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APPLICATION OF RISK ANALYSIS AND QUALITY CONTROL METHODS FOR IMPROVEMENT OF LEAD MOLDING PROCESS

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The aim of the paper is to highlight the significance of implication of risk analysis and quality control methods for the improvement of parameters of lead molding process. For this reason, Fault Mode and Effect Analysis (FMEA) was developed in the conceptual stage of a new product TC-G100-NR. However, the final product was faulty (a complete lack of adhesion of brass insert to leak) regardless of the previously defined potential problem and its preventive action. It contributed to the recognition of root causes, corrective actions and change of production parameters. It showed how these methods, level of their organization, systematic and rigorous study affect molding process parameters.

Key words: lead, molding process, risk analysis, quality control

INTRODUCTION

The improvement of production processes is a natural activity of the enterprise which it is oriented on continuous development and increase of competiveness. A variety of methodologies are available for process improvement (e.g. Six Sigma, Lean Management, Lean Six Sigma, Agile Management, Re-engineering, Total Quality Management, Just-In-Time, Kaizen, Hoshin Planning, Poka-Yoka, Design of Experiments, and Process Excellence) [1-3], however, their choice depends on information obtained from the process on the basis of the applied methods of risk analysis and quality control.

Fault Mode and Effect Analysis (FMEA) is a basic method used for process risk analysis in any industry. It is conducted to identify and assess risk of potential failure modes in a process and the effects of their appearance in relation to fulfilling clients' expectations. This method also allows to indicate the elements of the process where preventive and corrective actions should be undertaken. Moreover, its application leads to the recognition of causes which can make it difficult to meet client specifications or disturb the manufacturing process. They can be related to work methods, process parameters, measurement and control devices or machines and tools used in the technological process [4]. FMEA is supported by the tools which facilitate conducting two important steps such as: identification of hazards and their cause-effect analysis. The first tool, which can be used to identify hazards, is brainstorming. In industrial practice two variations of this method are applied: individual brainstorming to use intellectual potentials of participants and Brainwriting 635. Firstly, the employees participating in the analysis, are urged to generate and note down all problems and provide them to the leader of the team who is responsible for their record. The obtained results are compared with the outcomes of Brainwriting 635. This technique involves 6 participants whose task is to write down three ideas in 5 minutes on a piece of paper. After that time the paper is passed to the next person in a clockwise direction. After the course of 5 rounds a total of 108 ideas is collected [5].

The next tool, which can support FMEA, is Ishikawa diagram (also called fishbone diagram). It is a visual presentation of the analysis of diverse connections between an event (effect) and its possible causes. For manufacturing problems it encompasses such categories as 5 M's + E (manpower, machine, method, material, measurement and environment) [6]. Its application is supported by 5Why method of root cause analysis which allows to identify how the causes of a failure event arise and define the cause-effect failure path [7].

The hazard risk analysis cannot substitute control and monitoring of manufacturing process. During the control of molding process not only manufacturing process parameters are measured but the attention is also paid to the final product. It is required to monitor temperature of liquid raw material, mold and submerged elements in the the mold. Furthermore, in order to conduct quality control of the casting product it is necessary to carry out destructive and non-destructive testing. In destructive testing special samples or final products are destroyed, and therefore it is done on very limited samples (3-5 items). In contrast to it, non-destructive testing covers a wide group of analysis techniques which provide information about the properties of the investigated casting without causing damage, i.e. changing its operation usability.

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The aim of the paper is to show how the methods of risk analysis and quality control influence molding process parameters. The choice and frequency of the application of these methods resulted from the observations and analyses made together with organization staff responsible for performing molding process. The investigation is done on the example of gravity low-melting heavy metal – lead, which is relatively soft metal resistant to corrosion and has good self-lubricating properties.

LEAD MOLDING PROCESS IN THE ANALYSED COMPANY

In the investigated company the molding process is done manually by pouring the liquid lead to a metal mold. These molds are multi-use and their spacers allow to use them to diverse product dimensions such as height and diameters. The final product is a pilar which constitutes a component of battery or industrial battery. The quality of the pilar depends on the adhesion of brass insert to lead. The adhesion is assured by tin alloy coating of insert. In this paper the molding process of TC-G100-NR is presented (Table 1).

Table 1 **Molding parameters for TC-G100-NR**

	Controlled parameter	Requirement
Process	Temperature of 4,5 % lead	500 ^{0}C ± 25 ^{0}C
	Temperature of mold	90 ^{0}C – 180 ^{0}C
	Temperature of tray	60 ^{0}C
Final product	Test of torque wrench	50 Nm
	Adhesion of insert to pilar	Detected traces of lead on insert
	Diameter 1	Ø 20,2 – 0,2
	Diameter 2	Ø 24 – 0,1
	Total height	97 ± 0,2
	Height of undercut	55 ± 0,2
	Surface	Lack of defects

The product dimensions, which are mentioned in Table 1, are shown in Figure 1.

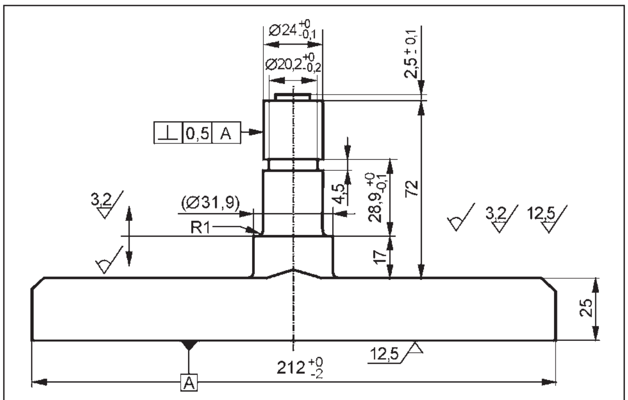

Figure 1 Dimensions of TC-G100-NR

APPLICATION OF METHODS OF RISK ANALYSIS AND QUALITY CONTROL: A CASE STUDY

Launching a new product (TC-G100-NR) to production was preceded by the Process FMEA. It allowed to identify mishap hazards resulting from potential failure modes at the stages of material reception in warehouse, production of brass insert, molding and preparing goods for shipping to customers. Totally, it consisted of 17 process steps and it was possible to implement 14 corrective actions in the manufacturing process. During the team work it was possible to use brain storming to identify potential hazards and 5Why to define effects. Table 2 shows the Process FMEA for molding.

FMEA was one of the elements of Production Part Approval Process (PPAP) which aim was to show that the supplier of the component (TC-G-100NR) developed the design and production process to meet client's requirements. It included process flow diagram, control plan, measurement systems analysis, calculation of process capability indices (Cpk, Cp), records of material tests, initial sample inspection reports, indication of machines and equipment used in this process and their control equipment, and Part Submission Warrant (PSW). The applied methods of process and product quality control are presented in Table 3.

In spite of the fact that the PPAP was set up, a total lack of adhesion of brass insert to lead appeared in some production batches. The client's requirement was to make immediate corrections and then take corrective actions and present their results. For this aim FMEA was checked to verify that such a potential failure was identified and what corrective or preventive actions were implemented. It appeared that a potential failure mode "inappropriate adhesion of insert" was documented in FMEA form. It resulted from "inappropriate temperature" and its corresponding preventive action was "follow production instruction". The risk priority number was 96.

Due to the fact that the preventive action taken to eliminate the cause of a potential nonconformity was not successful it was necessary to identify other potential causes of lack of adhesion. It was concluded that during the introduction of a new product it was not made sure that such a potential failure mode as "incorrectly written instruction" could appear and thereby, it was not written down in FMEA. The application of Ishikawa diagram and 5Why allowed to ascertain that the production instructions of new products are prepared on the basis of the previous long-standing experience in the lead foundry and the production of similar products from the same type of lead. The result of this diagnosis was the possibility of indicating three source causes and corrective actions (Table 4).

The implementation of the proposed corrective actions was perceived positively and the client accepted all new products with the proposed changes of process parameters to the manufacturing process. The implemented changes in product and process parameters after tests are presented in Table 5.

Table 2 **Fragment of application of Process FMEA for TC-G-100NR**

ALCOMOT					FAILUREMODE AND EFFECTS ANALYSIS (PROCESS FMEA)								Number of FMEA: 1					
Number of part (level of changes): TC-G100-NR (001888)						Responsible for process: Plant manager							Page:					
													Team: P. Piasek, M. Kita, G. Wiśniewska, T. Szukała, H. Gołaś, M. Smal, M. Graś					
Number of part: TERMINAL COLLECTOR TC-G-100 NR						Figure: 02.8601/02.C.6757G							Date of issue: 11.03.2014	Revision: 09.05.2014				
Number and name of process: 160. Serial production						Process scheme: 17.03.2015				Revision				Results				
No.	Operation	Potential failure mode	Potential effect(s) of failure	Severity	Classification	Potential failure cause(s) of failure	Occurrence	Current process control Prevention	Current process control Detection	Detection	RPN	Recommended actions RPN>100	Responsibility and term	Undertaken actions	Severity	Occurrence	Detection	RPN
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
160. Serial production																		
160.5/2	Putting inserts into mold	Putting unheated insert	Product does not comply with requirements	8		Too low temperature of insert	2	Using FIFO on heating trays	Visual control of adhesion	7	112	Establishment of standard for utilization of insert in molding Training of molding operators	Quality control, 16.05.15	Done	8	1	7	56
160.6/1	Molding of pole in a mold	Cracks	Product does not comply with requirements	9	I	Mold defect	2	Appropiate material and construction of mold	Visual check	7	126	Establishment of guides for testing molds	Quality control, Foreman 15.04.15	Done	9	1	7	63
160.6/2	Molding of pole in a mold	Cracks in casting	Product does not comply with requirements	9	I	Too short time of cooling	2	Training of molding operators	Visual check	7	126	Establishment of standard for cooling cast in mold Training of molding operators	Forman, Quality control, Master 30.04.15	Done	9	1	7	63
160.6/3	Molding of pole in a mold	Cracks in casting	Product does not comply with requirements	9	I	Too much of cork emulsion in mold	2	Training of molding operators	Visual check	7	126	Establishment of standard of using cork emulsion	Quality control, 30.04.15	Done	9	1	7	63

CONCLUSIONS

The effective Process FMEA requires not only understanding fundamentals and procedures but also applying the learned lessons. Therefore, it should be periodically updated on the basis of the observed potential hazards before their effects are noticed. In the analysed company the application of the tests, development of labour standard for founder and quality control allowed to eliminate other similar serious problems in the future.

Table 3 **Process and product quality control for TC-G-100NR**

	Controlled parameter	Requirement	Quality control
Process	Temperature of 4,5 % lead	500 ^{0}C ± 25 ^{0}C	Records of temperatures once per 8 hours On-line monitoring of temperature on display by molding operator
	Temperature of mold	90 ^{0}C – 180 ^{0}C	On-line monitoring of temperature on display by molding operator
	Temperature of tray	60 ^{0}C	On-line monitoring of temperature on display by molding operator
Final product	Test of a torque wrench	50 Nm	Records of tests 3 times per shift from each mold form
	Adhesion of insert to pilar	Traces of lead on insert	Visual check after cutting the casting and forging
	Diameter 1	Ø 20,2 – 0,2	Calipering
	Diameter 2	Ø 24,0 – 0,1	Calipering
	Total height	97 ± 0,2	Calipering
	Height of un-dercut	55 ± 0,2	Calipering
	Surface	Lack of defects	Visual check

Table 4 **Root causes of problem**

No.	Root Causes	Corrective actions
1.	Lack of labour standard for founder	Establish standard
2.	Lack of agreement with cli-ent on applied temperature	Determine temperature after testing
3.	Lack of agreement on stan-dards for quality control	Develop and agree on assess-ment of product standard

Table 5 **Comparison of product and process parameters before and after tests**

Controlled parameter	Before test	After test
Temperature of 4,5 % lead	500 ^{0}C ± 25 ^{0}C	440 ^{0}C ± 25 ^{0}C
Temperature of mold	90 ^{0}C – 180 ^{0}C	120 ^{0}C – 160 ^{0}C
Temperature of tray	60 ^{0}C	80 ^{0}C – 100 ^{0}C, one layer of inserts on tray
Test of a torque wrench	50 Nm, record 3 times per shift	30 Nm, test 100 % of casts
Adhesion of insert to pilar	Record 3 times per shift	Test of adhesion of insert to pilar every 50 pilar – until cancelation

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Note: The responsible translator for English language is Paulina Butlewski, Poznan, Poland