Abstract

Failure mode and effect analysis-FMEA of a ceramic tiles manufacturing plant has been applied. The risk priority number (RPN) for the prioritization of failure modes of ceramic tiles was calculated. Pareto diagrams for the depiction of the frequency and importance of causes that may cause a problem were applied. Also, Ishikawa diagrams for the real potential main causes of possible failures in the production of ceramic tiles are showed. The proposed techniques for failure analysis will help to understand the failure behaviour of component(s) in the production process and to adapt suitable management practices to improve the performance and the quality of the ceramic tiles.

Keywords: Logistics of the ceramic tiles production line, FMEA, Quality tools, Pareto and fishbone diagrams.

Introduction

Today’s competitive market is continuously integrated new Industries with products where increased competition for the presentation of more customers through the satisfaction of their claims exists. The main purpose of business strategy of each company is to achieve the satisfaction of the requirements of the customer is the quality of product. Although, the key of success of an industry is the quality of products, it is possible a product will not be qualitative if it does not function properly or malfunctioning, maybe due to some failure in the product design or in the processes of production which followed by industry.

FMEA (Failure Mode and Effect Analysis) is a systematic method of identifying and preventing product and process problems before they occur. FMEAs are focused on preventing defects, enhancing safety and increasing customer satisfaction. Ideally, FMEAs are conducted in the product design or process development stages although conducting an FMEA on existing products and processes can also yield substantial benefits (McDermott et al., 2009). The engineers need to analyze product design, production processes and products
for potential failure modes led them to use a technique called Failure Modes and Effects Analysis-FMEA. This is an important technique that is used to identify and eliminate known or potential failures to enhance reliability and safety of a simple product or even complex system (Hawkings and Woollons, 1998). Teng and Ho (1996) presented the FMEA technique as an integrated approach for product design and process control.

FMEA is proposed as long as its use will help classification of risk ruled by the factors of severity (S), probability of occurrence (O) and probability of detection (D) of raw materials at risk. Analysis is made, based both on best expert opinion and historical information for similar items, of all the ways that each component or subsystem might fail to fulfil its intended function (James, 1998). FMEA appears to be an appropriate matrix for this activity (McDermott et al., 2009).

Juran (1989) refers to FMEA as “failure modes and criticality analysis (FMECA)” and defines it as a methodical way to examine a proposed design for possible ways in which failure can occur. In FMECA, potential failures are identified first in terms of failure modes. For each mode, the effect on the total system is then studied. Finally, a review is made of the action being taken (or planned) to minimize the probability of failure or to minimize the effect of failure.

Ben-Daya and Raouf (1996) proposed an improved FMEA model to provide a quality improvement scheme for the production phase of a product or service. Also, Sankar and Prabhu (2001) have presented modified approaches to FMEA. Pfleeger (1998) defined a failure as the departure of a system from its required behavior; failures are problems that users or customers see. Tsarouhas (2009) exhibited the methodology to classify the primary failure modes in categories based on failure data of a production line.

In this study, the failure mode and effect analysis-FMEA technique of all stages of the production process for a ceramic tile manufacturing plant was carried out. Also, cause and effects analysis was computed to identify the roots and causes of the main problems for the line. Furthermore, Pareto diagrams prior to correctives actions and after corrective actions for the tile production line were employed towards the potential optimisation of FMEA.

Case Description

The FMEA technique could be applied in one of the bigger units of ceramic tiles manufacturing plant in Greece, “CERAMICS S.A.” The developments of recent decades have shown that many industries of ceramic tiles believe that the concept of quality is the
most basic and the most effective condition for industries success because it is the conformity of products characteristic with the specifications.

A popular mosaic material on account of the wide range of colors available which is made from thin layers of fire clays, called “ceramic tile”. More exactly, the word “ceramic” came from the Greek word “keramikos” which literally translated means “of the earth”. That means Ceramic tiles are products made from naturally occurring earth which is shaped and then permanently hardened by heat.

Ceramic tiles are produced in a variety of colors and patterns, usually square or rectangular. The most popular types of ceramic tiles which usually produce a ceramic tile manufacturing plant are ceramic floor tiles, ceramic wall tiles, ceramic wall and floor tiles and ceramic tiles for special fittings.

_Production Process of Ceramic Tiles_

The production of tiles dates back to ancient times and peoples, including the Egyptians, the Babylonians and the Assyrians. For instance, the Step Pyramid for the Pharoah Djoser, built in ancient Egypt 2600 B.C., contained colorful glazed ceramic tile. Later, ceramic tile was manufactured in virtually every major European country and in the United States (Jones and Berard, 1972).

Nowadays, the European Union is a leader in manufacturing ceramic tiles in terms of design, quality and value while China is leading in the field production. Consequently, Europe is a world leader in production of ceramic tiles. As a result, phenomenal growth has presented the ceramic tile industry in Greece. CERAMICS S.A. is a leading company in the production of the ceramic tiles which hold the ISO 9001:2000 quality certificated which soon will be replaced with the ISO 9001:2008 as the industry produce a wide range of 1200 products that include: Wall tiles, floor tiles for internal and external use, swimming pool tiles and tiles of all kinds of industrial uses. Usually, there are three types of ceramic tiles: Glazed, Unglazed and Monoporoza. The manufacturing plant “CERAMICS S.A.” produce ceramic tiles in 10 stages and has 4 productions lines. The process flow of ceramics tiles production line (Figure 1) is as follows:

_Stage 1 (Storage gravels):_ Gravel, clay, silicon, feldspar and some other minerals which are mined from the earth’s crust are used to be the raw materials which are used to form a ceramic tile. However, the most important raw material for the production of ceramic tiles is mainly gravel which is obtained and stored in its warehouses or sometimes outdoors. That procedure is used to follow the manufacturing plant also for the rest of raw materials.
Stage 2 (Weighing – Break): Depending on the quantity of ceramic tiles which the Industry must produce in accordance with the orders which the Industry has accepted, weighs the gravels and directing to the special screws to shatter into several smaller pieces. At the same time, through the special screws gravel and the other raw materials are thrown in order to be mixed with the gravel and crushed together.

Stage 3 (Grinding): The weighing and break into pieces is followed by Grinding preparative to reduce the size of the pieces. The grinding becomes in specific bearing grinding.

Stage 4 (Drying Pulp): Result of grinding is the raw materials in form of dust. That dust entering from a pump in a special tank (tower) and mix approximately 6 to 10 hours. Then mix with water and mix again and modified into a kind pulp material like a uniform thin mud. Then the pulp enters in the drier and there performs the drying of the pulp. The dust which gets out of the drier keeps up minimum moisture which ranging from 4-6 %. The kind of the dust mass which will come from the drier every time depends on the type of ceramic tile which is going to be generated.
Figure 1: The production process of Ceramics Tiles in 10 Stages.
Stage 5 (Storage Dust): Industry’s next move after the drying of pulp is the storage of dust in specific storage space where the Ceramic tiles manufacturing plant can use for the production of Ceramic tiles.

Stage 6 (Formation): Formation is the first essential production stage of ceramic tiles. At this stage the dust that is obtained from the specific storage space and maintains a minimal form of moisture, is placed in special forms and compressed by automated presses with operating pressure as high as 600kg/cm². Originally, pressed under a low pressure and then under extreme pressure which can reach up to 250 bar giving shape to the ceramic tile.

Stage 7 (Drying): A ceramic tile usually must be dried after forming. By inference, drying is the next step after formation where the Ceramic tile enters raw into drier in order to remove the moisture.

Stage 8 (Glazing): The next stage of construction of ceramic tile is glazing which is achieved by passing the ceramic tile of a machine where the glaze is fed through a rotating disc that flings or throws the glaze onto the ceramic tile and covering it with enamel. In some causes because the time where Ceramic tiles are moving overhead bands to the Glazing machine is very fast, forces employees to store the Ceramic tile in push carts and place them after slowly for glazing. That happens mostly when accidentally created a problem during the production process of Ceramic tiles. The glazing takes place when the customer asks for glazed Ceramic tile. On the other hand, when the customer asks for unglazed Ceramic tile then the Ceramic tile rejects glazing and goes to the next stage which probably can be design and firing or only firing.

Stage 9 (Design – Firing/Oven): Following glazing the ceramic tile accepts a design. Design is essentially the design of Ceramic tile with lines, rhombus, etc. but in special causes CERAMICS S.A. give the responsibility for some Ceramic tiles processing (design) to other Companies especially when CERAMICS S.A. want to decorate ceramic tiles for example with drawing. Following procedure after Ceramic tiles design is firing one of the most important stages of production process of ceramic tiles. Ceramic tile always must be heated intensely to strengthen it and take the final shape. Firing is the introduction of a ceramic tile in the oven where the firing gradually starts from low temperatures until they reach 1200°C as highest point. Specifically, in this process, the ceramic tile goes through a low temperature firing to
highest temperature firing and again to a low temperature firing and then gets out of
the oven ready for selection, packing and promotion to the customer.

Stage 10 (Selection – Packing): One of the last stages of the production process of
ceramic tiles is Selection. For this process contributes both the human factor and a
specific measurement machine. The purpose of both is the implementation of quality
control to the final product in order to have every time the industry qualitative
ceramic tile. So, if the final product has a good quality then it could pass to the next
step which is packing. The packing technique is performed automatically and in some
causes with helping of human factor. On the packing of ceramic tile always the
ceramic tile manufacturing plant print the elements of Ceramic tile which is actually
his identity. Finally, the sales help the industry to grow the profits of the company.

Operation Management
The strategy of CERAMICS S.A is to produce ceramic tiles according to the
customer’s orders. The company meets the demand by taking the opportunity to
communicate with potential customers by presenting products that can be produced
for them in low prices. Thus, each individual customer specify his preferences
regarding the characteristics of the product he want to have and then CERAMICS
S.A. produce that product and sell it to the customer.

CERAMICS S.A. is one of the first companies on producing ceramic tiles in Greece.
Founded in 1962 for first time and located in Thessaloniki. The company has 220
employees in her own private installations. The staff works in 3 shifts 24 hours per
day. Each employee is responsible for his job in industry i.e., before a shift is ended
the stuff stops working and cleans the machines to be ready for the next shift.
Moreover, company’s need to achieve her purpose of producing a high quality
product leads her to use today all the necessary kinds of machines in the production
line. Furthermore, company’s need to direct and control her activities in order to
produce qualitative products which can satisfy all the requirements of the customers
established and use a Quality Management System in all sections according to ISO
9001:2000. The Ceramic tiles manufacturing plant today operates in Greece and only
20% abroad in Romania, in India, in Cyprus, in England etc.
Process FMEA

Process Failure Mode and Effect Analysis (PFMEA) used to analyze production processes and product assembly. The objective of a PFMEA is to look for all the ways a process or product can fail. PFMEA focuses on indentifying possible future modes of failure of the product which can come from incomplete processes of production. This analysis includes all the phases of production, machinery, operators and controlling instruments, production materials and working environment.

Failure Mode is a symptom, condition or fashion in which hardware/software fails. A failure mode might be identified as loss of operation for the equipment. Each failure mode has a potential effect and some effects are more likely to occur than others. In addition, each potential effect has a relative risk associated with it. The FMEA process is a way to identify the failures, effects and risks within a process or product and then eliminate or reduce them. The relative risk of a failure and its effects is determined by three factors:

♦ Severity (S): the consequence of the failure should it occur
♦ Occurrence (O): the probability or frequency of the failure occurring
♦ Detection (D): the probability of the failure being detected before the impact of the effect is realized

By multiplying the ranking for the three factors (S x O x D) a risk priority number (RPN) will be determined each potential failure mode and effect (McDermott at el., 2009).

When the quotes of one or more characteristics of the product are outside the limits of the specification of these characteristics, then the product is no compliant with the standards or faulty. The aim of ceramic tiles manufacturing plant is the accomplishment of final product quality requirements the Company make quality controls to the final product for the feasance of quality standards. As a result, some of the final Ceramic tiles may often have a bad quality which can be separated on the problems of colour, curvature, size, quality and some other problems such as broken or cracked Ceramic tiles, badly faults in their surface etc. Therefore, a product failure
<table>
<thead>
<tr>
<th>Component and Function</th>
<th>Potential Failure Mode</th>
<th>Potential Effect(s) of Failure</th>
<th>Potential Cause(s) of Failure</th>
<th>Current Controls, Prevention</th>
<th>Recommended Actions</th>
<th>Responsibility and Target Completion Date</th>
<th>Action Taken</th>
<th>Responsibility and Target Completion Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oven</td>
<td>Steep change of the temperature</td>
<td>Negative Curvature</td>
<td>6</td>
<td>Human error</td>
<td>Observation of the operator usage</td>
<td>8</td>
<td>Staff education</td>
<td>Head of production</td>
</tr>
<tr>
<td>Glazing machine</td>
<td>Stop operation</td>
<td>Denaturation of the exterior surface</td>
<td>6</td>
<td>Short – Circuit</td>
<td>Observation and Checking of the machine</td>
<td>5</td>
<td>Measurements and Maintenance</td>
<td>Head of production</td>
</tr>
<tr>
<td>Press</td>
<td>Bad Function</td>
<td>Wrong Flatness of the Ceramic tile</td>
<td>5</td>
<td>Bad management</td>
<td>Observation of the machine and of the worker</td>
<td>6</td>
<td>More information and control</td>
<td>Production Manger</td>
</tr>
<tr>
<td>Drier</td>
<td>Bad function</td>
<td>Cracks</td>
<td>5</td>
<td>Old machine</td>
<td>Check of the machine</td>
<td>6</td>
<td>More scholastic control and maintaining of the machine</td>
<td>Production Manger</td>
</tr>
</tbody>
</table>

**Table 1**: Process Failure Mode and Effect Analysis in production process of Ceramic tiles.
occurs when the product does not function as it should or when it malfunctions in some way. The cause of the failure of a product with customer requirements can be a component, its fictions etc. A good solution for CERAMICS S.A. to avoid a possible failure of a ceramic tile in the production line is PFMEA.

PFMEA is very useful quality tool, and is used in a ceramic tiles manufacturing plant for identifying potential failures modes of ceramic tiles in the production and the potential effects of failure. Table 1, presents PFMEA during the production process in a ceramic tiles manufacturing plant.

Results of PFMEA

Oven
The cause of non-conformation of a ceramic tile with the requirements can be the oven of ceramics tiles. A potential failure mode is the steep change of the temperature when the ceramic tile is baked in the oven. As a result, a potential effect of failure is a negative curvature of the ceramic tile which is a clear indication of ceramic tile low quality. In that occasion, the Severity ranking is (S)=6. The potential cause of failure probably is a human error. Respectively, the Occurrence ranking is (O)=8. The current control which is used to prevent this failure is the observation of the operator of the oven and then the Detection ranking become (D)=8. Thus, the risk priority number (RPN= S x O x D) is 384 which is non-acceptable number. This number considered unacceptable as it should be in the range of 0-130. A recommended action could be the staff education in responsibility of head of production. Therefore, the actions which should be taken is training and informing of staff and the observation of the functions which is going to reduce the risk priority from 384 to 60. This new RPN is called the ‘‘resulting RPN’’ and it is determined by reevaluating the Severity, Occurrence and Detection rankings. As a result with Severity ranking (S)=3, Occurrence ranking (O)=4 and Detection ranking (D)=5 the new risk RPN will be 60, which is acceptable number as it is <130.

Glazing Machine
The Glazing machine of Ceramic tile is another machine which causes the creation of a non-acceptable product quality. A potential failure mode is a sudden stop of the operation of the machine with potential effect of failure a denaturation of the exterior
surface of the Ceramic tile. In that case, the Severity ranking is \( S = 6 \). A potential cause of failure is a Short – circuit in the electrical and so the Occurrence ranking is \( O = 5 \). The current control which adopted from the Ceramic tile manufacturing plant is the observation and the checking of the glazing machine and then the Detection ranking probably can be \( D = 5 \). Thus, the RPN will be 150, which is non-acceptable number as it is >130.

Some recommended actions which could be good for the company to follow are measurements and maintenance of the machine with responsible person for that the head of the production. Thus, the actions which should be taken are the establishment of maintenance and the upgrade of the glazing machine. The Severity ranking will reduce to \( S = 4 \), the Occurrence ranking \( O = 4 \) and Detection ranking \( D = 4 \) the new risk priority number (RPN) will become 64.

**Press**

Another machine in the production which causes a failure production of a Ceramic tile is the Press. A potential failure mode is a bad function of the press which have a potential effect of failure the wrong flatness of the Ceramic tile with Severity ranking \( S = 5 \). A potential cause of failure is the bad management of the Press with Occurrence ranking \( O = 6 \). The Current controls which are used are the observation of the machine and the observation of the worker with Detection ranking \( D = 7 \). Thus, the RPN is 210, which is non-acceptable number.

Recommended actions could be more personnel information and better control of machine functions whose responsibility is Production Manager. So, the actions which should be taken are to raise the awareness of staff to be sensitized and better control with better Measurements. The Severity ranking will reduce to \( S = 4 \), the Occurrence ranking \( O = 4 \) and Detection ranking \( D = 5 \) the new RPN will become 80.

**Drier**

The last one production machine which causes a non-conformation Ceramic tile is the Drier. A potential failure mode as they support in the Company is the bad function of the Drier which can cause Cracks in the Ceramic tile and they said that the Severity ranking is \( S = 5 \). A potential cause of effect comes from the old age of the machine. As a result, the Occurrence ranking is \( O = 6 \). The currents controls which usually use to follow the Company is the checking of the Drier so the Detection ranking is \( D = 6 \). Thus, the RPN is 180, which is non-acceptable number.
More scholastic control and maintaining of the machine are some recommended actions which could be useful for the company with the production manager as responsible person. Thus, the Maintenance, the upgrading or the replacement of the machine could probably be some of the actions which should be taken of the ceramic tile manufacturing plant as the risk priority number will reduce from 180 to 36. This could be possible as the Severity ranking will reduce to (S) = 3, the Occurrence ranking (O) = 3 and Detection ranking (D) = 4.

Ishikawa/Fishbone diagrams/ Cause and Effect diagrams

The Ishikawa diagrams, also known as the Fishbone diagrams or the Cause and Effect diagrams, are diagrams that show the causes of a certain event. Common uses of the fishbone diagram are product design and quality defect prevention, to indentify potential factors causing an overall effect. Each cause or reason for imperfection is a source of variation. Causes are usually grouped into major categories to indentify these sources of variation. The Categories typically include materials, man, machine, methods and the environment (Tague, 2004).

An implementation of fishbone diagrams for the two machines Oven and Press which have the highest Risk Priority Number (RPN) is given in the following figures. These fishbone diagrams are typical examples of analysis of the main causes of non-conformation of the Ceramic tile with the requirements because of the Oven and Press problem. The possible causes for the Oven problem are identified in Figure 2. It is obvious that some possible causes which shows as the main cause the man for the problematic operation of the Oven and especially for the non-conformation of the ceramic tile are the lack of the staff, the bad assessment of educational needs, the low payment and the low cost of financing which should be resolved by the ceramic tile manufacturing plant and corrected to let it to produce a conformal product. By the observation of the competition for lower prices of better quality materials, with the selection reliable Suppliers, with the appropriate choice of storage and with the correct prediction order where the materials will not be stored for a long time of period, and as a result they will have a good quality. Respectively, the knowledge, the cost, the alternations trends of electric current can introduce even the equipment as the main cause of bad usage of the machine and non-conformation of the products which must be in attention in order the Manufacturing plant to produce qualitative product.
Figure 2: Ishikawa diagram (Fishbone diagram) for Oven.
The ceramic tile manufacturing plant focusing further on achieving the desired cost, the avoidance of carelessness, the acquisition of knowledge and the correct operation it will succeed perfectly the proper adoption of creations methods a good quality Ceramic tile. Furthermore, as shown in Figure 2, some other possible causes that may establish the environment as the main cause of failure, is attention to the evaluated temperature in the environmental place, the adoption of appropriate safety measures and better communication.

In Figure 3, the possible causes for occurring problems of Press are identified. It is clear that some possible causes which can establish as the major cause of problematic operation of Press and hence the production of a non-conformation product is the bad planning, the inappropriate administration, the low performance evaluation of the employee and the bad cooperation. These are the fields were the company should be focused and directed to preventive and corrective actions. In addition possible causes of failure of a ceramic tile may be the incomplete education, the low budget, the ignorance and the reduced purchase of raw materials which conclusively indicate that the materials are a possible main cause. Thus, the company must be careful and continue with corrective actions. Furthermore, the careful selection of manufacturer machinery, the pursuit of financing and low maintenance cost of the machine as the use of the machine as regards the time if they will be in attention from the company they will not establish as main cause of failure of a ceramic tile the machine. Similarly, through lower costs, proper supervision, a good production planning and a good division of labour means that the company follow appropriate methods that contribute to product conformity to requirements. A better product, a good environment and sufficient equipment of environmental protection are important for a good environment that will not cause a problem in the Press and in the production of non-quality product.

Moreover, in figure 4 Pareto diagram was drawn, aiming at the determination and display of particularly the risk priority number (RPN) for each machine prior to corrective actions. Then, the second Pareto diagram in figure 5 was drawn aiming the determination of a new risk priority number (RPN) for each machine after corrective actions.
Figure 3: Ishikawa diagram (Fishbone diagram) for Press.
Conclusions

In this study, the FMEA during the production process of ceramic tiles was carried out. The risk priority number (RPN) for the prioritization of failure modes of ceramic tiles was calculated, and it is found that the machines Oven and Press have the highest RPN. To find the main cause of the problem for Oven and Press the Ishikawa diagrams were showed. Furthermore, Pareto diagrams for the depiction of the frequency and importance of causes that may cause a problem were applied, prior to corrective actions and after corrective actions with a new RPN. Therefore, the
incorporation of PFMEA, Ishikawa and Pareto diagrams in the ceramic manufacture tiles are considered imperative as these could be useful quality tools for improving the quality and the performance of the tiles.

References