productivity. Besides that, an optimized dressing interval avoids the unnecessary grinding wheel and dressing tool consumption. The dressing overlap (the rate between the dressing tool width and the dressing lead), on the other hand, is related with the grinding wheel cutting capacity after the dressing process, as well it useful life (Machado et al., 2009).

3.6.5 Quality Tests

The quality tests are performed to check if the ground workpieces achieved the desirable geometrical and superficial requirements. Once the part passes through the quality tests, it leaves the system as the main product. However, if many parts do not pass through the quality tests, all the product system has to be investigated to find and ro repair the causes of those failures.

A reproved product pushes down the system eco-efficiency, once it generates negative environmental contribution (eco-contamination, power consumption and waste production) as the system is performing with low (piece rework) or none (piece reject) wealth generation.

4. CONCLUSION

Through the performance of the LCA's First Phase – Objectives and Definition Scope, it was possible to define the product system diagram, identifying the most important inputs, outputs, process, flows, limitations and impact categories, shaping the basic framework for the grinding Unit Process Life Cycle Inventory.

The most important parameters involved on the product system eco-efficiency improvement (based in the chosen impact categories) were defined: the grinding time, the cutting fluid management and the dressing interval strategy. Other important parameters also were determined, as the geometric and superficial quality of the preceding machining process and the dressing overlap.

As a result, the necessary information will be available to perform the next step: Life Cycle Inventory Analysis, in order to achieve a lean and effective UPLCI, aiming to improve grinding unit process eco-efficiency.

5. ACKNOWLEDGMENTS

The authors would like to thank the CAPES (Coordenação de Aperfeiçoamento de Pessoal de Nível Superior) and CNPq (Conselho Nacional de Desenvolvimento Científico e Tecnológico) for supporting this research.

6. REFERENCES

ABNT, 2009a. “ABNT ISO 14040:2009 Environmental management - Life cycle assessment - Principles and framework” Associação Brasileira de Normas Técnicas. Rio de Janeiro, Brazil.

ABNT, 2009b. “ABNT ISO 14044:2009 Environmental management - Life cycle assessment - Requirements and guidelines” Associação Brasileira de Normas Técnicas. Rio de Janeiro, Brazil.

Alves, S. M., de Oliveira, J. F. G., 2007. “Environmental adequacy of machining processes using Cleaner Production as strategy of environmental management”. Produção, Vol. 17, p. 129-138.

Brinksmeier, E., Tönshoff, H. K., Czenkusch, C., Heinzel, C., 1998. “Modeling and optimization of grinding processes”. Journal of Intelligent Manufacturing, Vol. 9, p. 303-314.

Brino, H. R. H., de Francisco, A. C., Piekarski, C. M., da Luz, L. M., Zocche, L., 2012. “Life Cycle Analysis: Methods for LCIA”. In International Congress of Administration - ADM2012. Ponta Grossa, Brazil.

Chen, X., Allanson, D., Rowe, W., 1998. “Life cycle model of the grinding process”. Computers in Industry, Vol. 36, p. 5-11.

Denkena, B., Reichstein, M., Kramer, N., Jacobsen, J., Jung, M., 2005. “Eco- and energy-efficient grinding processes”. Key Engineering Materials, Vol. 291-292, p. 39-44.

IEA, 2012. “Key World Energy Statistics” International Energy Agency. Paris, France.

Li, W., Winter, M., Kara, S., Herrmann, C., 2012. “Eco-efficiency of manufacturing processes: A grinding case”. CIRP Annals - Manufacturing Technology, Vol. 61, p. 59-62.

Linke, B., and Overcash, M., 2012. “Life Cycle Analysis of Grinding”. In Leveraging Technology for a Sustainable World. Retrieved from http://link.springer.com/chapter/10.1007/978-3-642-29069-5_50.

Kellens, K., Dewulf, W., Overcash, M., Hauschild, M. Z. and Duflou, J. R., 2012. “Methodology for systematic analysis and improvement of manufacturing unit process life-cycle inventory (UPLCI) — CO2PE! initiative (cooperative effort on process emissions in manufacturing). Part 1: Methodology description”. Journal of Life Cycle Assesment, Vol. 17, p. 69-78.

Kopac, J., Krajnik, P., 2006. “High-performance grinding - A review”. Journal of Materials Processing Technology, Vol. 175, p. 278-284.

Machado, A. R., Abrão, A.M., Coelho, R.T. and da Silva, M.B., 2009. Teoria da Usinagem dos Materiais. Editora Blucher, São Paulo, 1st edition.

WBCSD, 2000. “Ecoefficiency: Creating More Value with Less Impact” World Business Council for Sustainable Development. Geneva, Switzerland.

7. RESPONSIBILITY NOTICE

The authors are the only responsible for the printed material included in this paper.