Metal Penetration and its Resolution: Ranking of Qualitative Factors in Automatic Flaskless Green Sand Casting Process Using Analytic Hierarchical Process

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Abstract

Defects in casting often lead to rejection, which would ultimately results in loss of productivity for a foundry. In order to ensure the required quality level, the foundry has to implement a continuous quality enhancement strategy to produce defect free casting. This paper proposes a strategy to prioritize the qualitative factors which are responsible for random occurrence of metal penetration in an automatic flaskless molding casting process using Analytic Hierarchical Process (AHP). An AHP structure is formed with criteria severity, occurrence and detection as in an FMEA framework. The alternatives are four areas of the foundry i.e. moulding sand, mold, operator and environment. Various causes for metal penetration are placed as sub-alternatives under these alternatives. After AHP analysis the critical causes of metal penetration were found and suggestions were made so as to reduce the probability of occurrence of the defect.

Keywords

Analytic Hierarchical Process (AHP), Flaskless Moulding, Metal Penetration.

I. Introduction

Automatic flaskless molding production line is used for fast manufacturing of sand molds for casting of sand. This method is used to mass manufacture of metal castings for the automotive and machine industry. Today molding lines can achieve a molding rate of 500 sand molds per hour.

The process consists of a molding machine and mold carrying conveyor. A sand molding mixture, commonly green sand, is blown into a rectangular steel chamber using compressed air. The molded sand is squeezed then before two shapes, which are with the 2 ends of the chamber and squeezing, one of them one chamber plates swings open and the opposite plate pushes the finished mold on the conveyor. Now, any of the cores are automatically fixed into the mold cavity while the next mold is being prepared. The cycle repeats until a chain of finished molds butt up to each other on the conveyor. The molds are then filled with molten metal and placed on the cooling conveyor, that moved at the same pace as the conveyor of fabrication. At the end of the conveyor the solidified castings are separated from the molds and further processed, while the sand is directed to the sand preparation plant for reconditioning and reuse in the molding process of the next cycles. [1-7]

Metal penetration is described as any kind of burnt on the surface of casting, where the molten metal for one reason or another forces into the sand grain structure of the casting mould interface Figure 1 show a typical penetration defects caused by excessive moisture content in the moulding sand, resulting in violent vapour development in hot corner of the casting .The vapour bubble from the sand next to the hot casting were pressed into the molten metal forcing equivalent metal portion to penetrate the spaces between the sand grains resulting in rough surface of the casting.[8,9]

Possible cause of metal penetration

- Excessive pouring temperature
- Excessive pouring rate
- Ingate located to close to critical area of casting cavity
- Too short pouring time
- Excessive moisture content

- Poor sand compaction
- Excessive content of inactive fines makes mould surface too weak
- Insufficient content of inactive fines makes sand surface to open
- Too course moulding or core sand
- Insufficient inactive bentonite content makes the mould cavity surface too weak
- Insufficient fresh sand addition does not suppress the inactive fines sufficiently, thus demanding a higher moisture content Too hot moulding sand has deteriorated strength properties

Figure 1: Metal Penetration [8]

Although in well controlled automatic molding line casting process the level of defective casting is very low still casting with metal penetration is produced in dominance, this may be accounted for the random qualitative factor related to moulding sand, mould, operator and environment.

2. Literature Review

T.A. Selvan et al. [10] proposed a strategy to finalize the mould design of a specific cast component through the failure analysis using case study data of a foundry. This research paper used an alternate of failure mode and effect analysis (FMEA) approach named FEAROM (Failure Effects and Resolution of Modes) to prioritizing the possible failure modes Analytical Hierarchy Process (AHP) is used for validating the results obtained.

Arun Mathews Varikatt et al. [11] presented a paper which deals with the collection of defect data from an Aluminium extrusion capability, analyze the data so as to locate the major defect and find the dangerous causes for each of these major defects. The causes of these defects were analyzed and ranked by fuzzy data envelopment Analytical Hierarchy Process (FDEAHP). Two causes each with the highest Final Weight (FW) of each problem were selected for improvement and appropriate suggestions were made. Dabo B. Hammad et al [12] critically analyze maintenance need of specific structures using Analytic Hierarchy Process (AHP), S. Z. Qamaet al. [13] analyze product defects in a typical Aluminum extrusion facility using AHP. Shirland, L.E. et al. [14] presented a paper titled "Prioritizing Customer Requirements Using Goal Programming. R. G. Chougule, B. Ravi [15] proposed a variant process planning of castings using AHP-based nearest neighbour algorithm for case retrieval. D. Benny Karunakar [16] *et al* used back propagation neural networks *for p*revention of defects in castings.

3. Methodology

The analytical hierarchy process (AHP) was first proposed by Saaty [17]. It is a widely used decision-making analysis tool to deal with complicated, unstructured decision troubles, particularly in situations where there are important qualitative aspects that must be considered, in con-junction with various measurable quantitative factors based on hierarchical structures and the decision of choice maker. It has unique advantages when important elements of the decision are difficult to quantify or com-pare, or where communication among team members is impeded by their different specializations, terminologies or perspectives. It has successfully been applied to many decision situations in areas such as selection, estimate, preparation and progress, conclusion making and forecasting.

In general, the AHP concept for decision making requires four steps.

- In the first step, the hierarchy structure of decision must be constructed. The first layer of the hierarchy structure is the main objective of the problem. The second is decision criteria. Sometimes, when the problem is complex, criteria can be divided further into sub-criteria and sub-sub-criteria and so on. The last layer is the substitute, which have to be chosen.

- In the second step, the decision-maker(s) must build the judgment matrix by having pair-wise comparison criteria and alternatives in each criterion, based on discrete scales 1-9 Each scale a_{ij} of scale of the judgment matrix are the three rules: $a_{ij} > 0$, $a_{ij} = 1/a_{ji}$, and $a_{ii} = 1$ for all i.

- In the third step, the local weights (LW) of each judgment matrix are calculated. Based on Saaty, the eigen-vector method (EVM) is used to yield priorities for criteria and for alternative criteria.

- The last step is to synthesize the priorities of the alternative criteria into composite measures to arrive at a set of ratings for the alternatives or final weights (FW), based on the hierarchical arithmetic aggregation.

Table-1: AHP Scale of importance for paired comparison

Importance	Numeric Rating
Equal Importance	1
Moderate Importance	3
Strong Importance	5
Very strong Importance	7
Extreme Importance	9
Intermediate importance	2,4,6,8

3.1. Use of statistical data to choose critical defect

Statistical methods are used to find the critical defects occurring in the casting process. The inspection data recorded by the company was used for this purpose. Although in well controlled process the level of defective casting is very low still casting with metal penetration is produced in dominance.

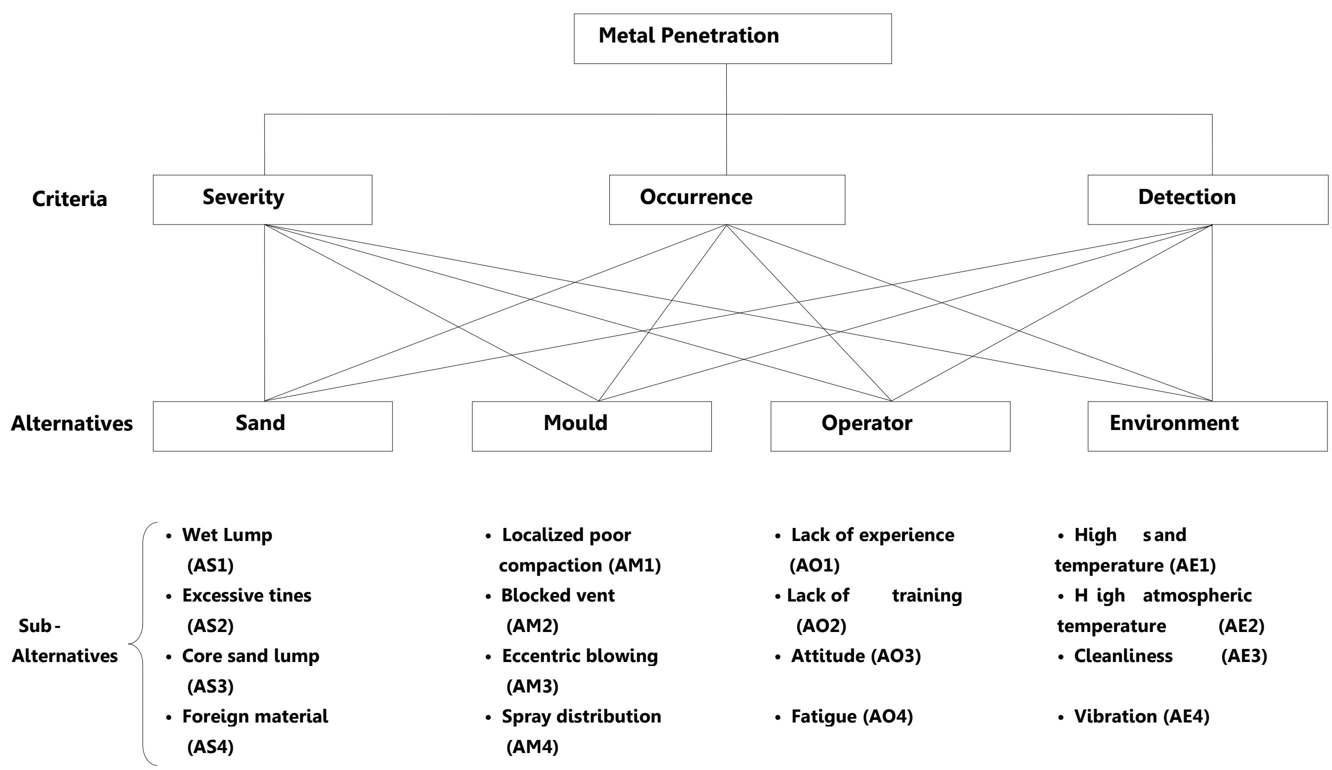
3.2. Finding the cause by using cause and effect diagram

From literature review and critical assessment of the process occurrence of metal penetration in casting in random manner may be accounted for the transient qualitative factor related to moulding sand, mould, operator and environment. Important factor which could be responsible for causing metal penetration under this four alternatives areas are listed in Table-2.

Table-2. Possible qualitative factor causing metal penetration

Mouding sand	Mould	Operator	Environment
• Wet lump (AS1) • Excessive fines (AS2) • Core sand lump (AS3) • Foreign material (AS4)	• Localized poor compaction ((AM1) • Blocked vent (AM2) • Eccentric blowing (AM3) • Spray Distribution (AM4)	• Lack of experience (AO1) • Lack of training (AO2) • Attitude(AO3) • Fatigue (AO4)	• High sand temperatur e (AE1) • High atmospheri c temperatur e (AE2) • Cleanliness (AE3) • Vibration (AO4)

3.5. Model for qualitative random causes of Metal Penetration using Analytic Hierarchical Process (AHP)



3.6. Ranking of criteria

Step1. Pair wise comparison matrix for criteria

	Sev	Occ.	Det.
Sev.	1.0000	3.0000	5.0000
Occ.	0.3333	1.0000	3.0000
Det.	0.2000	0.3333	1.0000

Step 2. Deriving eigen vector and maximizing the eigen value the weight of various criteria are as follow

Severity	0.6397
Occurrence	0.2573
Detection	0.1030

Step 3. Check for consistency

$\lambda_{\max}$ = 3.0385

Consistency index = $\frac{\lambda_{\max} - n}{n-1}$ = 0.0193

Consistency ratio =

$$\frac{Consistency\ index}{Index\ of\ Consistency\ of\ random\ judgement}$$

CR =0.0193 / 0.58 = 0.0332

Because CR value is less than 10% the present work is consistent.ss

3.7. Ranking the alternatives

Ranking of alternatives for the four areas of the casting process are calculated in similar way considering severity, occurrence and detection as criteria and the following LW were obtained

Alternatives	Severity	Occurrence	Detection
Sand	0.2641	0.6216	0.2500
Mould	0.6247	0.2372	0.2500
Operator	0.0784	0.1031	0.2500
Env.	0.0328	0.0381	0.2500

3.8. Ranking of sub-alternatives

Ranking of sub-alternatives of each alternatives i.e. moulding sand, mould, operator and environment are calculated considering severity, occurrence and detection as criteria separately and the following LW were obtained

sub-alternatives of moulding sand	Severity	Occurrence	Detection
Wet lump	0.6817	0.5377	0.2500
Excessive fines	0.1599	0.1313	0.2500
Core sand lump	0.0545	0.2713	0.2500
Foreign material	0.1038	0.0597	0.2500

Sub-alternatives of mould	Severity	Occurrence	Detection
Localized poor compaction	0.6601	0.5449	0.2500
Blocked vent	0.2308	0.3192	0.2500
Eccentric blowing	0.0702	0.0446	0.2500
Spray distribution	0.0389	0.0913	0.2500

sub-alternatives of operator	Severity	Occurrence	Detection
Lack of experience	0.5598	0.2500	0.2500
Lack of training	0.0980	0.2500	0.2500
Attitude	0.3079	0.2500	0.2500
fatigue	0.0344	0.2500	0.2500

sub-alternatives of environment	Severity	Occurrence	Detection
High sand temperature	0.5391	0.3637	0.2548
High atmospheric temperature	0.1100	0.0708	0.5936
Cleanliness	0.3009	0.4021	0.1027
Vibration	0.0500	0.1634	0.0490

3.9. Final Weight (FW) of Sub-alternatives (Causes of metal penetration)

	Severity	Occurrence	Detection		Criteria		Overall weight
AS1	0.1800	0.3342	0.0625	x	0.6369	=	0.2076
AS2	0.0422	0.0816	0.0625		0.2583		0.0545
AS3	0.0144	0.1686	0.0625		0.1048		0.0593
AS4	0.0274	0.0371	0.0625				0.0336
AM1	0.4123	0.1293	0.0625				0.3026

AM2	0.1442	0.0757	0.0625				0.1179
AM3	0.0438	0.0106	0.0625				0.0372
AM4	0.0243	0.0217	0.0625				0.0276
AO1	0.0439	0.0258	0.0625				0.0412
AO2	0.0077	0.0258	0.0625				0.0181
AO3	0.0241	0.0258	0.0625				0.0286
AO4	0.0027	0.0258	0.0625				0.0149
AE1	0.0181	0.0139	0.0637				0.0218
AE2	0.0032	0.0027	0.1484				0.0183
AE3	0.0102	0.0153	0.0257				0.0132
AE4	0.0013	0.0062	0.0122				0.0037

4. Result and Discussion

On the basis of final weight of various sub-alternatives the following ranking is obtained for the causes of metal penetration

Ranking	Possible cause of metal penetration
1	Localized poor compaction
2	Wet lump
3	Blocked vents
4	Core sand lump
5	Excessive fines
6	Experience
7	Eccentric blowing
8	Foreign Material
9	Negative attitude
10	Spray distribution
11	High sand temperature
12	High atmospheric temperature
13	Lack of training
14	Fatigue
15	Cleanliness
16	Vibration

The Three main causes of metal penetration are localized poor compaction, wet lump in moulding sand and blocked vents. Based on the analysis following recommendations were made to process control team.

Localized poor compaction may occur in some part of mould due to uneven mould hardness distribution. Sand shot pressure, squeeze pressure and compressibility of mould should monitor and controlled. Wet lump may occur due to poor mixing of moulding sand in sand muller or water level toward higher side of specification. Personnel responsible for operation of sand plant must establish a moulding sand checking routine. To avoid vacuum formation in the deep pattern during lift-off and to ensure proper air evacuation during sand blow operation air vents are mounted in the bottom of deep patterns. Air vent can only function as intended if they are not blocked. Therefore they must clean regularly.

5. Conclusion

The main objective of the paper was to identify and rank the random factor causing metal penetration in automatic flaskless molding casting process. After AHP analysis the critical causes of metal penetration were found and suggestions were made so as to reduce the probability of occurrence of the defect.

The AHP method is very simple and straight forward and can be used for making multi-criteria decision quickly.

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