periodica polytechnica

Transportation Engineering
36/1-2 (2008) 73–78
doi: 10.3311/pp.tr.2008-1-2.14
web: http://www.pp.bme.hu/tr

RESEARCH ARTICLE

Dry milling of magnesium based hybrid materials

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Received 2007-10-01

Abstract

In the transportation industry, a general desire is to reduce the energy consumption. One way to achieve this is the use of light weight metals like magnesium and its' alloys. An alternative solution is the use of magnesium based hybrid structures which are combinations of magnesium and another material like aluminium or steel in one machine part. Hybrid materials can offer optimal technical performance due to the favourable strength-weight ratio. On the other hand during cutting increased difficulties arise due to the different nature of the coupled materials. Hybrid material couples due to their constructions have to be machined in one operation. Particularly the magnesium–sintered steel combination requires special approach because of the completely different machinability of the constituents. Authors aimed to optimize face milling process of hybrids in dry conditions. Experiments focused on the tool material and cutting edge geometry. The milling tests on the hybrid material couple specimens were carried out basically by single cutting edge, and the cutting forces, torque, surface roughness, the chip temperature was measured in the cutting process. Because of the flammability of magnesium chips, shape and type of chips were also examined.

Keywords

magnesium · face milling · hybrid material · environmentally clean technologies

Acknowledgement

Authors are grateful for the support of EU6 CRAFT Framework Programme, project COOP-CT-2003-508452 and the Faculty of GAMF (Kecskemét College)

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1 Introduction

Magnesium is a very promising light metal for the universal use in vehicles. Traditional materials like steel and cast iron or even also aluminum can be replaced with it in automotive parts. Mg alloys have by 33% lower density in comparison to aluminum and by 77% compared to steel [6]. On the other hand, the wear resistance and stiffness of magnesium is not sufficient for many applications. In order to improve the technical performance of a magnesium based machine part the material has to be reinforced while requirement of low weight can be also fulfilled.

The application of lightweight construction of magnesium based hybrid material parts has been extended in the last few years since recent casting technologies made possible to include other materials directly into mould parts [4]. Magnesium–aluminum-silicon (Mg–AlSi hybrid) and magnesium–sintered metal (Mg-Sint hybrid) constructions are used more and more. Promising application in automotive industry is the Mg-based hybrid engine block (Fig. 1) [5]. The hybrid material is advantageous due to its low weight combined with high strength, good wear characteristics and heat resistance. Structural parts exposed to heavy loads are produced of wear or heat resistant, high strength materials like AlSi or sintered steel. These embedded parts improve the relative poor mechanical strength of magnesium alloy while the high volumetric proportion of magnesium ensures low weight for the whole structure.

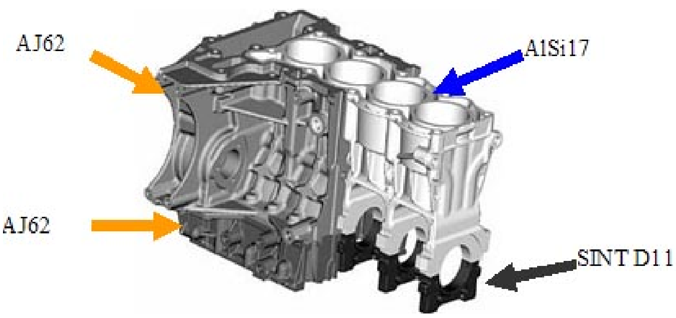

Fig. 1. Scheme of a Mg-hybrid engine block [5]

Cutting of hybrid structures causes increased process instability since the machinability of the simultaneously cut materials is different. As a result of the very different machinability of magnesium, aluminium and sintered steel, very special conditions come into being. The different cutting forces between the materials call for detailed investigations of the cutting tools, their cutting edges and coatings, and stable machine tools are also needed [3]. Cutting conditions have to meet the requirements of optimum simultaneous machining. Cutting of magnesium and their alloys holds great fire and explosion risk because of their ease of ignition which depends on the size and shape of the workpieces. The resulting magnesium chips and dust are highly combustible substances with high surface/volume ratio which may ignite spontaneously [4]. Fire risk is more significant at the presence of sintered steel in hybrid material because high temperatures of sinter metal chips may ignite the flammable magnesium chips.

Two main machining strategies of magnesium are possible in order to reduce the risks to acceptable level. Industrially implemented method is a hydrogen controlled large quantity emulsion lubrication [7]. Dry or MQL lubrication could be more advantageous from economical and ecological point of view since the lubricants, and their cleaning and recycling could be saved. Because of the fire hazard, this latter strategy requires moderate cutting data ensuring low chip temperature.

Due to constructional design of hybrid parts, typical machining operations are various kinds of milling and drilling. In the following, the paper deals with face milling.

2 Experimental work

The basic application sample of the research was a cylinder block, illustrated in Fig. 1. There is not accessible technological information about simultaneous machining of absolutely differently behaving materials like Mg–AlSi or Mg–sintered steel. Cutting force fluctuation in milling is even more characteristic in hybrid machining (Fig. 2). Cutting tool optimization experiments were performed in dry face milling of AZ91–AlSi12 and AZ91–SD11 hybrid couples respectively. However the chemical composition of AZ91 differs from AJ62 and AlSi12 differs from AlSi17, it has not significant influence to the deviation of machinability of different hybrid couples. AZ91 and AlSi12 materials are adequate for the general modelling of Mg-AlSi and Mg-sintered steel hybrid structures.

Focusing on tool optimization, the first important question is the possibly applicable tool material and/or coating for Mg–AlSi or Mg–sintered steel, respectively. Determination of most suitable insert materials for both experimental Mg–hybrids, the optimization of cutting geometry concerning cutting forces, chip temperature, surface roughness and chip formation were carried out by several face milling experiments. The main aim was to find the optimal edge material and cutting edge geometry for Mg–AlSi and Mg–sintered steel hybrid materials, furthermore to work out a general method of milling tool optimization of hybrid materials.

Since safe machining is emphasized when magnesium is machined, cutting temperature has to be a highlighted optimizing parameter. The temperature of sintered steel chips is the most important risk factor because it can reach the value of 600°C, which is enough to ignite magnesium chips. The ignition temperature strongly depends on the surface/volume ratio, 250°C was concerned as critical.

2.1 Experimental details

General principles of the face milling experiments for the chip temperature measurements were:

- Machining with a single insert, χ=45°,
- Symmetrical positioning of milling head, a_e=2/3×D or a_e=1×D,
- Fixed cutting depth: a_p=1 mm,
- Fixed cutting speed e.g.: v=330 m/min or 134 m/min,
- Cutter diameter: D=80mm,
- Feed/tooth was the altering cutting parameter: f_z= 0,05; 0,1; 0,2 mm/tooth,
- Tests were carried out on: AZ91, SD11, AZ91+AlSi12 and AZ91+SD11 hybrid materials
- Dry conditions.

The suitability of tested edge materials and the various edge geometries were ordered according to equal weighted ranking of measured values.

Measuring equipment used were:

- Kistler force measuring system (Fx, Fz, Fy),
- Data acquisition with Test Point software, evaluation with special program,
- Mitutoyo Surftest 301,
- Agema THV® 880 LWB IR camera.

2.2 Determination of chip temperature with thermovision

Most risky factor of magnesium ignition is the hot chip of sintered steel part of the Mg-Sint hybrid. For this reason, steel chips have to be investigated in their hottest condition: during cutting and directly after leaving the surface of insert. This means that temperature measurement has to be happened on the rotating and working tool.

Basically there are two possibilities to determine chip temperature. Chip temperature can be estimated on theoretical way by simulation of cutting process [1]. The numerical methods make possible the calculation of chip temperature at any time of the process or on any part of the chip. Experimental possibility is the infrared measurement during the machining process. Infrared technology is very fast and flexible compared to thermocouples or other touch based methods. There are no literature

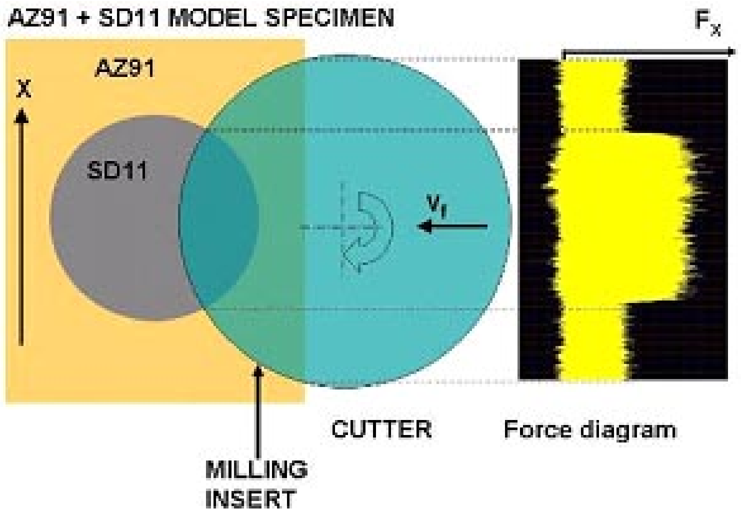

Fig. 2. Effect of different machinability on the cutting force

data regarding continuous thermovision of chip temperature of face milling of hybrid materials.

The principle of thermovision is based on detecting of infrared radiation of bodies. The thermovision scanner measures infrared radiation within a certain spectral range. The received radiation has a non-linear relationship to the object temperature and detection can be affected by atmospheric damping and includes reflected radiation from object surroundings.

The received and detected infrared radiation in the instruments for numerical measure is called thermal value. The relationship between thermal value and received photon radiation is linear. However, the relationship between thermal value and object temperature is non-linear.

Generally, in thermal measurement situations, where several factors influence the measurements, the true object temperature has to be derived by calculation. The resulting measurement formulae together with the calibration function are used as algorithms in the software of the computer for thermovision system [6].

Using the line scanning mode of AGEMA infrared camera a unique method for real time investigation of working tool was developed. The scheme of the process is shown in Fig. 3 [2].

The IR detector of the instrument gets information only from a line. According to the markings of Fig. 3/a the y position of the camera is adjusted slightly over to the plane of previously milled surface. The perfect adjustment ensures that all inserts or insert seats are "visible" for the IR detector of the instrument during the whole rotation except when inserts cover each other. The scanning frequency is 2500Hz, which means 0,4ms period time. According to the connection between rotary movement and alternating movement, the period time of the rotating tool (n=1314/min) is 21,9Hz. The high difference between frequencies ensures that chip and insert do not move to significant distance during one scanning cycle. When thermographs of each line scan are packed onto each other approximation of the sinus curve of the rotary movement of the inserts will be displayed. (See Fig. 3 and Fig. 4).

The steel chips has to be investigated in their hottest condition: during cutting and directly after leaving the surface of insert. This means that temperature measurement has to be done on the rotating and working tool. Using the line scanning mode of AGEMA infrared camera a unique method for real time investigation of working tool was developed. The scheme of the process is shown in Fig. 3.

The IR detector of the instrument gets information only from a theoretical line. When thermographs of each line scan are packed onto each other approximation of the sinus curve of the rotary movement of the inserts will be displayed. Chip temperature can be determined according to kinematical geometry.

3 Analysis and comparison of cutting edge materials

In general AZ 91 is well machinable with Al cutting geometry and this material can be cut with the lowest force. The cutting speed is limited from bottom values because of forming of built-up edge and flank build-up [3].

The machinability of AlSi12 and especially sintered steel is worse. Because of the significant wear of the tool cutting speed is limited from top values [3].

Commerce available inserts were tested in the milling experiments in order to choose the most suitable ones. AZ91–AlSi12 hybrid specimens were tested with 12 different insert types: *uncoated or polished cemented carbide inserts (γ =+25^o), coated cemented carbide inserts with Al geometry (γ =+25^o), conventional diamond coating, nano diamond coating, PCD insert, thick diamond film coated insert.*

In case of AZ91–SD11 hybrid the number of tested inserts was lower and 6 different types were tested: *uncoated cemented carbide, coated cemented carbide, cermet.*

The most suitable cutting material was selected according to the experiment series, the measured data and evaluation principle is detailed in point 2.1.

Different tendencies of the cutting force can be observed in

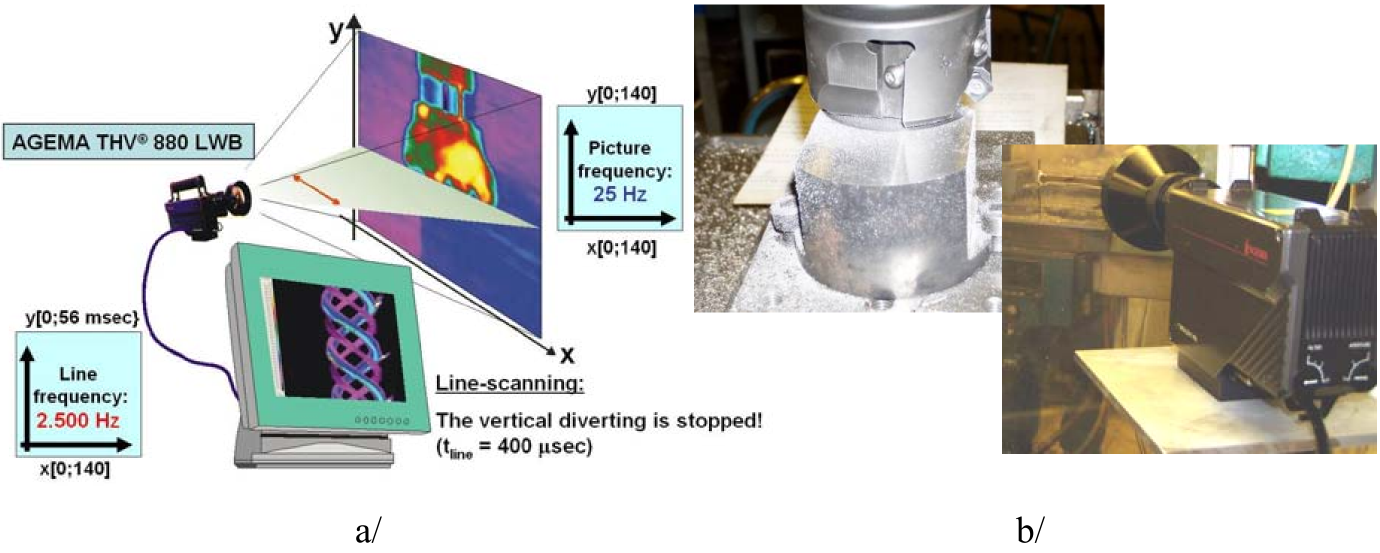

Fig. 3. Scheme of line scanning mode (a) and photo of the experimental setting (b)

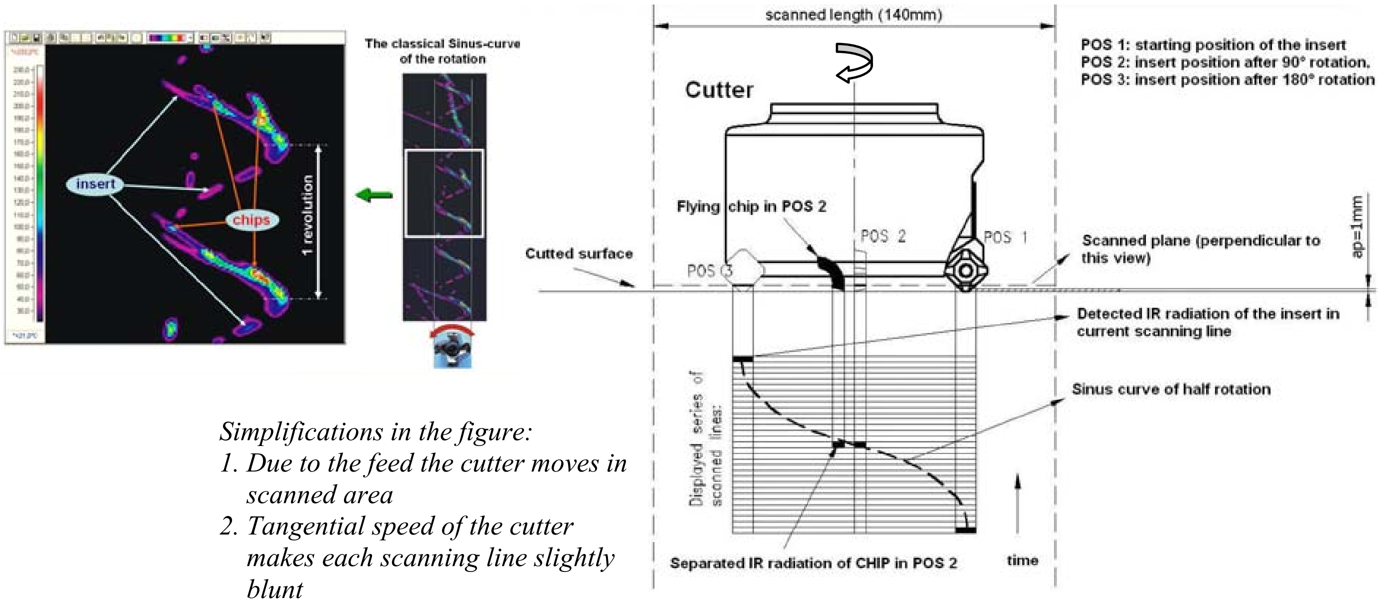

Fig. 4. Scheme of IR chip temperature measurement according to the kinematical geometry

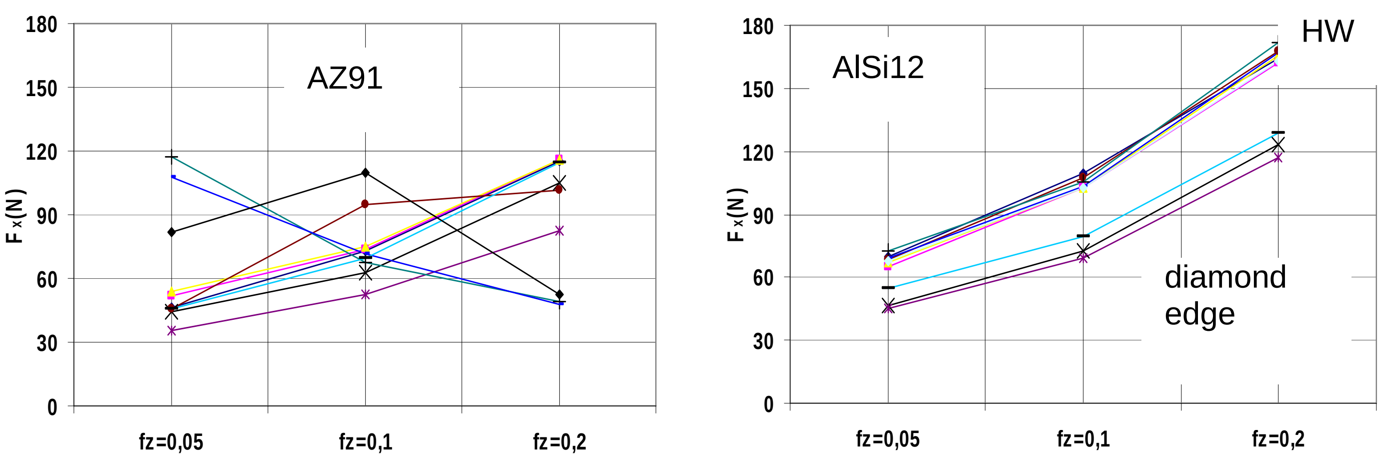

Fig. 5. Cutting force (F_x) during machining of pure specimens at three f_z steps

Fig. 7. Special experimental milling head and built-in-tools (cartridges) developed by project partner LOSONCZI Ltd.

γ_p= +4°; 0°; -4°; -8° γ_p / γ_f = 0°/3°; 8°/3°; 8°/0°

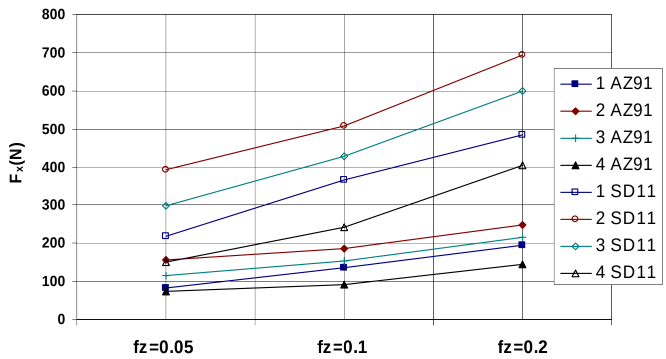

Fig. 6. Comparison of F_x cutting force of 4 different inserts in milling of magnesium (AZ91) and sintered steel (SD 11)

milling of AZ91 according to the cutting edge materials (see Fig. 5). Force values decreased at two uncoated cemented carbide inserts, while CVD diamond coated insert showed mixed behaviour. Force values monotonously increased at the other cases. The geometry of these inserts is recommended for aluminium.

When AlSi12 was milled by cemented carbide (HW) and diamond edge inserts two clearly divided groups were formed (see Fig. 5).

The difference between cutting force can be observed in Fig. 6. The results were measured on four different inserts when AZ91–SD11 hybrid specimen was milled. Inserts 1-3 are recommended for steel, this is the reason for higher AZ91 values than ones displayed in Fig. 5. Insert 4 is a coated cemented carbide with high rake angle. The average chip temperature was also very favourable on the insert 4 compared to the other three types.

As a result of the experiments, the mostly recommended cutting materials for AZ91–AlSi12 hybrid are uncoated cemented carbide insert (γ =+25^o), CVD diamond coated insert (γ =0^o) or with nano diamond coated cemented carbide insert.

TiAlN coated cemented carbide insert (γ =+25^o) proved to be the most suitable for milling of AZ91–SD11 steel hybrid.

4 Developing of special edge geometry

For geometry optimization a special experimental milling head was developed which made possible to realize several cutting geometries. This cutter had four different seats with various axial rake angles (γ_p), and three different built-in-tools (cartridges) were developed with various axial and radial angles (γ_p / γ_f). The cutting geometry of face milling was determined by the insert–, the buildt-in-tool– and the seat geometry of milling head.

γ_p= +4^o; 0^o; -4^o; -8^o γ_p/ γ_f = 0^o/3^o; 8^o/3^o; 8^o/0^o

The optimum rake angles of the seat were determined separately according to the evaluation of experimental results (F, R_a, temperature, chip formation) for milling of AZ91–AlSi12 with uncoated HW insert and AZ91–SD11 when using TiAlN coated HW insert. Cutting force and chip temperature decreased using the optimized cutting edge geometry.

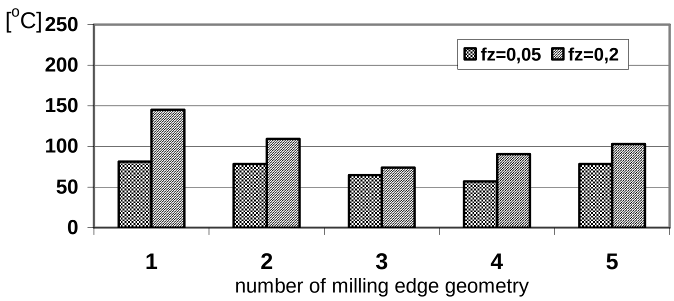

Fig. 8. Characteristical chip temperatures at different milling edge geometries

5 Summary

The pre-determined aims of development of Mg-hybrid milling have been reached. As a result of the research, the optimized tool material and cutting edge geometry is available for dry machining of Mg–AlSi12 and Mg–SD11 hybrid materials.

New results of MQL and dry face milling experiments with AZ91D–AlSi12 and AZ91D–SD11 magnesium-based hybrid materials: Various tool materials and coatings were compared and

- cutting force components and their change,
- achievable surface roughness,
- maximum chip temperature

were measured. Experiments were performed with continuous force measurement and evaluation system. A new thermovision method was developed for examination of chip temperature on rotating milling tool. The method is based on line scanning, and chip temperature is determined according to kinematical geometry of the rotating cutter.

References

1 **Ben Amor R**, *Thermomechanische Wirkmechanismen und Spanbildung bei der Hochgeschwindigkeitszerspanung*, Vol. 03, 2003. Dissertation Universität Hannover.

2 **Ozsváth P, Szilágyi A, Takács J, Szmejkál A**, *Determination Of Chip Temperature With Thermovision*, Proceeding of 24th Int. Colloquium on „Advanced Manufacturing and Repair Technologies in Vehicle Industry", Unknown Month 22, pp. 77-84.

3 **Ozsváth P, Szmejkál A, Takács J, Eidenhammer M, Obermair F**, *Development of Face Milling Process for Mg-hybrid (Mg-Al, Mg-sintered steel) Materials*, Proceedings of the 7th Int. Conference on Magnesium Alloys and Their Applications, Wiley-VCH Verlag, 2006, pp. 894-900.

4 **Sanz C, Fuentes E, Obermair F, Muntada L**, *Efficient and ecological machining of magnesium hybrid parts*, Proceedings of the 7th int. conference on magnesium alloys and their applications, 2006, pp. 916-921.

5 **Segeud JM**, *Entwicklung von Al/Mg Verbundkurbelgehäusen für PKW-Motoren*, Giesserei (2004), no. 9, 102–104.

6 **Kalincsák Z, Szilágyi A, Takács J**, *Thermovision Monitoring on Laser Marking Process*, Proceedings of 22nd International Colloquium on „Advanced Manufacturing and Repair Technologies in Vehicle Industry", Unknown Month 17, pp. 61-66.

7 **Schwerin R, Jaksch S**, *Water miscible cutting fluids for the machining of magnesium*, Oemeta Industrial Lubricants, 2006.

8 available at `www.ecohyb.com(2007-09)`.