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Model of quality management in development of new free-cutting Al-alloys

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ABSTRACT

Purpose: of this paper: In this paper, an attempt to apply the general model of quality management in development and machining of new ecologically more acceptable aluminium alloys for free cutting is made.
Design/methodology/approach: The conventional approach has its limitations and that a new and innovative (alternative) approach is essential within the framework of an environmentally oriented quality management system. Meeting the requirements of ISO 9000 and ISO 14000, the model ensures the fulfilment of the basic requirements leading to the required quality of preparation processes and the end products.
Findings: The properties of semi-manufactures, analyses of machining tests results and large economic advantages confirm that the alternative procedure (press quenching methodcan be used for preparation of bars from free-cutting aluminium alloys. Besides better economy in terms of energy consumption, the alternative procedure is also ecologically more acceptable.
Research limitations/implications: The restrictions resulting from legislation force us to develop new materials and alternative technologies. This provides a technological challenge to the scientists and engineers and increases the importance of ecological manufacturing as a competitive factor.
Practical implications: The quality of a company,s product directly affects its competitive position, profitability and credibility in the market. Quality assurance system must undergo a process of continuous improvement, which extends from the deployment of preventive quality assurance methods to the application of closed loop quality circuits.
Originality/value: One good example of the use of alternative processes, in the case of preparation of work material, is the replacement of standard method for pre-forming and heat treatment of aluminium alloys by alternative method (press quenching). The second one is the substitution of lead with tin because it is harmful for human organisms and environmentally not acceptable element.
Keywords: Quality management; Al-alloys; Eco-alloys; Free-cutting; Machinability

1. Introduction

One of the pre-requisites for successful production is the use of quality materials with defined mechanical and technological and also ecological properties. Therefore, for the development and introduction of new ecologically more acceptable material, it is necessary to carry out a number of studies with the purpose to optimise the chemical composition, fabrication and pre-fabrication procedures, and the resulting material machinability [1-4].

Standard aluminium alloys for free cutting contain next to major alloying elements also the additions (lead, bismuth), which form softer phases in the matrix. These “free machining” phases improve the machinability of the alloys because of easier breaking of chips, smooth surface, lower cutting forces and smaller tool wear. Since lead is poisonous, a tendency is to replace it with other elements: tin and partially indium are the most frequently used as substituents. Alloys with tin must have similar or better properties in regard to microstructure, workability, mechanical properties, corrosion resistance, and machinability in comparison with standard alloys [5]. In the recent time, tin is added mainly to Al-Mg-Si (AA 6000 series) and Al-Cu (AA 2000 series) alloys, which standard contained lead and bismuth or only lead. Semi-finished products made from these alloys in the form of bars are used for free cutting or more precisely turning [6,7].

The aim of this paper is to establish the general model of an environmentally oriented quality management in the field of pre-forming and machining of semi-manufactures made from new developed and ecologically more acceptable aluminium alloys for free cutting [8-10].

2. Strategic approach in the development of model

In the search for solutions to develop new material and improve manufacturing processes it is essential that the conventional approach be replaced by new and innovative methods, which allow us, achieve a minimum of environmental contamination in conjunction with suitable technologies providing high process stability and reliability and acceptable economic conditions. The increasing sensitivity to environmental and health issues is reflected in the increasingly stringent legislation and national and international standards, Fig. 1 [11].

The restrictions resulting from legislation force us to develop new materials and alternative technologies. This provides a technological challenge to the scientists and engineers and increases the importance of *ecological manufacturing* as a competitive factor. On the other side high quality of contemporary manufacturing processes depends on three main parameters: *energy, ecology* and *economy.* The model of quality of the processes is shown in Fig. 2 [12].

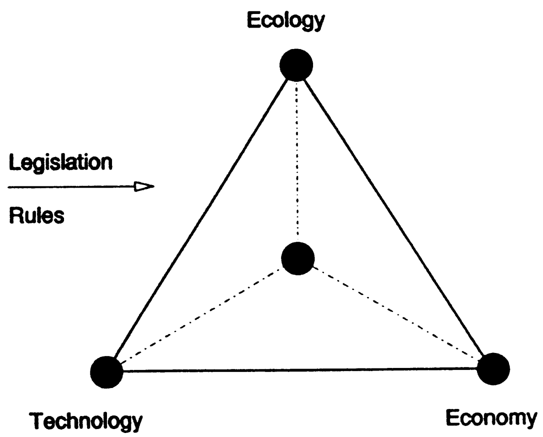


Fig. 1. The balance between economy, technology and ecology

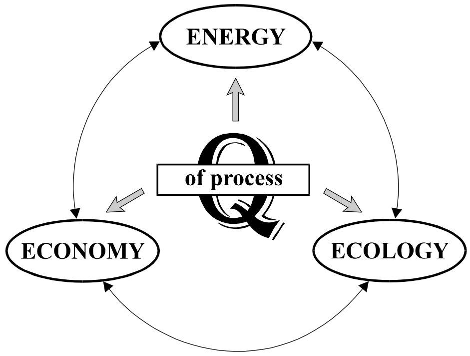


Fig. 2. Quality of contemporary manufacturing processes

The quality objectives that in the phase of technologies planning want to achieve are:

- Energy savings,
- Ecologically acceptable materials and processes,
- The right choice of manufacturing procedures, they are number and sequence.

Manufacturing processes have to be developed which are not just suited to the needs of today products, but rather reach in a strategic way into the future and are suited to the products, materials and conditions with witch we will be confronted in the coming years.

3. Design of the model

The quality of a company›s product directly affects its competitive position, profitability and credibility in the market. Thus, the major objective of quality management becomes that of achieving and maintaining the leadership in product quality and reliability. Product quality requirements should be defined for each product based on factors related to satisfying the needs and expectations of those whom the product serves.

The concept of overall total quality control system should be encompassed all of the elements of quality assurance and quality control. Some problem-solving techniques on this area include the following:

- Statistical process control,
- Root cause analysis,
- Quality control circles,
- Quality improvement techniques.

Quality assurance system must undergo a process of continuous improvement, which extends from the deployment of preventive quality assurance methods to the application of closed loop quality circuits. Quality assurance methods are thus frequently effective only when they are integrated into so-call *"quality control circles"*.

Quality control circles are quality tools, which are used for achieving the above-mentioned aims and enable to transition from the quality of process to the quality of product throughout the active quality control. Its can be exist as:

- process or machine-oriented or
- multi-level closed loop quality circuits.

The principle behind systematic feedback into various levels of the closed loop quality circuit is that the use of historical data will prevent the same mistakes from being repeated, for example at the planning stage.

The component linking them is the quality database containing historical quality data. The process of collection and evaluation of quality-related data is the most important pre-requisite for closed loop quality circuits and additional elements of quality management. It provides most of the information field in the quality database about the *quality status.* The operative prerequisites of a quality management strategy are connected with one another via ordered information processing. The term *"ordered"* applies not only to the technical side but also more particularly to the smooth processing and transfer of information between the individual in company interfaces.

The basic elements by the establishment of the model of quality management in the case of development and manufacturing of the free-cutting aluminium alloys are [8,12]:

- Development of alloys,
- Preparation of alloys (pre-forming and heat treatment),
- Testing of alloys (in laboratory and workshop conditions),
- Industrial applications.

The first step of quality management in our case was optimisation of chemical composition of alloys (Fig. 3). In the development of new free-cutting aluminium alloys the initial phase was carried out by the selection of the type of alloys. The most important standard aluminium free-cutting alloys are:

- Al-Cu with 0.2-0.6 m. % Pb and 0.2-0.6 m. % Bi (AA2011),
- Al-Cu-Mg with 0.8-1.5 m. % Pb and up to 0.2 m. % Bi (AA2030), and
- Al-Mg-Si with 0.4-0.7 m. % Pb and 0.4-0.7 m. % Bi (AA6262).

In these alloys, mainly lead and bismuth are forming the free-machining phases. These soft phases appear in alloying with elements, which are not soluble in aluminium and should have low melting temperatures and must not form intermetallic compounds with aluminium. The formed heterogeneous phases cause discontinuity of the matrix. The cohesive forces are weaker at the locations of discontinuity, which facilitates the breaking of chips during the machining process. The distribution of free-machining globulitic phases must be fine and uniform. These phases, having size from few µm to few ten µm, were distributed in interdendritic spaces and on grain boundaries.

Free-machining phases in the AlCuPbBi alloy (standard referee material - sample P3) consisted of primary bismuth crystals enveloped with Pb_3Bi phase. Quantitative EDS analysis are shown that Bi crystals contained 98.5 m. % Bi, while Pb_3Bi phase consisted of 72.8 m. % Pb and 26.2 m. % Bi. Next to lead and bismuth, these inclusions contained also aluminium, cooper, and impurity elements. There contents locally varied from few tenths to few m. % [2]. It is known from practical experiences that breakage of chips is the best at eutectic compositions of elements insoluble in aluminium [13-15].

In the recent time, a tendency appeared to substitute lead with other elements because it is harmful for human organisms and from environmental reasons. Tin and partially indium are the most frequently used as substituents. The possibility to apply tin in aluminium free-cutting alloys is known already for a long time. Tin was one of the first elements, which were added to aluminium free-cutting alloys up to 2 m. %. Its wider use was not accepted into practice due to supposed worsening of corrosion properties, lower ductility of alloys, and high price. Lately, tin has been added mainly to the Al-Mg-Si alloys (AA6000 series) and Al-Cu alloys (AA2000 series), which standard contained lead and bismuth or only lead [2,3,6,7].

Substitution of lead with tin in the AlCuSnBi alloy (sample S4) caused formation of small spheroidal and polygonal phases on the basis of tin and bismuth. Their size was up to 10 µm. The distribution of both elements in the phases was non-uniform and not consistent with the mass ratio witch correspondents to the eutectic in the Sn-Bi equilibrium diagram. Beside tin and bismuth, there was also aluminium (up to 7 m. %), cooper (up to 2.5 m. %), magnesium (up to 4.5 m. %), and iron (up to 0.5 m. %). Tin was present in smaller quantities (up to 0.2 m. %) also in some Al-Cu intermetallic compounds (Al_2Cu).

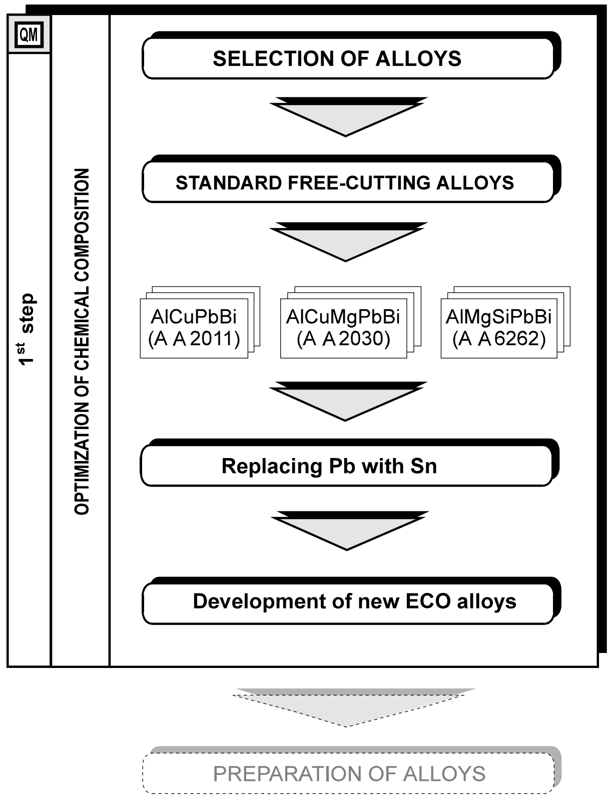


Fig. 3. First step of quality management – development of new type of alloys

In the AlCuSn alloy (sample S3) tin as solely free machining constituent was distributed only on the grain boundaries. The tin phases had of polygonal shape and they were of the order of magnitude between few µm up to 10 µm. These phases, found as networks, surrounded together with the phases based on Al and Cu the crystal grains. There were no tin phases inside the grains. The elements, which accompanied tin, were aluminium (up to 3 m. %), magnesium (up to 4 m. %), and cooper (up to 3 m. %).

Metallographic analyses of free-machining phases carried out by optical microscopy, microradiograph, electron microanalysis and scanning electron microscopy (on JMS35), and qualitative and quantitative EDS (electron dispersive spectroscopy on EDS-Link ISIS 300).

Formation of suitable chips is in the alloys with tin dependent on the influence of free-machining phases on the mechanism of rupture of material in cutting, *i.e.* similarly to the behaviour in the alloys with lead and bismuth. Investigation till now and the explanations of the chips breaking mechanism were based mainly on the alloys with lead and bismuth [1,3, 13,15].

The second step of quality management was carried out by the selection of the method of preparation (pre-forming and heat treating) of semi-manufactures made from selected type of alloys. The investigated alloys were semi continuously cast into logs with a diameter of 285 mm, which were after homogenisation turned to a diameter of 275 mm. The logs were extruded by extrusion process into rods with 27 mm in diameter, which were further heat treated by the different procedure.

In the search for solution and ways to improve manufacturing procedures it is essential that the conventional approach be replaced by new and innovative methods (Fig. 4), which allow us, achieve a minimum of environmental contamination in conjunction with suitable technologies providing high process stability and reliability and acceptable economic conditions [10,11].

These two methods differ mainly in the manner of solution treatment and quenching. By the *standard method* the extruded and drawn bars were solution treated in a salt bath at a temperature of 525 ^{o}C and quenched in water. By the *press quenched method* the quenching took place directly after the extrusion of the material from the die with a water shower. In quenching on the press, solution annealing uses the heat released during extrusion.

The third step of quality management, the decision for the machinability tests offers the correctness of the previous steps on one hand and provides the correct dates about the time and the costs of machining on the other hand (Fig. 5), considering the selected parameters of machining and required product quality [14,15].

In order to establish the influence of chemical composition and different technological preparation (technological history of worked material) on the machinability by cutting, we need the machinability tests. These tests encompass workpiece materials, cutting tools, and the cutting operation and its characterization. The considerations used in selecting and evaluating cutting tool performance and workpiece machinability. Besides the machined surface quality chip shape is one of the main criteria for the machinability of free-cutting aluminium alloys.

The influence of tin on the machinability of the investigated alloys has been determined with regard to the shape and size of chips, and the formation of chips on the transition of worked material through the shear zone. The chips of all the tested alloys which were obtained in turning test at the cutting speed v_c = 180 m/min with HSS tool, belonged into the group of satisfactory chips (Fig. 6).

The formation of chips during the turning operation has been determined with QSD-test which enabled to "freezing" of the conditions in the cutting zone during the machining (Fig. 7). The shear angles Φ and the shrinkage coefficients λ of the alloy with tin (sample S3) differed from the other ones (Tab. 1). Lower shrinkage coefficient is characteristic for material with better machinability behaviour.

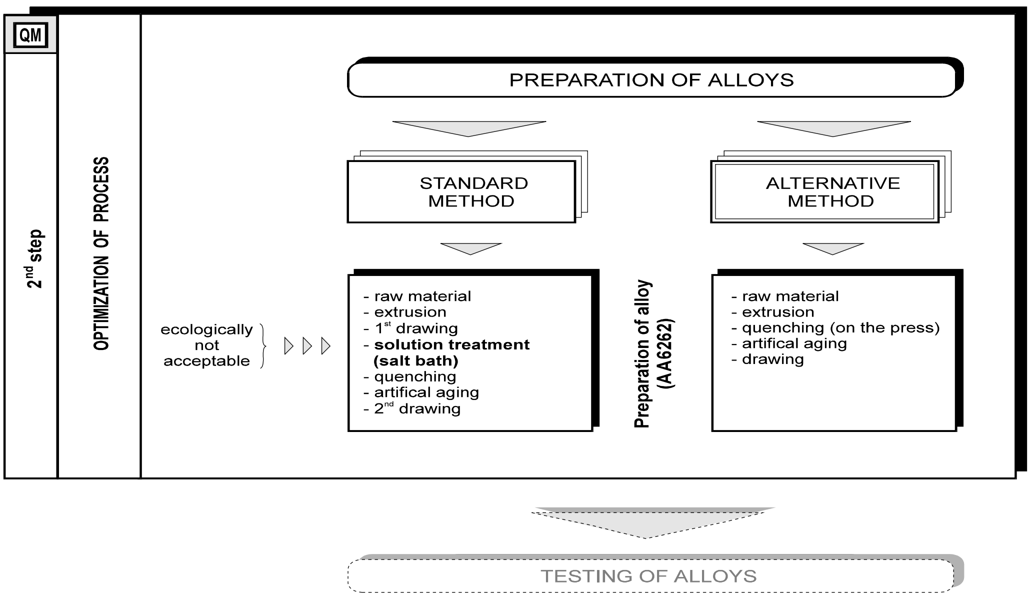


Fig. 4. The second step of quality management - preparation of alloys

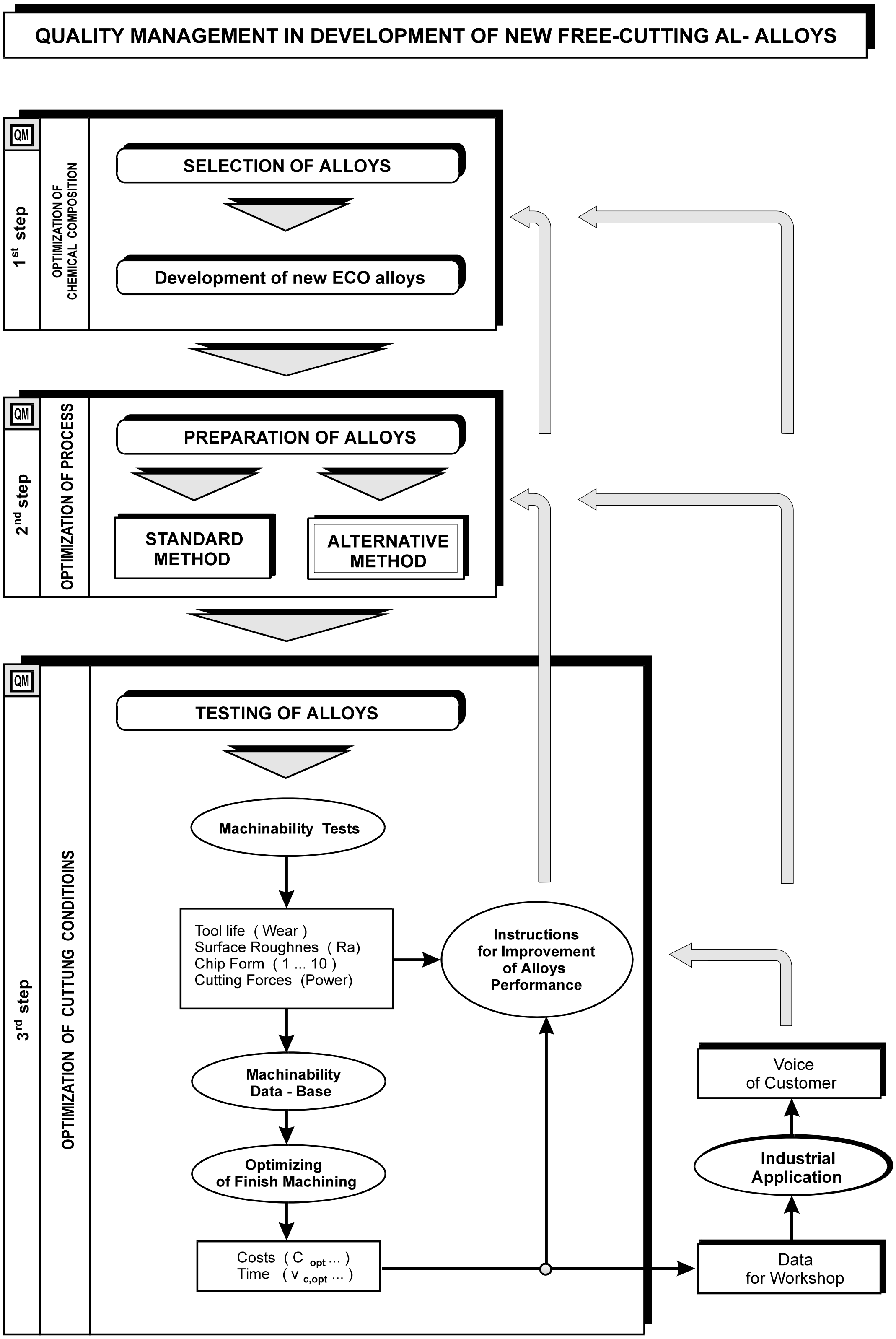


Fig. 5. Model of quality management in the case of development of the new free-cutting Al alloy

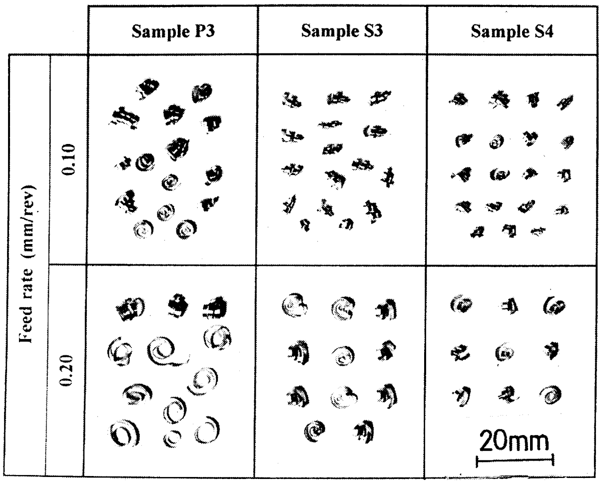
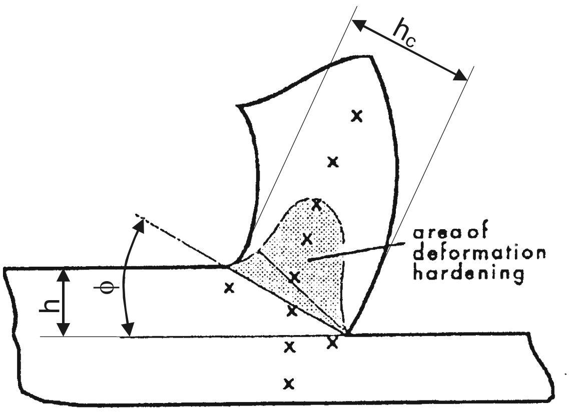


Fig. 6. Shapes of chips of the AlCu-alloy with various additions of Pb+Bi (P3), Sn+Bi (S4), and Sn (S3)



$$\lambda = h_c / h > 1$$

Fig. 7. Geometry of chips in the cutting zone

Table 1.
The results of the QSD-tests analysis

Sample	Φ [°]	λ
P3	33 ± 2	1.55 ± 0.15
S3	45	1.25 ± 0.05
S4	34 ± 1	1.50 ± 0.20

4. Conclusions

In many cases present manufacturing processes are not adequately clean. Current trends in the manufacturing world indicate that this situation will not be acceptable in the future and that extensive research and development work is very important in order to meet the future requirements of legislation. The conventional approach has its limitations and that a new and innovative approach is essential within the framework of an environmentally oriented quality management system. Processes have to be subjected to fine analysis giving detailed consideration to the various inputs and outputs. Combined processes, alternative processes, new technologies, energy requirements etc. have to be evaluated from the environmental perspective. One good example of the use of alternative processes, in the case of preparation of work material, is the replacement of standard method for pre-forming and heat treatment of aluminium alloys by alternative method (*press quenching*). The second one is the substitution of lead with tin because it is harmful for human organisms and environmentally not acceptable element [15].

From the machining process control point of view, one of the pre-requisites is the use of quality incoming material with defined mechanical and technological properties. The purpose of presented model of quality management was to improve the semi-manufactures performance throughout optimisation of chemical composition (1st step) and quality improvement of the technological procedures for pre-forming and heat treatment of aluminium free-cutting alloys (2nd step). In the third phase, according to the requirements of ISO 9000 and ISO 14000, an attempt was made to apply the general model of quality management also to the field of machining by cutting of these aluminium alloys.

The properties of semi-manufactures, analyses of machining tests results and large economic advantages confirm that the *alternative procedure* (press quenching method) can be used for preparation of bars from free-cutting aluminium alloys. Besides better economy in terms of energy consumption, the alternative procedure is also *ecologically more acceptable.*

References

[1] J. Kopac, M. Sokovic, A. Smolej, Strategy of machinability of aluminium alloys for free cutting. Proceedings, 30th Int. MATADOR Conference, UMIST Manchester, 1993, 156-161.

[2] A. Smolej, B. Breskvar, M. Sokovic, V. Dragojevic, E. Slacek, T. Smolar, Properties of aluminium free-cutting alloys with tin: Part 1. Aluminium, Vol. 78, No. 4 (2002) 284-288.

[3] A. Smolej, B. Breskvar, M. Sokovic, V. Dragojevic, E. Slacek, T. Smolar: Properties of aluminium free-cutting alloys with tin: Part 2. Aluminium, Vol. 78 (2002) No. 5, 388-391.

[4] L.A. Dobrzanski, R. Maniara, J.H. Sokolowski, The effect of cast Al-Si-Cu alloy solidification rate on alloy thermal characteristics, Journal of Achievements in Materials and Manufacturing Engineering, Vol. 17 (2006) 217-220.

[5] A. Smolej, V. Dragojevic, T. Smolar, M. Sokovic, B. Breskvar: Unleaded free-cutting aluminium alloys for extruding. Keynote Paper, Proceedings of 4th World Congress on Aluminium, Montichiaty (Brescia), Italy, 12-15 April 2000, 32-41.

[6] A. Smolej, B. Breskvar, M. Sokovic, V. Dragojevic, T. Smolar: Tin in free-cutting aluminium alloys. Proceedings of 14th Int. Con. AMT ´98, Krynica, Poland, 1998, 522-527.

[7] A. Smolej, B. Breskvar, M. Sokovic, V. Dragojevic, T. Smolar, Properties of lead-free machinable aluminium alloys. Proceedings of 4th Int. Con. AMPT ´98, Kuala Lumpur, Malaysia, 1998, 145.

[8] M. Sokovic, J. Kopac, A. Smolej: Quality management model in development of new free-cutting Al-alloys. Proceedings of 7th Int. Conf. TMT ´2003, Lloret de Mar, Barcelona, Spain, 15-17 September 2003, 117-120.

[9] M. Sokovic, J. Kopac, Quality management in machining of aluminium alloys for free cutting, Proceedings of 4th Int. Conf. AMME ´95, Gliwice-Wisla, Poland, Vol. 4, 1995, 299-302.

[10] M. Sokovic, J. Kopac, A. Smolej, Quality management in machining of free-cutting aluminium alloys, Metall, 53 (1999) 12, 692-695.

[11] G. Byrne, E. Scholta, Environmentally clean machining processes - a strategic approach, Annals of the CIRP, 42 1 (1993) 471-476.

[12] J. Kopac, M. Sokovic, Quality management in machining of aluminium alloys, Proceedings of 12th Int. Con. BIAM ´94, Zagreb, Croatia, G-6- G10.

[13] P. Johne, Handbuch der Aluminium-Zerspanung, Aluminium-Verlag, Düsseldorf, 1984.

[14] A. Smolej, M. Sokovic, J. Kopac, V. Dragojevic: Influence of heat treatment on the properties of the free-cutting AlMgSiPb alloy, Journal of Materials Processing Technology 53 1-2 (1995) 373-376.

[15] J. Kopac, M. Sokovic, F. Cus, QM and costs optimization in machining of Al-alloys. In, Total quality - Creating Individual and Corporate Success, (Edited by Ahluwalia J.S.), Institute of Directors - Excel Books, New Delhi, 1996.