Failure Modes Analysis System in Casting Parts by PFMEA Method

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Abstract

Improving the level of quality of products and services provided by companies is the first and main factor of development to get a major market share. In this regard, the failure mode and effects analysis are an effective method to improve the quality and reduce waste in products. To eliminate the existing defects, especially melt run out from the casting molds, the analysis of potential failure modes by multiplication of three numbers
1-intensity2- occurrence and 3- detect probablity was estimated. The results of the study showed that to reduce the melt run out defect, the most important potential for failure is the lack of skills and experience of personnel in assembly, inadequate quality of raw materials, non-compliance with continuous molding process with a risk priority number of 300,400,450, respectively. Continuous training, preparation of a checklist for input items and controlling the molding continuity reduced waste run outs defect by 70%.

Keywords: Failure Effects, Melting Run Out, PFMEA.

1. Introduction

Failure mode and effects analysis (FMEA) is an engineering technique which is widely used to design, identify, classify, analyze potential or known problems and failures in a system, process, or service before it reaches the customer; It provides a framework for analyzing the cause and effect of potential product failures [1]. The purpose of FMEA in a process or product is to prevent the failure before the mass production to identify the potential defects in the process. FMEA reduces the costs by optimizing processes, continual improvement and corrective and preventive action [2]. Efforts to prevent failures during the production and development of products and processes, as well as failures prediction and finding the least costly way to prevent failures are the main goals of using this method. In other words, FMEA is a process failure analysis method that tries to maximize the potential hazards in the area where the production process takes place and scores it based on a specific mechanism [2].

The results of the research conducted by the Fraunhofer Institute in 2011, which surveyed 180 manufacturing companies, show that FMEA is a method which often used in these companies. In this survey, 60.3 percent of the companies use the common FMEA method, and 52.5 percent of the risks are assessed in workshops and team meetings. Also, the methods of Design Review Based on Failure Mode (DRBFM) (9.5 percent) and Failure Tree Analysis (FTA) (7.3 percent) have been used less in risk analysis [4].

In FMEA, the goal is failure mode and analysis of its effects on products and processes during the initial stages of development in the case of potential failure and initiation of measures to prevent failure through integrated risk analysis. As a result, FMEA reduces development time and costs, while the increase in quality will result in the reduction of product defects; Therefore, FMEA is a

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valuable tool for risk management. Common arguments against FMEA are the high costs of implementation, the impact of mental perceptions and the difficult interpretation of the number of risk priority number (RPN), which will not be considered as an absolute level for risk. Also, it is not possible to determine the financial risk based on the priority number of risks; Therefore, the only application of FMEA is a quantitative determination of risk objectives and is not a solution to eliminate the causes of failure; But it allows the systematic and organized collection of explicit and implicit knowledge about the probability of failure. In the framework of FMEA, the risk analysis begins from the partial system stage and a list of ordered failure cases and the effect of those failure cases is analyzed by calculating an index called the RPN. Also, this method has been used in the field of project management, and finally, the use of this method has led to the reduction of project costs [4,5].

In this regard, one of the process defects with high reproducibility was selected and its causes were studied by the above method.

2. Method

Many studies have been done to analyze the modes and effects of failure. According to the FMEA topics, the aim of the research was to analyze the failure modes and effects in the production process which was the melt run out, in different parts of the assembled mold being melted in all cast parts with tonnage above five tons and by static casting method.

The flow of melt from the inside of the mold to the outside, during pouring is defined as the melt run out. According to the variety of molds and the different molding processes and the type of related equipment and assembly tools, different places for melt run out can be predicted. Therefore, in the following, different molding process with different molding methods will be examined in regard of the location of the run out defect (Figure 1).

There is a possibility of melt run out in an ingot mold assembly with quadrangular machined grooves, where the ceramic gating system is embedded inside the grooves, from 5 locations:

A- From below the base plate (A).

B-from the gap between base plate and the ingot mold (B).

C- from the gap of the in ingot mold that is usually one peice (therefore weak probability of run out), (C).

D- Among the ingot mold and cope molding box (D).

E- From the junction of the pouring basin and ceramic gating system(E).

In the sand molds where the main gating system is connected to the mold by means of ceramic tubes, the following items are added to it in addition to the above items:

G- Run out of the melt from the ceramic tube joints (M).

H- Run out of the melt from the ceramic tubes (N).

In permanent molds for roll manufacturing that by assembling one or more round cast iron metal molds on top of each other, there is also the possibility of melt run out from these locations:

H-Among the gaps between assembled metallic molds (P).

I-from gaps between sand molding box and metallic chill molds (R).

In all molds, the entry of melt into the mold space (melt penetration into the mold space) is also called a type of melt run out from the mold, and this possibility is intensified in three areas:

J- under the coreprint (F).

K- From the gap of cope box (G).

L- From the cope box to reinforcing bars (H).

M- melt run out to the core, as a result of transverse cracking of the of core or the presence of volatile substances such as foam inside the core (very low probability).

N- melt run out to gas vents in molding box.

After identifying the most important causes of the defect through the priority risk number, current controls were identified and future actions were presented by team members (Figure 2). The obtained data were analyzed after plotting the graphs (Figure 3).

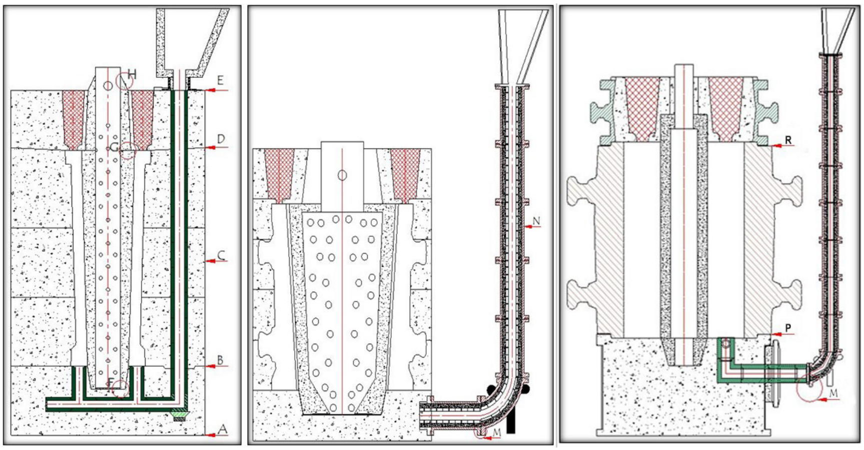

Fig. 1. Most Probably Melt Run Out Positions In Different Molding Processes.

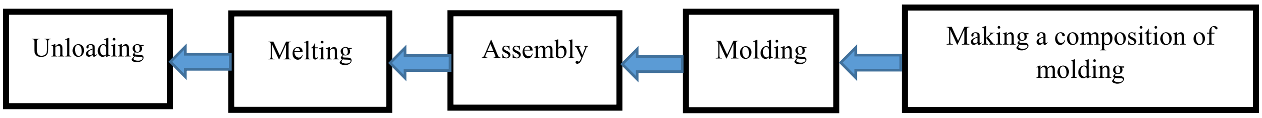

Fig. 2. workflow process form.

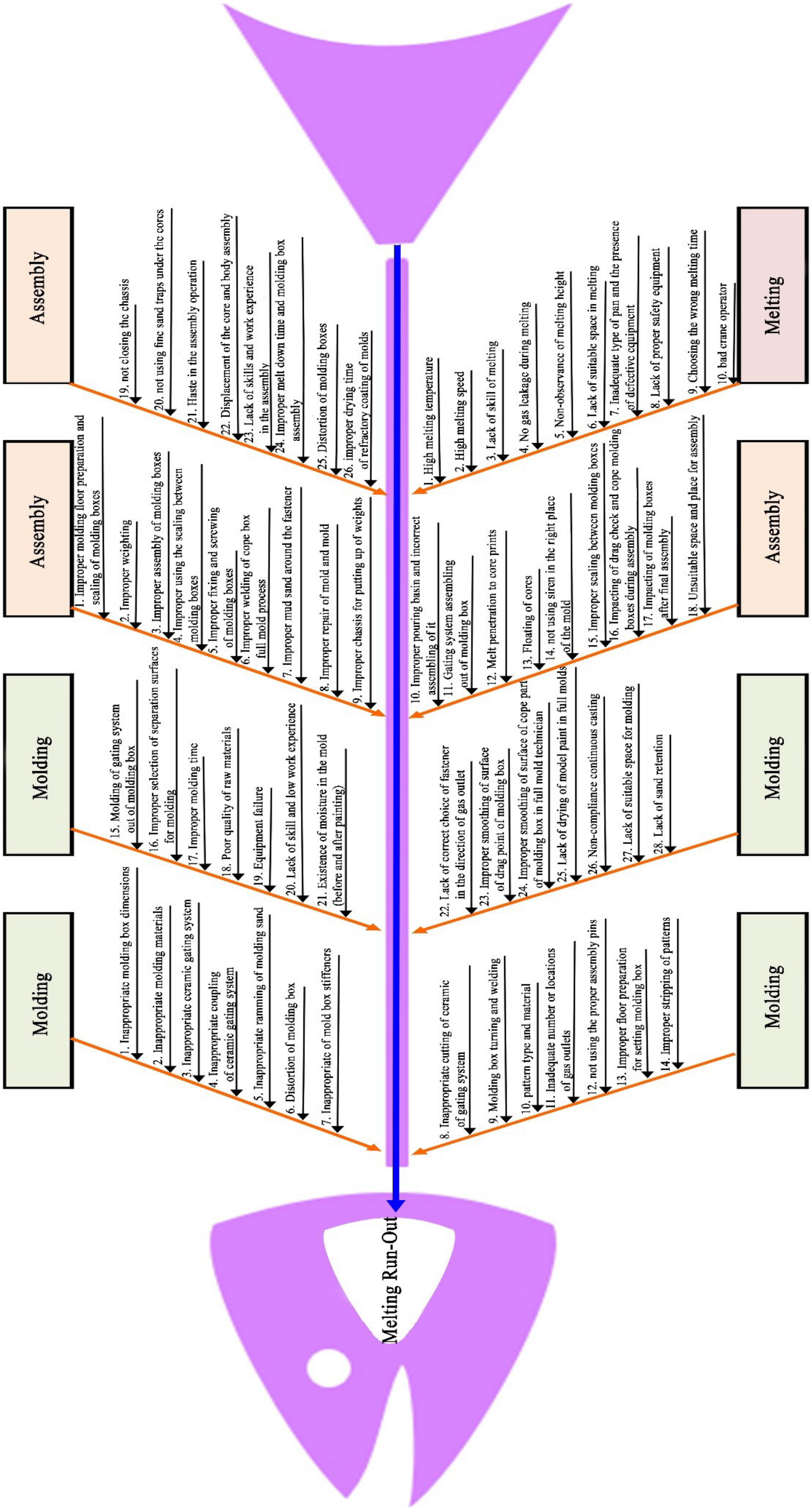

Fig. 3. Fishbone diagram related to melting run-out fault.

The production process in three stages of molding, assembly and melting, were identified and considered to investigate the potential causes of the melting run out process. In the next step, identifying failure modes using customer feedback, defect reports observed in manufactured products, and performing a brain storming to identify potential failure modes were considered and registered in the relevant form. In this method, the evaluation team evaluated three indices of severity (Table 1), the probability of occurrence and the capability to detect for each failure, and then a number between 1 and 10 was assigned to them. The following tables provide qualitative scales on these three common indices. The probability of occurrence also determines the frequency a potential cause or mechanism of danger occurs. It is only by eliminating or reducing the causes or mechanisms of each hazard that can be hoped to reduce the number of events (Table 2). Risk detection probability (detect) is the detection probability of an assessment from the point of capability that identifies a cause or mechanism of occurrence of a hazard; In other words, the possibility of discovering the capability to detect danger before it occurs (Table 3).

Table 1. Form related to the severity of potential failure mode effect.

Ranking / impact factor	Impact on the internal process	Example / Description	Impact on the customer process	Example / Description
1	no effect	fastener difference in size of 3 to 5 cm	no effect	Subsurface defects in areas of the part that are not affecting application of part
2	Like the process goes on by spending time and without much change.	High temperature when casting unbreakable cast iron	The part works and there is no possibility for the customer	Improper structure in some cast iron grades
3	The process continues with minor repairs	Staining while molding	The part works and there is a possibility of fault detection for the customer	Welding repair on non-critical location of casting parts and surface defects
4	A part of the process needs to be reworked	The color of the mold must be repainted	The part works and the defect can be solved by the customer	Blistering or sandblasting in invisible places of parts
5	The part can be sent with major repairs and rework.	Welding the part	The part works with lower efficiency	Low strength
6	The part runs into problem in casting by the melt run-out	small explosion inside mold	The part works with lower efficiency and the customer is dissatisfied	Welding repair of parts
7	The piece is lost in the casting stage	crack after evacuation	The part works with lower efficiency and causes severe customer dissatisfaction	Dislodging of ingot mold inner surface by melt
8	The part is lost without any loss of life	melt run-out or reduction of melt volume inside the mold due to penetration into the mold	The melt runs out from the ingot and the plates and can be remanufactured.	Washing and erosion of ingot mold base or bare plate by melt
9	The part is lost and the equipment is damaged	high melt run-out or high tonnage	The part is lost and causes damage and stops the customer's production line	Ingot mold cracking and melt run-out and destruction of base plate and trumpet
10	The part is lost and there is a loss of life	Mold explosion	The part is lost and causes the customer's production line to stop	Ingot mold breaking during pouring and severely melt run-out

Table 2. Form related to the probability of occurrence of potential failure modes.

Ranking / impact factor	occurrence	
	occurrence	Example / Description
10	Over 50%	Very high occurrence / rejecting of 7 pieces out of 10
9	Over 20%	Very high occurrence / rejecting of 4 pieces out of 10
8	Over 15%	Very high occurrence/ rejecting of 3 pieces out of 10
7	Over 10%	Very high occurrence / rejecting of 2 pieces out of 10
6	Over 7%	moderate occurrence and waste / 1 out of 10 parts
5	Over 5%	Moderate occurrence / rejecting of 4 pieces out of 10
4	Over 3%	Low occurrence / rejecting of 3 pieces out of 10
3	Over 1%	Low occurrence and waste with rework/ rejecting of 2 pieces out of 10
2	Over 0.001%	Low occurrence / rejecting of 1 piece out of 10
1	Less than 0.001%	Rare occurrence with little surface defects, rejecting of 3 pieces out of 10

Table 3. Form related to the possibility of detect of potential failure modes.

Ranking / impact factor	detection	
	occurrence	Example / Description
1	There are definite controls for defect detection.	Loss of the part due to melt run-out
2	It can be detected by visual inspections / (it is detectable)	Loss of the part due to melting run-out
3	It can be detected by visual inspections / (it is detectable)	surface defects as sand burning and surface cracks and fines
4	It can be detected by visual inspections / (it is detectable)	Surface cracks and voids that revealed after grinding
5	It can be detected by visual inspections / (it appears after casting)	Surface shrinkage draws
6	There are special tools for detection / can be detected by testing	Voids in casting parts due chemical analysis fault after determination by remelt
7	Requires special non-routine tests / can be possibly detected	Tensile strength or ultrasonic testing as necessary
8	It is recognizable, but it is not seen in the initial examinations / it appears in the turning phase	Inside voids that revealed after machining
9	Cannot be identified or not checked / will be identified by customer inspections at the post-delivery stage	Subsurface cracks that are identified after machining
10	Unrecognizable / will definitely not be discovered and will be identified during operation	Cracking and failure of ingot mold during pouring

The basis of analysis in FMEA technique is calculating the multiplication of the values of these three indices for each failure mode; In this way the risk priority number (RPN) of the failure mode is obtained. To determine the weight of the considered risks, the severity (S), occurrence (O) and detect or detection (D) have been evaluated. Higher-numbered failures are a priority, and the assessment team must first analyze the higher-priority failures. In the mentioned questionnaire, the colleagues were asked to assign a number from very low to very high for each of the effective cases in melting: intensity, occurrence and detect. The value of RPN for each index is:

$$RPN = S \times O \times D \qquad \text{Eq. (1)}$$

In this relation, RPN = risk priority number, D = detection, O = occurrence and S = severity [1]. There is another new way to classify the severity or risk of failures. This new method, called "Area Chart", is of particular importance for the severity and occurrence [1, 3, 6]. This chart focuses on three areas: high priority area, medium priority area, and low priority area.

Detection is an estimate of the control process capability that is used to diagnose the causes of design failure or the capability to detect faults. Occurrence indicates the probability of any cause of failure being determined. The severity of failure is an estimate of the severity of failure on the process. To number each of these factors, a summary and localization of special tables presented in various sources was used. Ranking is done by group members using the brainstorming method. Usually a number of high-process RPNs are considered to examine the high-risk process [1, 3, 6].

3. Discussion

3.1. Summary, potential modes of failure

The result of the RPN in three stages of molding, assembly and casting is presented in the diagram below to obtain the critical points (Diagram 1).

3.2. Determine the Acceptable Risk

In the method used in this research, the risk criterion number has been used for the acceptable point of risk. Risk criteria is an index for separating acceptable and unacceptable risk. A failure whose RPN number is more than the risk criteria is unacceptable and will be acceptable if it is less than the risk criteria. To determine the risk criteria, a scatter diagram was drawn for each component of the device based on the RPN number and the critical point of that component. According to the diagram, the first point that is placed in critical point 3 is the risk criteria for the process.

3.3. Define the Critical Point

In the ranking of factors, from the number 6 and above, the effect has the probability of occurrence of waste in the state of failure, then this number is chosen as the basis of the criticality of the factors in this research [9,10].

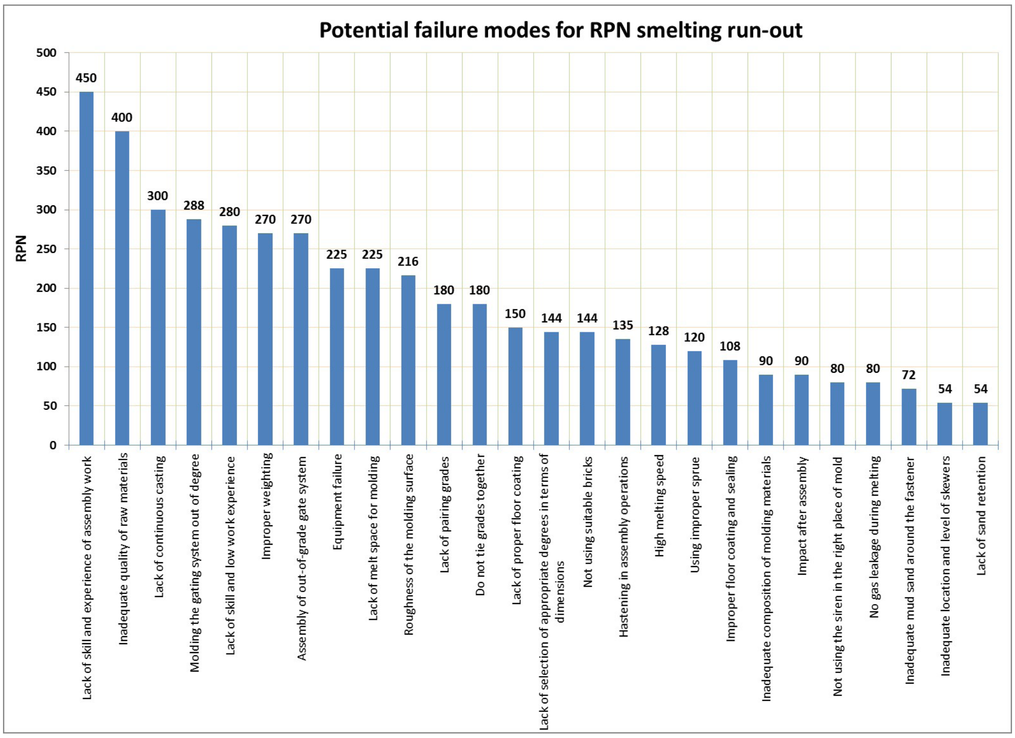

Diagram 1. RPN potential mode of total system failure.

Point 1- Normal point which all three factors of the RPN number have a number less than 6 or the RPN number is low and therefore need for preventive actions is not felt.

Point 2 - The semi-critical point which a maximum of one of the three factors of the RPN number has values higher than 6 but the RPN number is low. In this case, it is necessary to take preventive actions.

Point 3 - Critical point in which at least two of the three factors of the RPN number have values higher than 6. It is clear that this point requires immediate preventive actions (Diagram 2 and Table 4).

Table 4. Analysis of potential failure modes in production processes at the critical point 3.

row	Operation phase	Potential failure mode	Intensity	occurrence	detection	RPN	Critical Points	Needed measure
1	Assembly	Lack of skills and work experience in assembly	9	5	10	450	3	Needs immediate preventive action
2	Molding	Inadequate quality of raw materials / lack of control of input materials	8	5	10	400	3	Needs immediate preventive action
3	Molding	Failure to observe continuous molding	5	6	10	300	3	Needs immediate preventive action
4	Molding	Molding the out of molding box gating system	8	4	9	288	3	Needs immediate preventive action
5	Molding	Lack of records and low work experience	7	5	8	280	3	Needs immediate preventive action
6	Assembly	Improper weighting	9	3	10	270	3	Needs immediate preventive action
7	Assembly	Assembling the out of molding box gating system	9	3	10	270	3	Needs immediate preventive action

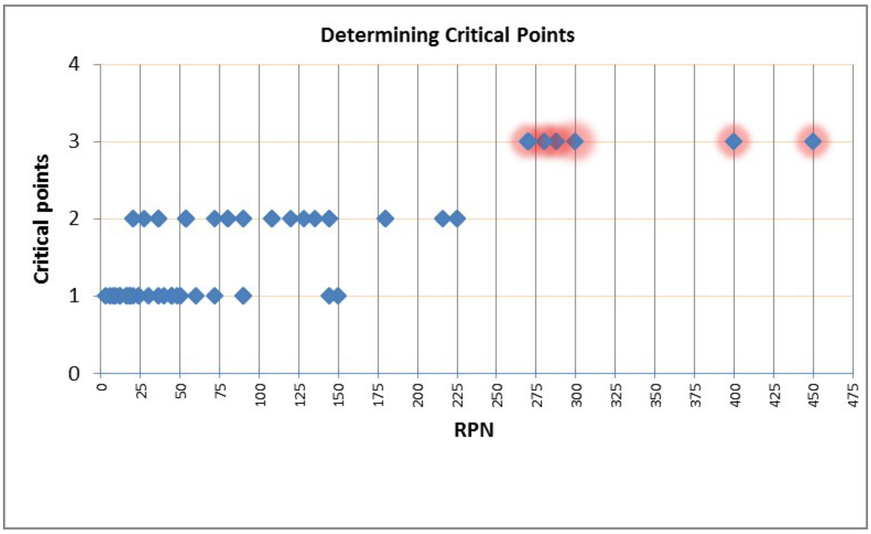

Diagram 2. Determination of critical points.

3.4. Proposed Actions

After prioritizing failure modes based on RPN number, corrective and preventive actions should first focus on priority and critical cases. The intention of any proposed action must be to reduce the number of at least one of the three cases of "occurrence", "severity" and "detection". All the proposed actions in the study were defined for potential failure modes that have a critical point of 3.

3.5. Recommendations

After determining the corrective and preventive actions, the person responsible for its execution and the time required to perform it were also determined. To do this, the following recommendations are presented as corrective and preventive actions.

A- Immediate training for personnel (defects training class for personnel)

B- Performing specialized training at the beginning of employment for semi-skilled technical workers in the production line by the technology unit

C- Using the monitor to monitor the drawings and instructions on a daily basis and with the plan for the production line

D- Examining the gating system designs in different parts that use double-sprue design and revising them to single-sprue gating system design

4. Conclusions

After performing all the initial phases of FMEA, the following results were obtained to reduce the losses in the run-out process in three points of critical (point 3), semi-critical (point 2) and insensitive (point 1):

- The highest RPN is related to lack of skill and experience of personnel in assembly, inadequate quality of raw materials, non-compliance with continuous molding, molding of out-of-box gating system, low staff experience and improper weighting, with RPN number 270, 270,280,288,300,400,450, respectively which also included critical points. For solving this problem we decide to more experienced molding workers and as a result the severity of problem due to this matter considerably reduced.
- According to the obtained results, it was decided that the training of casting defects in the production line for the executive personnel should be in the forefront. By this action and after evaluating the results the run out problem reduced considerably.
- It was also decided to be on the agenda the checklist of input items affecting the direct quality of parts production, and review the quality specifications of the input and, if necessary, adding the technical specifications, as well as provide tools or control methods for input items that have no criteria for entering the line.
- Controlling the mechanized molding machine , placing a continuous technical expert next to the molding system to eliminate possible defects in a timely manner, reviewing the designs made in the appropriate gating system, and using gating systems inside molding box and application of standard weights for the production line were some decisions that were made .At the end by permanent control of an expert on sand mixer working process the problem due to mixer and sand quality that caused run out defect considerably reduced .

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