International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Job Safety Analysis and Elimination of Casting Defects by Application of Design of Experiments

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Abstract: ***This paper studies and analyzes the safety aspects by identifying existing or potential job hazards in the workplace. The project was carried out in a public sector foundry industry. The objective of the project was to eliminate and prevent hazards at workplace and to increase the production and profit of the company by minimising casting defects. Accident history of the company was studied, it was found that burning injury during casting process has the highest rate of disabling injuries and illness and the main reason for the injuries was due to the defects in the mould. Pareto chart and cause effect diagram are effective tools for casting defect analysis. The design of experiments was used to analyze the sand related defects in green sand casting. The green sand related process parameters considered are, moisture content, green compression strength and permeability. For optimization of the process parameters, Taguchi based L9 orthogonal array was used for the experimental purpose and analysis was carried out using Minitab software.***

Keywords: Job safety, Casting defects, Process parameters, Optimization, Taguchi method.

1. Introduction

Job-related injuries and fatalities occur every day in the workplace. One way to prevent workplace injuries is to establish proper job procedures and train all employees in safer and more efficient work methods [1]. Establishing proper job procedures is one of the benefits of conducting a job safety analysis by carefully studying and recording each step of a job, identifying hazards, and determining the best way to perform the job or to reduce or eliminate these hazards [2, 3]. Improved job methods can reduce costs resulting from employee absenteeism and workers compensation [4]. Safety culture is a stable and enduring feature of the organization and is a sub-element of the overall organizational culture [5]. Foundry industries suffer from poor quality and productivity due to involvement of number of process parameters in casting process [6, 7]. Casting defect analysis has been carried out using techniques like Cause effect diagrams, Design of experiments(DoE), and Artificial neural networks [8]. With the help of Pareto diagrams, critical areas are identified. Then Cause effect diagram is applied to explore possible causes of defects [9].The present research is associated with sand casting process which involves various parameters at different levels and affects the casting quality. Considering the features of Taguchi method, it is used to reduce the rejection of product due to sand and moulding related defects by setting the optimum values of the process parameters of the green sand casting [7].

2. Methodology

In this proposed method Data collection of job was done by interviewing, questionnaire, personal observation and participant diary /logs. For casting defect analysis, the defects were identified with Pareto chart and the causes for the defects were identified with Cause effect diagram. Optimization of process parameters was done with Design of Experiments (Taguchi method) to improve the mould quality.

A. Safety analysis

A job safety analysis can be performed for all jobs in the workplace, whether the job task is non-routine or routine. Job safety analysis should be conducted first for jobs with the highest rates of disabling injuries and illnesses. Involve the employee in all phases of the analysis from reviewing the job steps and procedures to discussing potential hazards and recommended solutions. Nearly every job can be broken down into job tasks or steps. In the first part of the job safety analysis, each step of the job was listed in order of occurrence. After recording the job steps, next each step is examined to determine the hazards that exist or that might occur. After listing each hazard or potential hazard and the job is reviewed with the employee performing the job, then the next step is to determine whether the job could be performed in another way to eliminate the hazards or by implementing safety equipments that are needed to control the hazards.

B. Casting defect analysis

Casting defect analysis has been carried out using Pareto chart, Cause effect diagrams and Design of Experiments. The number of casting defects for a certain period of time was collected and the various types of defects were noted. With the help of Pareto chart critical defects were identified and casting defects in sand casting have been prioritized by arranging them in decreasing order of importance. Then cause effect diagram was applied to explore possible causes of defects. After the particular cause has been identified, remedies are suggested to eliminate the defects.

C. Optimization of process parameters of sand casting

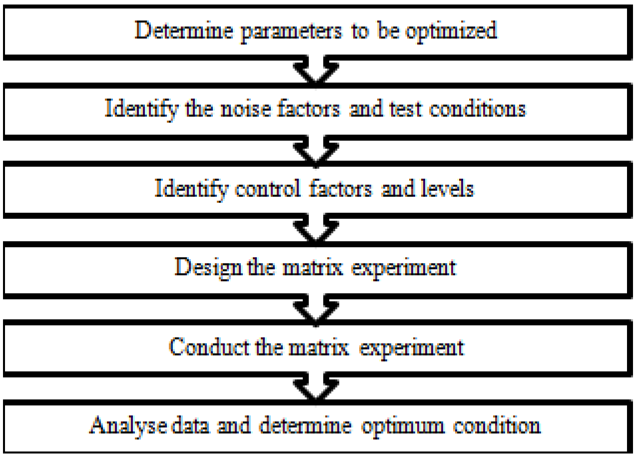
Process optimization is the discipline of adjusting a process so as to optimize some specified set of parameters. In a sand casting process there are many process parameters like green compression strength, moisture content, hardness, permeability, sand particle size, adhesiveness, plasticity and compatibility. Among these parameters the three most critical parameters were selected using Analytical hierarchy process. After identifying the three parameters, the values of each parameter were optimized using thaguchi method. By this the quality of the mould is improved and the percentage of casting rejection due to defected castings is minimized.

1) Prioritisation of Most Critical parameters Using Analytical Hierarchy Process

The analytic hierarchy process (AHP) is a structured technique for organizing and analyzing complex decisions, based on mathematics and psychology. Prioritising these factors to find out the most critical factors which affect the mould quality of the mould required for casting was done in AHP calculator. The comparison between two parameters was done based on the importance scale. After this the priorities of each parameter were obtained based on the resulting weights for the criteria based on the pair wise comparisons.

2) Design of Experiments – Taguchi method

Taguchi method is one of the best options for Design of Experiments when three or more number of process parameters is involved in the process. Taguchi approach is suitable in experimental designs which involves designing and developing of robust products or processes irrespective of variation in process parameter in the process. The present research is associated with sand casting process which involves various parameters at different levels which affects the casting quality. Considering the features of Taguchi method, it was used to reduce the % of defect due to sand and moulding related problems by setting the optimum values of the process parameters of the green sand casting. The steps used to achieve optimized process parameters using DoE were as given below.



3. Data Analysis

After collection of data of the jobs hazards for the past one year using critical incident method, interviewing, questionnaire, personal observation, participant diary / logs, the following observations were correlated.

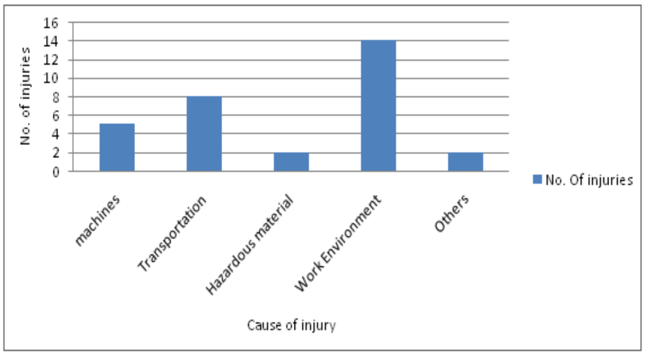


Figure 1: Correlation between cause of injury and no. of injuries.

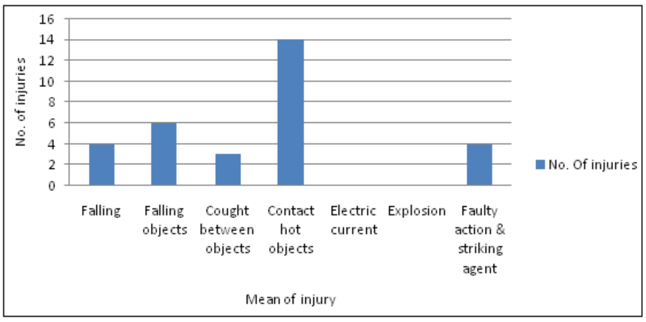


Figure 2: Correlation between no. of injuries and mean of injuries

It was found that job with the highest rates of disabling injuries and illnesses were Metal casting (burning injuries). From the discussion with the employees it was found that casting of flange with smaller diameter (80mm to 150mm), caused most of the accident. The jobs were broken down into three stages: mould making, metal pouring and shake out. Each job were separately analysed and various hazards occurring at the work place were noted. Based on the risk evaluation scale alternative methods were suggested to eliminate hazards at the work place. Table 2 shows the proposed measure to reduce the accidents for each job respectively.

Table 1: Risk evaluation scale

Code	Description
0	No need of improvement
1	Safety measures can be recommended
2	Safety measures is recommended
3	Safety measures is imperative
4	Intolerable; work should not be started or continued until the risk has been reduced

Table 2: Job safety analysis record sheet

Job task / part	Hazards	Comments	Eval	Proposed Measures
1.Metal casting 1.1 Mould making	Falling of objects. Cutting injury.	Improper handle of heavy mould boxes. Mistakes during ramming.	2	Use of lifting equipments with adjustable holding facilities. Use of pneumatic rammer. Lockout procedure. Improve machine guards.

1.2 Metal pouring	Burn injuries. Explosion of mould	Pouring metal without sufficient shoe top protection. Poor mould quality.	3	Use of automatic feeder. Use of proper tools. Improve instructions. Improve quality of mould. Metatarsals, spats.
1.3 Shake out	Respiratory problems Eye injury	Intakes of dust, rising during shake out. Avoidance of mask and goggles by workers.	2	Use of vibratory machines. Mounting fans below floor height for quick settling of dust. Respirators, face shield for shake out workers.

Eval = Evaluation code from table 3.1

Based on the study conducted, the number of defected products based on the type of defect was recorded during a casting day for different casting models in February 2015.

Table 3: Defects and no. of occurrence

Defects	No. of occurrence
Crush	18
Misrun	12
Blowholes	9
Sand inclusion	13
Mould shift	22
Shrinkage	29
Mould breakage	6

Pareto chart

Defective factor table is drawn showing the major defects of casting product and it's mean occurrences and from this result a Pareto chart showing critical effects of major defects in percentage and its causes in decreasing order is plotted and the cumulative percentage for defects and causes of defects are identified.

Table 4: Defective factor table

Types of defects	No. of occurrence	Cumulative No.	Cumulative percentage
Shrinkage	29	29	26.6
Mould shift	22	51	46.78
Crush	18	69	63.3
Sand inclusion	13	82	75.28
Misrun	12	94	86.23
Blowholes	9	103	94.49
Mould breakage	6	109	100

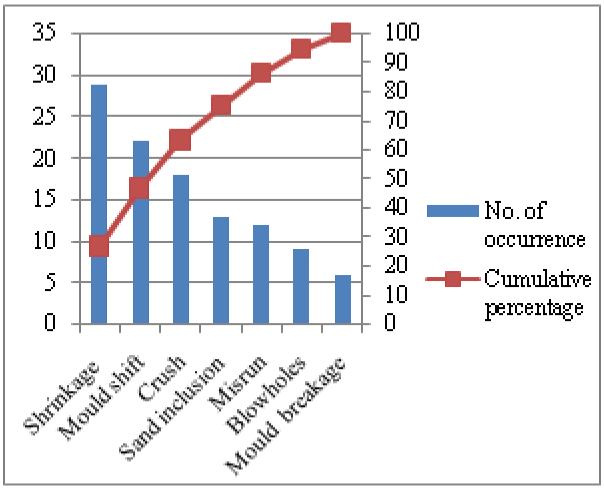


Figure 3: Pareto chart for casting defects

Cause effect diagram

Cause effect diagram is one of the best approaches to enumerate the possible causes. After identifying particular causes of casting defects, remedies are suggested to eliminate the defects. The cause effect diagrams of two most significant defects are shown below.

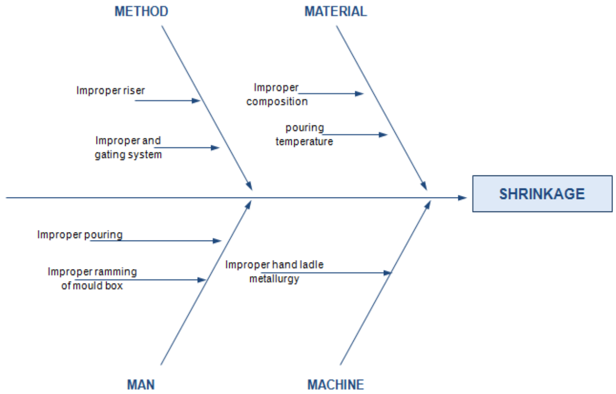


Figure 4: Cause effect diagram for shrinkage

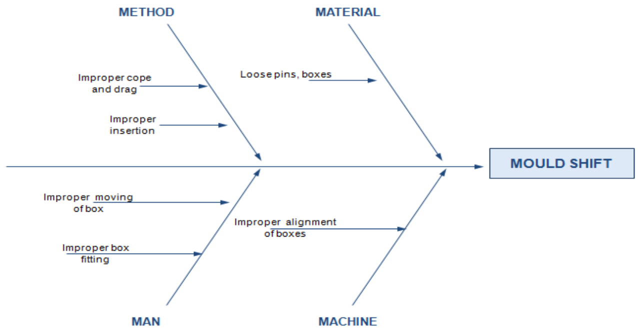


Figure 5: Cause effect diagram for mould shift

A. *Optimization of process parameters*

Process optimization is done to optimize some specified set of parameters in a process to minimize cost, improve quality in the production. In the sand casting process optimization of process parameters is done to minimize the casting defect by improving the quality of the mould, thereby reducing the accidents caused due to mould defects. From a list of process parameters involved in casting process, three most critical parameters were selected using AHP calculator. And the optimizations of these parameters were done using thaguchi method.

1) *Prioritisation of Most Critical Factors Using Analytical Hierarchy Process*

In the AHP calculator these process parameters were given and the importance between two parameters considered at a time and the value of importance of one parameter to the other was given based on the importance scale. Based on the pair wise comparison of each parameter resulting weights are calculated from the values obtained from decision matrix. Thus priority and rank of each parameter was obtained. The different parameters considered are: green compression strength, moisture content, hardness, permeability, sand particle size, adhesiveness, plasticity and compatibility. The resulting weights are based on the principal eigenvector of the decision matrix. Figure 6 shows the decision matrix after pair wise comparison of parameters.

Principal Eigen value = 8.884
Eigenvector solution: 7 iterations, delta = 1.2E-8

	1	2	3	4	5	6	7	8
1	1	1.00	2.00	3.00	6.00	7.00	9.00	8.00
2	1.00	1	2.00	3.00	2.00	6.00	8.00	9.00
3	0.50	0.50	1	3.00	4.00	5.00	6.00	5.00
4	0.33	0.33	0.33	1	4.00	9.00	8.00	8.00
5	0.17	0.50	0.25	0.25	1	1.00	2.00	1.00
6	0.14	0.17	0.20	0.11	1.00	1	6.00	4.00
7	0.11	0.12	0.17	0.12	0.50	0.17	1	1.00
8	0.12	0.11	0.20	0.12	1.00	0.25	1.00	1

Figure 6: Decision matrix

Figure 7 shows the priorities and rank of each parameter. These are the resulting weights for the criteria based on the pair wise comparisons.

Number of comparisons = 28
Consistency ratio CR = 9.0%

Category		Priority	Rank
1	green compression strength	27.0%	1
2	moisture content	24.3%	2
3	permeability	18.2%	3
4	hardness	16.0%	4
5	particle size	4.7%	6
6	adhesivenes	5.2%	5
7	plasticity	2.1%	8
8	compactibility	2.5%	7

Figure 7: Prioritised parameters

2) Optimization using Thaguchi method

The green sand related process parameters considered were, moisture content, green strength and permeability. For optimization of the process parameters, Taguchi based L9 orthogonal array was used for the experimental purpose and was done using Minitab software. Table 5 shows the L9 orthogonal array and Table 6 shows different levels taken from within the range of each parameter.

Table 5: L9 Orthogonal array

Trail No.	A	B	C
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Table 6: Different levels of parameters

Process parameters	Range	Level 1	Level 2	Level 3
Moisture content (%)	2.8 – 5	3.2	3.8	4.2
Green strength (KN/m²)	70 -120	75	85	110
Permeability	60 – 90	65	70	80

The optimized experimental setup, where the response factor percentage defect is minimum was identified. To analyze the results, the Thaguchi method uses a statistical measure of performance called signal to noise ratio (S/N Ratio). The S/N ratio values of the percentage defect are calculated using the smaller the better characteristics. Table 7 shows the percentage defect in casting and S/N ratio of different trails of experiment conducted.

Fn. to be maximized**:** S/N Ratio: Smaller is the Better;
S/N Ratio = $-10*\log(\sum Y^2/n)$.

Table 7: Experimental orthogonal array with S/N Ratio for % defect

Trail No.	Moisture (%)	Green strength (KN/m^2)	Permeability	% Defect	S/N Ratio
1	3.2	75	68	8.00	-18.0618
2	3.2	85	70	6.50	-16.2583
3	3.2	110	80	6.66	-16.4695
4	3.8	75	70	6.00	-15.5630
5	3.8	85	80	5.33	-14.5630
6	3.8	110	65	6.00	-15.5630
7	4.2	75	80	8.88	-18.9683
8	4.2	85	65	6.15	-15.7775
9	4.2	110	70	6.00	-15.5630

Table 8: Response table for S/N Ratios

Level	Moisture	Green strength	Permeability
1	-16.93	-17.53	-16.47
2	-15.22	-15.52	-15.79
3	-16.77	-15.87	-16.66
Delta	1.71	2.01	0.86
Rank	2	1	3

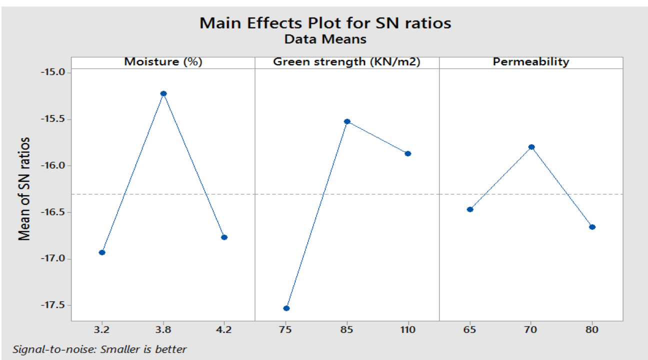


Figure 8: Main effect plot for S/N ratios

The AOM plot in figure 8 shows that the percentage defect is minimum at level 1 for moisture content and green strength and level 3 for permeability.

4. Conclusion

Job safety analysis was used to do safety analysis at the work place. The list of job tasks and the record of the analysis are used to produce an improved set of job instructions and safety measures to reduce hazards at workplace. From the job safety analysis it was found that molten metal burns occur mainly due to poor mould quality and ignoring safety regulations. These accidents could be largely reduced by improving the mould quality and proper practice of job at the workplace by following the job instructions. After the analysis it was recommended to implement automatic feeders with adjustable speed controller for molten metal pouring. Vibrating machine with fan mounted at the bottom for quick settlement of dusts to the ground was also suggested at the shakeout section.

Casting defect analysis was done using Pareto chart and cause effective diagram by identifying and evaluating different defects and its causes, responsible for rejection of casting products. So finally it was found that the manual metal casting operations are done with some negligence and carelessness. So by suggesting some other remedial issues and by implementing them reduces total rejection in casting. This study proves that by means of effective analysis of tools and processes, it is possible to control the casting defects.

The optimized levels of selected process parameters obtained by Taguchi method are: moisture content (level 1): 4.7 %, green compression strength (level 1):75 KN/m², permeability number (level 3): 80. Design of experiments method such as Taguchi method can be efficiently applied for deciding the optimum levels of process parameters to have minimum rejection due to defects in casting.

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