IMPROVEMENT OF THE HEAT TREATMENT PROCESS IN THE INDUSTRY 4.0 CONTEXT

Sandra GRABOWSKA

Silesian University of Technology, Faculty of Materials Engineering and Metallurgy, Katowice, Poland, EU
sandra.grabowska@polsl.pl

Abstract

Dynamically changing conditions of business activity, rapid development of new technologies, increasing intensity of competition, progressing globalisation pose for entrepreneurs new, much more difficult principles than before, especially due to the increase of intensity and complexity of the environment. It is reflected in the necessity of continuous improvement of processes and their quick reorganisation.

The aim of the article is to analyze individual stages of the heat treatment process to indicate the complications, errors and quality defects of products created at the manufacturing stage. The Ishikawa diagram was used to improve the quality. However, taking into account that the world is on the verge of the next industrial revolution, the directions of improving the heat treatment process in the context of Industry 4.0 have been indicated.

Keywords: Production process, Ishikawa diagram, Industry 4.0

1. INTRODUCTION

Rapidly changing business environment, development of new technologies, the increasing intensity of competition and increasing globalization pose businesses against increasingly difficult requirements [1]. In contemporary, highly competitive production environment, metallurgical enterprises face the challenge of coping with large amount of data, quickness of making right decisions or flexibility of production processes. Especially the aspect of production flexibility is here important element, because now the nature of production is shaped by the paradigm shift from mass production to on-demand, customer-oriented production [2]. Such actions result in shorter product life cycle, increased assortment of products, as well as the change of processes to processes of high efficiency and the change of devices and machines to more flexible devices and machines, taking into consideration the necessity of constant taking care of assumed quality of products.

Industry 4.0 is currently one of the most frequently touched on topics among practitioners and scientists, making it the priority for many research centres and enterprises.

Industry 4.0 is the fourth industrial revolution, in which it is assumed that it is a vision of intelligent factories built from intelligent cyber-physical systems. The implementation of this idea should allow to develop intelligent production systems, which besides above mentioned autonomy, will have properties of self-configuration, self-control or self-repair [3].

The concept of Industry 4.0 covers areas which include numerous technologies and related with them paradigms. The main elements which are closely related to the idea of Industry 4.0 include so: industrial internet of things, cloud-based production, intelligent factories, cyber-physical systems or social product development [4, 5, 6].

In this concept production process will be further structured sequence of activities, thanks to which the consumer (user) has the possibility to obtain a product(good, service). It must be designed and organized for set objectives(which can change). It has dynamic character, which is conditioned by variability of quantitative and qualitative characteristics, material, energy and information feeds. It should serve maximizing profit of enterprise and customer satisfaction [7].

Quality management tools in the Industry 4.0 concept will gain strength and will be still intended to collect and process data in order to supervise the process striving for the best possible quality. They are designed for monitoring, analyzing, they influence processes during whole production process of given product. These tools are also designed for detection of defects and errors during processes, in products or services. They are intended to visualize data in whole life cycle of product [8].

Thanks to quality management tools, it is possible to analyze and evaluate, whether taken actions bring assumed effects and benefits, all in order to improve the processes of products and services. These tools are widely used in designing, monitoring and control of processes of manufacturing products and also all kinds of services [9].

In production enterprises complications, errors and quality defects of the product occur, which arise at the stage of manufacturing product. Such problems have many consequences and affect the quality of product. Each plant with its own team of specialists strives for minimizing them. Therefore detailed research and analyses are conducted at various stages of production using appropriate tools. One of such tools is Ishikawa diagram, which gives the possibility to present graphically connections, which exist between analyzed problem and causes that underlie it [10].

The aim of the article is to analyze individual stages of the heat treatment process to indicate the complications, errors and quality defects of products created at the manufacturing stage. The Ishikawa diagram was used to improve the quality. However, taking into account that the world is on the verge of the next industrial revolution, the directions of improving the heat treatment process in the context of Industry 4.0 have been indicated.

2. CASE STUDY

Dynamically changing environment, progressive technological development, increasing intensity of competition and threats of crisis phenomena require the development, improvement and implementation of innovative management systems [11].

Production enterprise BGH LLC in Katowice is a plant producing square and flat bars of various sizes and narrow tolerances (even in small production batches). It is a subsidiary of Boschgotthard, which is located in Germany. At enterprise BGH mainly steel coming from the plants of group of BGH Edelstahlwerke GmbH is processed. The most important products include: steels for turbine blades, stainless steels for production of knives, tool steels and nickel alloys. At enterprise BGH steel is hot-rolled, what takes place on large rolling mill duo in the line of flat block and continuous line. In order to carry out various kinds of heat treatment different devices consisting of heating and cooling units are available.

At production enterprise BGH production takes place in many stages. Beginning from rolling through the stage of heat treatment and ending with finisher. Heat treatment allows to improve material and to give it appropriate properties according to wishes of customer. Heat treatment is a kind of technological process, which is intended to change mechanical and physico-chemical properties in material in solid state by changing its microstructure in order to obtain appropriate properties extending the product life, for example increasing hardness, resistance to high temperature or strength, plasticity. It is controlled process.

Following heat treatment procedures are applied at enterprise BGH:

- Heat improvement (hardening and tempering) - it is heat treatment process that consists in combination of hardening and tempering. In hardening material is heated to high temperature, maintained at this temperature and then quickly cooled. While tempering is final procedure, just after hardening, which gives the steel the best mechanical properties according to application.
- Annealing - in the general sense it means a group of operations of ordinary heat treatment, thanks to which structure close to steady state is obtained in treated material [10]. Softening annealing (applied in BGH

plant) is high-temperature heat treatment process aimed at softening the material as much as possible, so that material is easy to cut.

- Precipitation hardening (saturation and aging) - is a procedure combined with two consecutive heat treatment operations - saturation and aging. This is a way to strengthen materials, which uses the fact that the solubility of one component in the other component decreases with the decrease of temperature.
- Saturation - consists in heating the charge at temperature, which is above the limit of solubility in the area of single-phase solid solution and then in quick cooling it in order to freeze dissolved component and to prevent simultaneously repeated secreting component from solution
- Aging - while consists in heating the alloy (previously saturated) to lower temperature than limit temperature of solubility, heating it at this temperature and then cooling it down.

In researched enterprise it comes to complications, errors and quality defects of products arisen at the stage of manufacturing the product. Such problems have many consequences and affect the quality of product. Therefore proposal of solutions was developed to improve the quality of products. Quality improvement tool - the Ishikawa diagram was used.

The cause and effect diagram (Ishikawa diagram) is now a very popular tool in quality management. Currently, it is one of the most commonly used quality management tools. The essence of Ishikawa's diagrams is a graphic presentation of mutual connections between the effects that can cause them with various causes. Appropriate visualization on the one hand supports the search for causes, on the other hand it ensures the maintenance of an ordered structure between the identified elements [11].

Figure 1 presents Ishikawa diagram, which shows inconsistencies in following areas: people, machine, method (technological process), material and management. The diagram was prepared for the analyzed process.

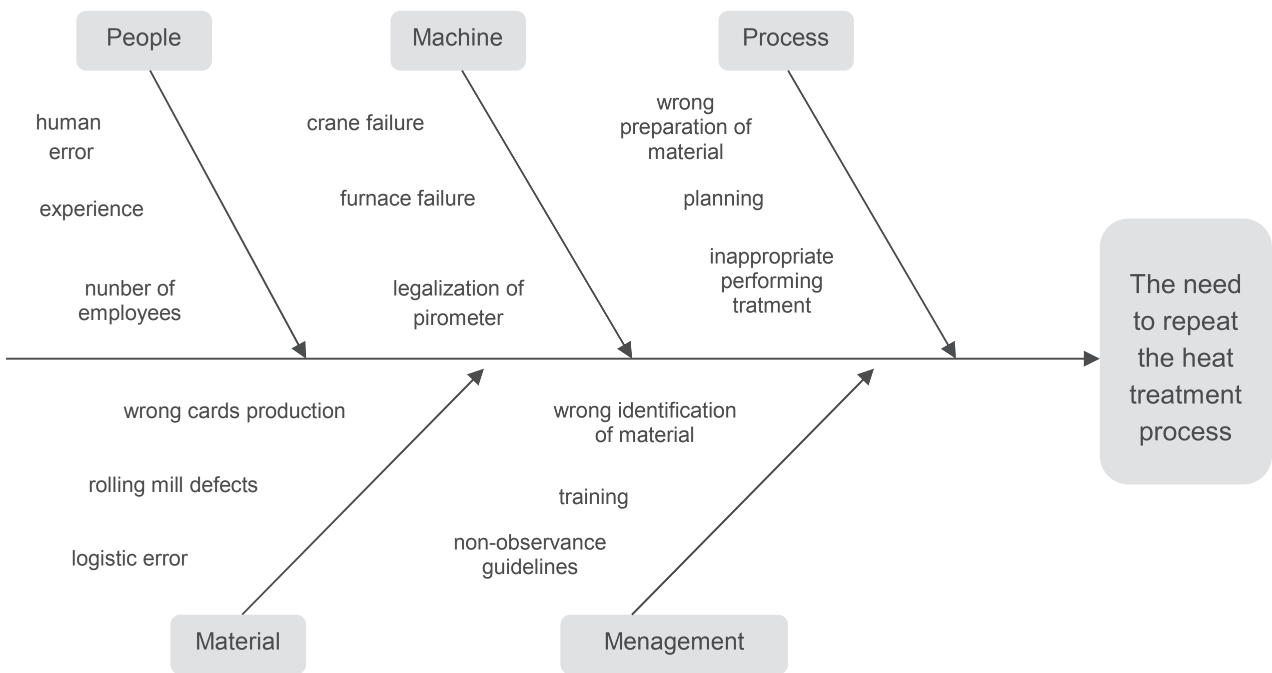

Figure 1 Ishikawa diagram

It was found that for the component „people” the most important cause of arising problem of repeated heat treatment is "human error". In order to minimize it, more breaks for employees, training courses, making employees aware of costs of made mistakes are proposed.

For the component "machine" the most important incompatibilities were gantry crane failure and furnace failure. To eliminate arising failures in the future, regular maintenance of machines, the increase of number of inspections, the increase of monitoring machine operations, creation of file with failures and finally replacement of machine with new machine should occur.

For "technological process" significant inconsistency was "inaccurate preparation of material for heat treatment department", in which the employee on the basis of heat treatment plan prepares the material, composition of the charges and in which it was easy to oversee material defects, as well as scratches, cracks or other surface defects. In order to eliminate this incompatibility experience of employees should be increased, the material should be checked more thoroughly before the execution of heat treatment, principles and rules should be observed on the basis of experience of employees, as well as guidelines should be followed and also the analysis of statistical data should be carried out.

For the component „material” the most important inconsistency was incorrect preparation of production cards, where it is easy to confuse for example assignment of the charge. The proposal of improvement is to create additional program analysing the selection of the smelt to specific order.

The most important inconsistency for the component ‘’management’’ was ‚incorrect identification of material. In order to minimize these inconsistencies, more training courses, emphasis on employees and the increase of awareness of costs of losses are proposed.

Short characteristic selected of causes and proposals of solutions are presented in tables 1. Improvement of problematic areas in the aspect of transformation of enterprise to the requirements of Industry 4.0 are also proposed.

Table 1 Characteristic selected of causes and proposals of solutions also according to assumptions of industry 4.0

Description	Proposal of solution	Proposal of solution according to assumptions of industry 4.0
• **Inconsistency - experience of employees**		
Heat treatment process is specific, experience of employees is very important here. At department both employees with long-term work experience as well as newly employed employees work. New employees must demonstrate willingness to acquire expertise and above all experience.	The support of experienced employees is the basis for the proper implementation of procedure of heat treatment. Friendly atmosphere in work is important.	Implementation of development program for employees (financing of training courses, cyclical search for possible areas of employee development).
• **Inconsistency - gantry crane failure**		
Seizing and temporary stop can cause the delay during hardening, resulting in, for example, overcooling of material.	Regular maintenance, inspections, monitoring of gantry crane operation, creation of a file with failures are proposed. Finally, eventually the replacement of gantry crane with new gantry crane.	Modern Maintenance of Operation. Tools supporting maintenance operation and preventative actions in machine park. Algorithms foreseeing failures. Remote support systems. Systems of management of maintenance of operation (CMMS, EAM). Integration of machines.

Table 1 Continue

Description	Proposal of solution	Proposal of solution according to assumptions of industry 4.0
Inconsistency - Inaccurate preparation of material for heat treatment (continue)		
Employee on the basis of plan of heat treatment prepares material and composition of charges. The furnace is loaded evenly, symmetrically in relation to its length and width. Additionally it should be inspected visually, if there are any scratches, cracks or other surface defects are present. Material with surface defects should not be hardened. For softening annealing is binding material in several places with the wire necessary in order to avoid dispersing.	Experience and analysis of statistical data (archive data file) are important in order to harden the charges evenly and at the same time to optimize the weight of the charge. With regard to annealing material can not exceed admissible weight depending on the dimension - for example max. 3 tonnes for ready rolled dimension 30x30 mm. To avoid problem of inaccurate preparation of material for heat treatment, more accurate checking material before performing heat treatment, observance of principles and rules on the basis of experience of employees and also guidelines are proposed.	Robotization - flexible, robotized production cells, "intelligent" systems. Modern manufacturing systems. Cooperation of robot with a human being. Machines with extended intelligence.
Inconsistency - Inappropriate identification of material		
At Heat Treatment Department rolled material is marked with appropriate labels by employees. These labels are intended to identify the species of steel. are very important element, because their identification enables further production process.	Wrongly marked labels from the moment of rolling or incorrect identification of material by the employee cause that the repetition of the process will be necessary in accordance with correct marking. More training courses for less experienced employees, laying greater emphasizing by supervising persons on employees responsible for labeling are proposed	Analysis of production data - advanced software for data processing and analyzing. Real-time analysis. Advanced algorithms ensuring the maintenance of assumed product quality.

Improvement of production processes and care for the highest quality of products is an absolute necessity. Industry 4.0 is the fourth industrial revolution in which it is assumed that it is a vision of intelligent factories built of intelligent cyber-physical systems. The implementation of this idea should enable the development of intelligent production systems that, in addition to autonomy, will have self-configuration, self-control or self-repair properties. In the surveyed enterprise, many problems faced by managers will gain completely new solutions, as presented in Table 1.

3. CONCLUSION

Rapidly changing business environment, development of new technologies, the increasing intensity of competition and increasing globalization pose businesses against increasingly difficult requirements [12]. Enterprises wishing to maintain the competitiveness competitiveness constantly have to take care of the highest quality of offered products.

Researched problem, it means the necessity of performing repeated heat treatment processes, which have negative impact on whole production process, was analyzed and evaluated on the basis of the Ishikawa diagram. Due to the fact that we are currently on the threshold on industrial revolution, solutions of the problem resulting from transformation of production enterprise BGH into factory of industrial 4.0 were proposed. The implementation of this idea should enable the development of intelligent production systems that, in addition to autonomy, will have self-configuration, self-control or self-repair properties. In the surveyed enterprise, many problems faced by managers will gain completely new solutions. as for example: robotization will eliminate manufacturing errors created as a result of human error, innovative systems will enable "virtual" machine park management or management of the entire enterprise.

Carried out cause and effect analysis can contribute to minimizing arisen problem, it can influence better production efficiency, increase qualifications, awareness of employees with their preparation for done job.

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