GCSM 11th Global Conference on Sustainable Manufacturing
2013
23rd - 25th September
Berlin - Germany

8.3 Cutting tool manufacturing: a sustainability perspective

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Abstract
Over the last few years, sustainability has become a major challenge for manufacturing systems, due to the rising awareness of energy consumption and to the associated environmental impact of processes. In order to measure the sustainability of a specific process, metrics for sustainable manufacturing were developed and proposed in the scientific literature. The research activities presented in this paper aim to apply a structured sustainable approach to a tool manufacturing process. More in detail, the production of a tap, starting from the raw material up to the finished product, is investigated. The process, divided into the various stages of the manufacturing route, is evaluated from a technological and sustainable point of view. Results provides a basis for decision-making, and are expected to be incorporated into the business strategy development processes.

Keywords:
Machining, Process consumption, Sustainable manufacturing, Tap production

1 INTRODUCTION

The rising awareness of the manufacturing impact on the environment, on the energy, and on resources consumption drives companies to the evaluation of their operations, considering also their sustainability. It has been widely agreed that sustainable manufacturing is a key component of sustainable development, balancing three principal requirements related to environmental, economic, and social objectives [1]. According to the National Council for Advanced Manufacturing (NACFAM, USA), sustainable manufacturing is defined as "the creation of manufactured products that use processes that are non-polluting, conserve energy and natural resources, and are economically sound and safe for employees, communities, and consumers" [2].

Focusing on the processes, there is still the need to achieve optimized technological improvement and process planning for reducing energy and resource consumption, toxic wastes, occupational hazards, etc. (Figure 1), and for improving product life by manipulating process-induced surface quality/integrity.

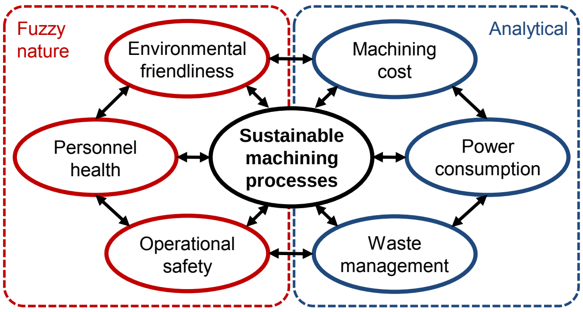

Figure 1. Basic sustainability elements in machining [3].

Industry is responsible for a significant percentage (around 25% in 2010 [4]) of the final energy consumption in Europe. Metrics for sustainable manufacturing were developed to quantify the performances of a specific process: for instance, the OECD toolkit provides a suitable set of indicators for analysis at different levels, from process and product to overall facility [5].

In order to achieve sustainability goals it is necessary to understand how the different variables influence the machining process [6], and many studies have been conducted in order to monitor and to improve the energy efficiency and to reduce the resources consumption. Mori et al. [7] investigated concrete ways to reduce power consumption, focusing on servo and spindle motors, which have the highest energy demands in machine tools. Drossel et al. [8] proposed HSC and HPC for improving resource and energy efficiency. Gontarz et al. [9] measured the energy consumption of an entire plant (manufacturing systems and machine tools) suggesting a case by case approach. Behrendt et al. [10] presented a three step methodology calculating the energy consumption of small, medium and large machine tools, considering the idle mode, the run-time mode and the production mode.

Power consumption is directly related to the CO_2 emissions (Figure 2), as a function of the national electricity mix (Figure 3), but it is not the only issue manufacturers have great interest in. Broader researches have been conducted analyzing the manufacturing route that brings towards the product. Li et al. [11] studied a grinding case and proposed an integrated approach to evaluate the eco-efficiency of such manufacturing process. Linke and Overcash [12] also focused on a grinding case, as it is one of the most-energy intensive operations among all machining processes. They monitored inputs (non product material, product material, energy, worker, grinding machine tool) and the outputs

G. Seliger (Ed.), Proceedings of the 11th Global Conference on Sustainable Manufacturing - Innovative Solutions
ISBN 978-3-7983-2609-5 © Universitätsverlag der TU Berlin 2013

(product, waste), providing a wide overview of the process up to the product. Klocke et al. [13] presented two different case studies within the manufacturing of metal parts, and analyzed the main perpetrators of the ecological impact regarding different consumption types in the industrial environment. Zhang et al. [14] investigated the manufacturing of metallic components for the automotive sector evaluating the total life cycle aiming at the sustainable improvement.

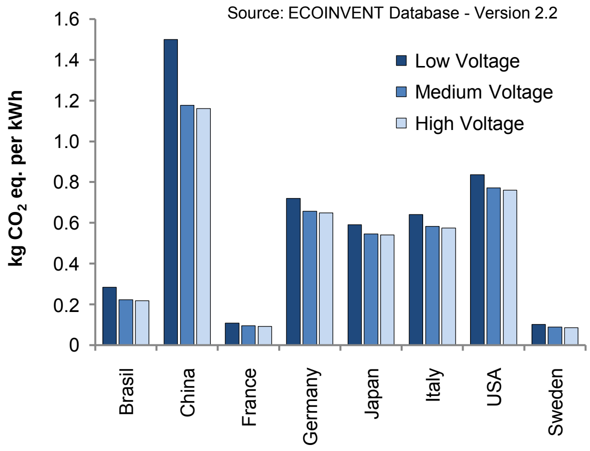

Figure 2. CO_2 emissions for the production of 1 kWh [15].

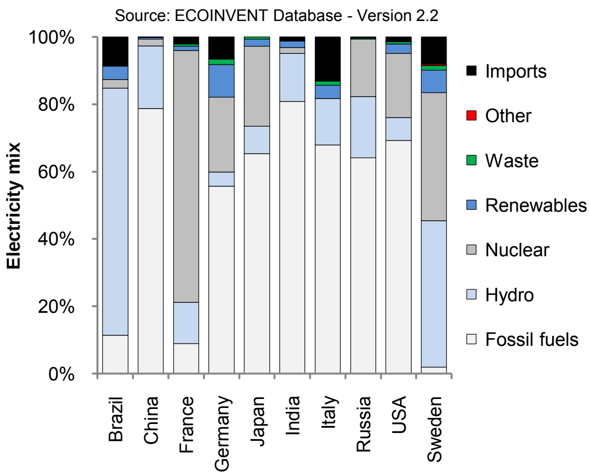

Figure 3. Electricity mix for different countries [15].

In this context, the present research work describes a structured sustainable approach to a complete tool manufacturing process. In the following, the framework is detailed with the description of all the subsequent operations, the analytic proposed approach is presented, and the correlation between each manufacturing stage and the different contributes on process consumption are critically analyzed.

2 TAP MANUFACTURING PROCESS

The production process for uncoated M10 spiral point taps, cutting tools designed for the execution of threaded through holes, was analysed in this research. Figure 4 details the different stages of the manufacturing route, on the basis of the conventional production procedures of the company UFS S.r.l. (Sparone, Italy), specialized in the manufacture of cutting tools. The taps are made from a W-alloyed high speed steel (HSS), produced by powder metallurgy and subjected to a cold drawing post-processing operation. The material is supplied in the form of round bars, with an expected hardness of 320 HB maximum. The bars were of 10.5 mm diameter and 3200 mm length.

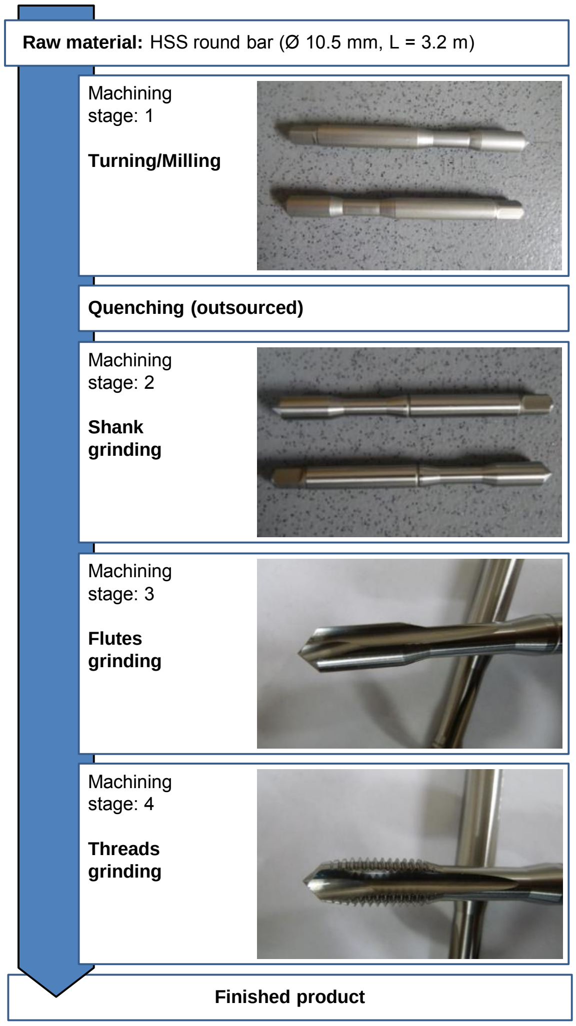

Figure 4. Spiral point tap production process.

The first machining stage is performed by a CITIZEN L20 sliding-head CNC lathe, fitted out with an automatic bar-loading apparatus. As it can be deduced from Figure 4, subsequent cutting operations (as centre-holes execution, longitudinal external turning, milling of the square cross-section at one end of the tool, parting of the semi-finished component) are carried out. Afterwards, the tap is subjected to a quenching heat-treatment. This activity is outsourced, therefore it was not considered at this level of the study. Then, the tool shank is grinded (second manufacturing stage), in order to accomplish the desired tolerance values, by means of a ZEMA cylindrical CNC grinding machine. After that, the three tool flutes were obtained (third stage) using a WALTER grinder retro-fitted by TAMIC (model TGG-SH-20-IC), and specifically designed to machine these geometries. Finally, on a GBA CNC grinding machine, the threads were manufactured (fourth stage). Tools and cutting conditions applied in each phase of the manufacturing route were chosen according to the standard process parameters adopted by the company for the production of HSS M10 spiral point taps. Figure 5 reports the cycle time for each stage: these values add up the cutting time and the time for the automatic workpiece handling inside the machine tools, whilst the time required for moving the semi-finished pieces between two successive workstations is not considered.

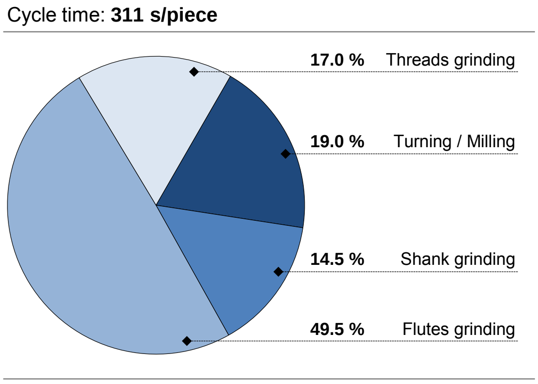

Figure 5. Cycle time for the production of a spiral point tap.

3 APPROACH TO PROCESS ANALYSIS

In order to analyze the whole tap production process, for each *i*-th manufacturing stage the different machine tools, together with their auxiliary apparatus, were assumed as black-boxes. As shown in Figure 6, during the processing from the workpiece to the (semi-)finished component, the major resources consumed during machining operations include electricity, lubricants, water, cutting tools and material [16].

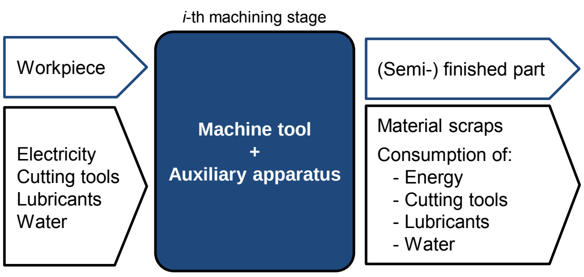

Figure 6. Experimental approach to process analysis.

The absorbed power was measured by a Chauvin Arnoux PEL 103 power/energy data logger, which was clamped onto the electricity supply wires of the machine tools. For each process step, the energy consumption was acquired during the steady-state manufacturing of 200 taps, and it was afterwards partitioned for each produced part. At this level of analysis, the power demand of machine tools was not split into the three different contributions (idle mode, run-time mode and production mode) proposed by Damhus and Gutowsky [17], but it was entirely considered. Only for the cases of flutes and threads grinding, the contributions of filtering/cooling external equipments were separately analyzed, since they are stand-alone units that significantly affect the total energy consumption.

The lubrication of each process was carried out using mineral cutting oils. More in detail, an oil supplied by Shell was applied for turning/milling, shank and flutes grinding processes, whilst an oil provided by Castrol was employed for threads grinding operations. For all the phases, not being used emulsions, the waste of water for lubrication is zero. In general terms, the cutting fluid used for lubrication is assumed to diverge into four paths during the machining process: (1) vapour waste stream generated through cutting fluid diffusion into the surrounding environment, (2) liquid waste steam created through fluid coating on the chips generated during the machining process, (3) liquid waste steam resulting from cutting fluid coating of the workpiece, and (4) lubricant flow collected and re-circulated through the system [18]. An accurate evaluation of the oil consumption for a small/medium production batch is relatively a problematic issue, being the direct measures subjected to uncertainties and errors. In order to quantify the amount of lubricant consumed for a single unit production and for each *i*-th manufacturing stage, the annual oil consumption was divided by the number of taps produced in one year, for every *j*-th machine tool (Equation 1). The amount of oil that was refilled and the complete oil changes were both taken into account. It is worth pointing that, in Equation 1, the *i*-th stage equates the *j*-th machine tool. This indirect measure was assumed to be acceptable for a first-attempt evaluation, since such machine tools are specifically dedicated to the production of taps fairly homogeneous in geometry and size (i.e. within the range from M8 to M12), although belonging to different production series/batches.

$$Oil\ consumption\ _{1\,tap}^{i-th\ stage} = \frac{Total\ oil\ consumption\ _{1\,year}^{j-th\ machine\,tool}}{Number\ of\ taps\ machined\ _{1\,year}^{j-th\ machine\,tool}} \qquad (1)$$

Each manufacturing step involves different cutting tools. For the first stage, centre drills, parting blades, inserts for external turning, and cutters for the insert mill are used. Moreover, four different grinding wheels are employed for shank, flutes, spiral point, and threads machining. For each case, the tool consumption was allocated to the single produced unit according to Equation 2, in which the denominator is the overall number of taps produced before the replacement of the *k*-th cutting tool.

$$Tool\ consumption\ _{1\,tap}^{k-th\ cuttingtool} = \frac{1^{\ k-th\ cutting\ tool}}{Number\ of\ taps\ machined\ ^{k-th\ cutting\ tool}} \qquad (2)$$

Finally, the loss of workpiece material due to the chip removal was directly obtained by the CAD/CAM software installed in the control units of the machine tools. In addition, the HSS bar scrap was weighted and subdivided by the number of taps produced by the bar itself.

4 RESULTS AND DISCUSSION

4.1 Power consumption

Figure 7 reports the measured energy consumption results. Overall, the production of a spiral point tap demands 1.64 kWh of electric energy. The major consumption is related to the flutes grinding, which also involves almost 50% of cycle time (Figure 5), while the turning/milling operations are basically negligible, although removing the highest percentage of workpiece material (60.4%), as shown hereafter in Figure 8. Shank and threads grinding absorbed 15.7% and 21.0% of measured energy, respectively.

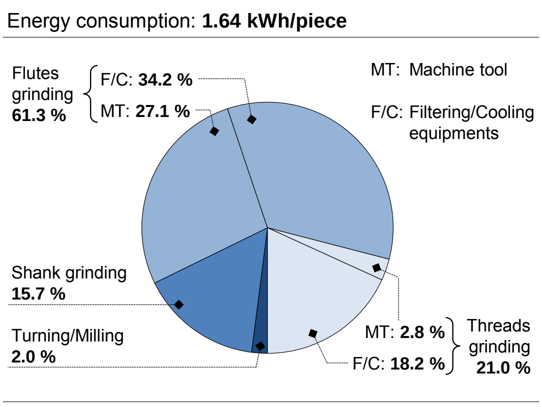

Figure 7. Measured energy consumption.

Flutes and threads grinding account together for approximately four fifths of the total consumption, and it is useful to remark that a considerable energy fraction goes to the filtering/cooling equipments. This result is particularly evident for the threads grinding operations, in which the consumption of the stand-alone machine tool is very low if compared to that of the external unit. These apparatus are needed to separate the lubricant (oil) from the chips by means of a centrifugal machine, which always rotates at a constant speed when the machine tool is turned on. Moreover, they have a cooling system for avoiding lubricant overheating, that is activated at regular time cycles when the measured oil temperature reaches a threshold value. In addition, each unit is equipped with pumps that allow the fluid re-circulation.

4.2 Workpiece material loss

As far as the workpiece material loss is analyzed, Figure 8 highlights all the contributions. The percentage values due to machining operations (turning, milling, and grinding) are obviously related to the different geometries obtained on the tap in each phase, being the turning/milling and the threads grinding the more and the less wasteful processes, respectively.

Furthermore, each bar can not be processed for all the 3200 mm length, and this can be traced back to two main reasons. Firstly, a minimum bar length is needed to ensure a rigid clamping in the chuck of the CNC lathe. Secondly, the length of a bar is not an exact multiple of the length of a tool. As a results, the bar scrap was also shared for every produced tap: the experimentally measured value of 0.17 kg (on average) per each bar was divided by the number of the tools realized with the bar itself, and this value resulted to be the 15.8% of the total material loss.

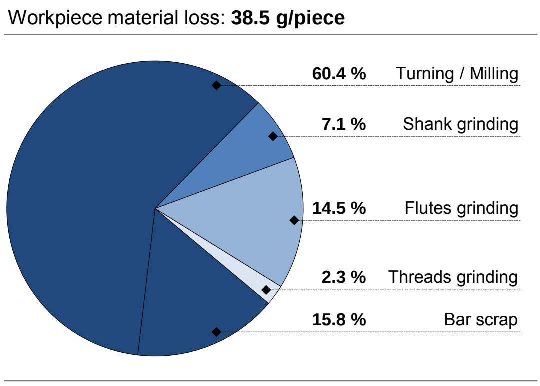

Figure 8. Workpiece material loss.

4.3 Oil consumption

The oil consumption (Figure 9) closely follows the electrical energy consumption trend, with comparable ratios between the different manufacturing stages. The estimated oil waste is quite low for the production of a single tap, but the discussion should be extended with a view on the several thousand units produced per year.

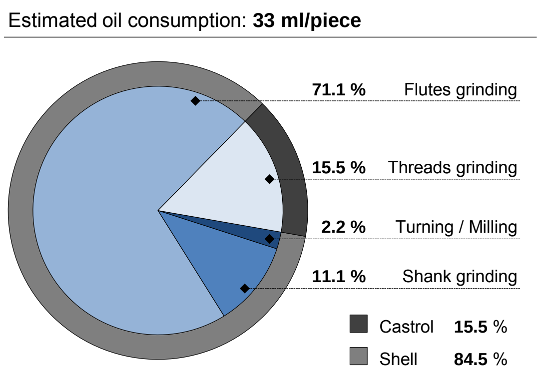

Figure 9. Estimated oil consumption.

The Shell's oil represents the 84.5% of total oil consumption, therefore its sustainability performances should be particularly taken into account. As for others highly refined mineral oils, and according to the EC classification, this oil does not present any specific risk for human health, even if prolonged or repeated exposure may cause dermatitis. Also, it is not classified as dangerous for the environment, even if it is not expected to be readily biodegradable.

4.4 Tool consumption

The spiral point tap is a cutting tool manufactured by other cutting tools. Worn tools have to be periodically substituted when the tool wear is too high to reach satisfactory surfaces quality and to guarantee strict tolerances. The values above each histogram bar in Figure 10 report the percentage of tool consumption. A value of 0.5 %/piece means that the *k*-th tool was consumed of 0.5% for the production of one tap, or else that 200 taps are produced prior to the worn tool substitution. From the graph observation it is evident that the turning/ milling operations should be considered and deeply analyzed for process optimization.

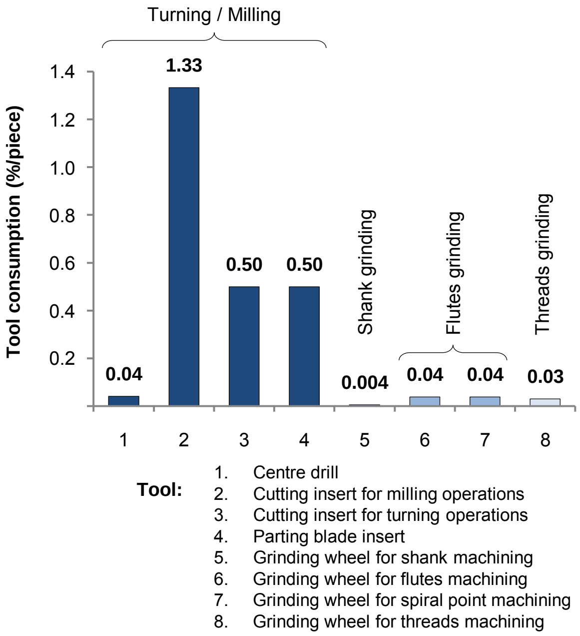

Figure 10. Estimated tool consumption.

5 CONCLUSIONS AND OUTLOOKS

In this paper, an analytical approach to cutting tool production has been implemented, aiming to reach an increased consciousness for sustainable manufacturing. The presented methodology does not focus only on absorbed electric energy, which represents a significant parameter, but it estimates also every consumption source. Moreover, this approach can be easily implemented at a company level, as the required data are not difficult to collect and are mostly known by the production department.

The results highlight the process stages which can be optimized, even if some technological constraints cannot be overcome. For instance, the chips produced by all the cutting operations resulted in a 44.5% reduction of the weight of the raw bar portion needed to manufacture a single tap. This value can be hardly reduced during the manufacturing route, unless changing the tap geometry (at the project stage) or the workpiece geometry (if economically possible). In this context, the analysis could be extended to the comparison between the use of near-net-shape WC sintered parts instead of WC bars.

Overall, it has been shown that the flutes grinding consumes most of the resources in terms of electric energy and lubricants. A way forward to enhance this stage could be the reduction of the time cycle, by modifying the process parameters (without adversely affecting the quality/integrity of the finished product), or by optimizing the sequence of machining operations (as the tool path strategy, the workpiece positioning, etc.).

Another issue that has to be investigated is the choice of the type of lubricant. Being identified the most commonly used oil, alternative and more sustainable solutions should be evaluated, aiming to zero (or, at least, reduced) toxicity and pollution levels. Finally, efforts to increase tool lifetime in turning and milling operations should be undertaken. All these tasks requires careful and in-depth analyses of the trade-off between technological and sustainable needs.

6 ACKNOWLEDGEMENTS

The authors kindly acknowledge Mr. Roberto Balaso, of UFS S.r.l. (Sparone), for his support in process analysis.

7 REFERENCES

[1] Krajnc, D., Glavič, P., 2003, Indicators of sustainable production, Clean Technologies and Environmental Policy 5, 279-288.

[2] National Council for Advanced Manufacturing, 2009, Sustainable Manufacturing, http://www.nacfam.org/ (Accessed on Oct. 7th, 2012).

[3] Jayal, A.D., Badurdeen, F., Dillon, O.W. Jr., Jawahir, I.S., 2010, Sustainable manufacturing: modeling and optimization challenges at the product, process and system levels, CIRP Journal of Manufacturing Science and Technology 2, 144-152.

[4] European Commission - Eurostat, 2010, Energy consumption by sectors (tsdpc320), Luxembourg.

[5] Bordt, M., 2009, OECD Sustainable Manufacturing Toolkit, Sustainability and U.S. Competitiveness Summit, U.S. Dept. of Commerce, Oct. 8th, 2009.

[6] Rotella, G., Lu, T., Settineri, L., Jawahir, I.S., 2012, Machining of AA 7075 aluminum alloy: A process optimization for sustainability, In: Proceedings of 10th Global Conference on Sustainable Manufacturing, Istanbul, 501-506.

[7] Mori, M., Fujishima, M., Inamasu, Y., Oda, Y., 2011, A study on energy efficiency improvement for machine tools, CIRP Annals - Manufacturing Technology 60, 145-148.

[8] Drossel, W., Neugebauer, R.; Wertheim, R., 2012, High speed cutting and high-performance cutting for improving resource and energy efficiency, In: Proceedings of 10th Global Conference on Sustainable Manufacturing, Istanbul, 211-218.

[9] Gontarz, A., Plehn, J., Sproedt, A., Weiss,L., Wegener, K., 2012, Resource consumption measurement in manufacturing environments, In: Proceedings of 10th Global Conference on Sustainable Manufacturing, Istanbul, 557-562.

[10] Behrendt, T., Zein, A., Min, S., 2012, Development of an energy consumption monitoring procedures for machine tools, CIRP Annals-Manufacturing Technology 61, 43-46.

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

[12] Linke, B., Overcash, M., 2012, Life cycle analysis of grinding, In: Leveraging technology for a sustainable world, Springer, 293-298.

[13] Klocke, F., Döbbeler, B., Binder, M., Schlosser, R., Lung, D., 2012, Ecological evaluation of main origins of consumption in manufacturing within the automotive sector, In: Proceedings of 10th Global Conference on Sustainable Manufacturing, Istanbul, 231-236.

[14] Zhang, X., Shuaib, M., Huang, A., Badurdeen, F., Rouch, K., Jawahir, I.S., 2012, Total life cycle based product sustainability improvement: End-of-life strategy analysis for metallic automotive components, In: Proceedings of 10th Global Conference on Sustainable Manufacturing, Istanbul, 507-512.

[15] ECOINVENT Database V.2.2, 2010, Swiss Centre for Life Cycle Inventories, Dübendorf, Switzerland.

[16] Diaz, N., Dornfeld, D., 2012, Cost and energy consumption optimization product manufacture in flexible manufacturing system, In: Leveraging technology for a sustainable world, Springer, 411-416.

[17] Dahmus, J.B., Gutowsky, T.G., 2004, An environmental analysis of machining. In: Proceedings of IMECE 2004 ASME International Mechanical Engineering Congress and RD&D Expo, Paper IMECE2004-62600.

[18] Munoz, A., Sheng, P., 1995, Analytical approach for determining the environmental impact of machining processes, Journal of Materials Processing Technology 53, 736-758.