To Investigate Significant Process parameters Causing Major Casting Defects of Green Sand Casting Process

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Abstract: Green sand casting process is near net shape process capabilities has greater possible to achieve quality characteristics in casting products. Present competitive market demands the defect free products with lowest possible prize and prompt delivery. Casting process involves the large number of parameters of sub process and typical working environment due to which foundrymen faced the problem of high level rejection of casting components. Hence objective of the study is to identify, optimize process parameters to achieve better results of automobile component made by cast iron and investigate significant parameters to make casting process more robust. Defective castings have analyzed to identify major casting defects such as shrinkage, blow holes and shrinkage by using parato diagram. Castings rejected due to major casting defects have characterized to determine process parameters responsible causing major defects. The process parameters considered are green compressive strength, permeability, loss on ignition, carbon equivalent, volatile data in return sand, pouring temperature, A.F.S .number, mould hardness, return sand temperature, active clay, dead clay, moisture content and compatibility at two different levels and experiments were conducted using L_{16} orthogonal array as per the taguchi method. Thus multi objective process parameter optimization is performed using grey relation analysis to to reduce rejection levels of major casting defects. Analysis of variance was done for robust design parameter values.

***Index Terms* – Casting defects, taguchi method, grey relation analysis, green sand casting process, parato diagram**

I. INTRODUCTION

Metal casting is more than 6000 years swain manufacturing process in which molten metal from furnace is poured in a prepared mold and removed after solidification. In real practice, any metal or alloy that can be cast and reused. Most common ferrous metals include grey iron, ductile iron, malleable iron and steel. Alloys of iron and steel (alloy content over 4%) are used for high performance applications such as temperature, wear and corrosion resistance . The most common non-ferrous metals include aluminium copper, zinc and magnesium based alloys. Indian casting industry with an annual production of 7.5 MT is the second largest casting producers in the world after China. With an approximated count of 4500 SME foundries and accounting for employing nearly 1 million people, the process is still considered as an art in itself to produce defect free and sound casting with higher production rate. The production of successful castings of decided shape is deeply dependent on the control of step of process, skill and experience of foundry persons. (Ravi,2010).

Even from start of the production, foundries producing cast iron components have been working on mechanism of defects. Also, Foundry engineers and researchers have been made attempt to understanding the behavior of defects and parameters causing defects to control rejection level. It has been observed that due involvement of large number of parameters linked with casting sub process such as pattern making, core setting, molding, melting, pouring, fettling and shot basting. Generally foundry men have been using trail and error based on experience to control level of rejection. Remarkable amount of productivity lost loss due production of defective castings. Now, foundries increase required to pay machining expenses for scrapped castings. To overcome difficulties and control rejection level at considerable level use of more systematic approach to indentify significant parameters causing major casting defects.

Up till now, parato diagram and statistical analysis used to found major defects. Cause and effect diagram used find possible causes of defects and questioning to focus the root cause. They found parameters responsible related to root cause and design of experiment to control the parameters explored. Majority of research have been done to control individual defect.

II. LITERATURE REVIEW

Though some contributions have been made earlier by previous researchers for identifying and controlling parameters remains a challenge for the foundyman. Casting defect analysis need considerable domain knowledge and past experience, coupled with in-depth scientific analysis due to involvement of large number of parameters and interactions in casting process.(Ransing et al., 1995).They have provided an intelligent computer aided defect analysis (ICADA) system based on artificial intelligent technique. They were explained interconnection defects, metacauses and root causes by three tier structured graph for sand erosion defect.
(Ulewicz and Kruzel, 2002) have applied the Pareto diagram and fishbone diagram quality tools to analyze casting defects and

used them to identify the causes of defects in malleable sand castings. (Chandrmohan P. et al,2003) have discussed rejection control for core related defects, blow holes, pin holes and sand drop defects in foundry. These authors were considered the contribution of row materials, manpower, energy and number of other factors was to control rejection. (Martins Luiz and Kannan Sudesh,2003) have presented comprehensive process to reducing inclusion related defects in aluminium casting. These authors were explained traditional trial and error method to finding the source of defect and steps to reduce inclusion defect.(Sienkanski K.and Borkowski S.2003)have shown some simple techniques like ishikawa diagram and perato lorenza diagram which can be used in identification of main way of defects in production of casting for heavy industry. These authors were proved the basic influence on castings quality have material factors, accepted technologies and human factors.(Chokkalingam B.et al 2006) developed defect solving techniques for correct identification of sources of sand drop defect. (Perzyk,2007) demonstrated the application of Pareto diagram in an industrial sand casting foundry and found that sand inclusion and gas holes caused 72% of rejections. (Verran G.O.et al 2008) have presented application of design of experiment for optimization of injection parameters of die casting process.(Senthikumar B .et al 2009) have optimized process parameters such as pouring temperature, carbon equivalent and gating system to control pull down defect. (Das Prasum 2009) have focused on sub processes of casting like mould making, sand preparation and metal preparation to determine performance level based on statistical process control.(Haq Nooral A. et al 2009) optimized set of process parameters such as weight of CO_2 gas, mould hardness number, sand particle size, percentage of sodium silicate, sand mixing time,pouring time, pouring height, pouring temperature and colling time for CO_2 casting process. (Chokklingam B.and Mohamad Naziruddin S.S. 2009)have made a case study to find root cause of a major defect mould crush in an automobile casting produced in a medium scale foundry. (Paknikar S. K. 2010) has identified defects correctly with the help of microscopic and/or macroscopic examination and to identify causes correctly and then appropriate remedial measures were taken to eliminate defect completely or reduce its level. (Kumar Shuhil 2011) optimized process parameters of green sand casting process to reduce rejection level by using taguchi method. The process parameters were considered were green strength, moisture content, pouring temperature, mold hardness vertical and horizontal .They have analyzed effect of parameters ,interaction of parameters by using signal to noise (S/N) ratio and analysis of variance (Borowiecki, et al., 2011) employed Pareto diagram to analyze the defects in grey iron sand castings . They have identified that major rejected castings due to sand holes, misrun, shrinkage, and slag inclusion defects and found improper design of gating system was the major cause. (Kumararavadivel A. and Natarajan U.2012) developed a process window approach (PWA) tool to optimize sand casting process parameters. Selected process parameters were moisture content, permeability ,loss of ignition, compressive strength, volatile content, vent hole, pouring temperature, pouring time and mold pressure. (Chourase Chandrakishor and Mahajan M.D.2014) performed experiments by considering pouring temperature and gating system parameters and measured percentage of approval castings. (Weldeanenia Kidu Geberecherkos and Abebe Asmamaw Tegegne, 2014) have optimized parameters of sand casting process taguchi based L_9 orthogonal array. They have selected parameters such as pouring temperature, runner size and pouring temperature at three levels to perform experimentation. (Joshi and Kadam, 2014) demonstrated the application of Pareto diagram and cause-effect diagram to improve the quality and productivity in an industrial sand casting foundry. They collected the data related to buckling, crush, coldshut, flash, mold shift, shrinkage, and poor surface finish, and found that flash accounted for the maximum rejections. (Juriani Avinash 2015) has analyzed critical casting defects raised in centrifugal casting and listed remedial measures with the help of industrial case studies. In his research, he has studied casting having well-known defect such as lamination, lumps. (Chokkalingam et al 2017) have investigated shrinkage defect in casting by quantitative ishkawa diagram with quantitative value of each cause. Also few investigators predict casting defects before pouring by use of artificial neural network (Zhang et al2009, Singaram 2010) and simulation (Ravi,2008,Kotas,2012,)

The above mentioned researchers have contributed significantly to find parameters responsible for individual defect and optimized parameter values to reduce individual defect. This is not sufficient for controlling overall rejection. This paper focuses on the determination of significant parameters responsible for casting defects such as shrinkage, blow holes and sand inclusion. In the present investigation the prime focus is on characterizations of major casting defects developed in cast iron automobile component made by green sand casting and contribution of each parameter towards major defects.

Initial step, Applied a systematic approach for categorization of sand casting defects in terms of their type, detection stage, size, shape, appearance, location, consistency and severity of occurrence. Second step, identified design, process and material related parameters causing major defects such as shrinkage, blow holes and sand inclusion. Third step , analyzed critical process parameters is carried out by taguchi and grey relation analysis. Finally, determined significant parameters responsible for casting defects such as shrinkage, blow holes and sand inclusion.

III.CATEGORIZATION OF SAND CASTING DEFECTS AND IDENTIFICATION OF PARAMETERS

It is important to correctly recognize the defect symptoms prior to assigning the cause to the problem. False remedies not only be unsuccessful to solve the problem, they can possible more confused issues like creating other defects and make it more difficult to cure the defect. So, the proper characterization a particular defect is the basic need to correct and control the rejection level of castings. The nature of casting defects can be determined by properly characterizing the shape, appearance, location and size of defects. Once casting defects are properly characterized the possible causes can be recognized and the corrective action can be taken. Then a controlled and entire defect analysis can be done.

A broad and logical approach suitable for categorization of sand casting defects is proposed here. All major defects encountered in sand casting, such as shrinkage, blow holes and sand inclusions. After characterization of each defect, identify design, material and process parameters causing specific defect. Major casting occurred defects identified FG 300 cast iron grade automobile component produced by green sand casting with the help of pareto diagram shown in figure 1. The categorization and parameters causing major casting defects shrinkage, blow holes and sand inclusions. shown in figure 2 ,3 and 4 respectively.

IV. TAGUCHI METHOD AND GREY RELATION ANALYSIS

4.1 Taguchi Method Taguchi method involves reducing the deviation in the process through robust design of experiments and to achieve high quality product at low cost (Ross,2005). The shop floor was busting with actions at a frantic pace in the midst of sand ,dust, fumes and high temperature which is common scenario of a foundry (Roy,2003). Casting process involved large number of parameters .At this situations, Taguchi method is more useful to attain the optimal process parameter setting with minimum number of experiment conduction. In the present work, taguchi method has been used to accomplish the following objectives:

1. To find the optimal process parameter setting for each response
2. To estimate the percent contribution of each individual factor and
3. Improve productivity of casting products produced and increase stability of casting process.

Process parameters were considered in the present study to analyze major casting defects . Signal to noise (S/N) ratio is a quality indicator term used in taguchi parametric design helps the experimenters and designers to evaluate the effect of change in design parameter on the outcome of the process (Ozcelik and Erzurumlu ,2006). S/N ratio of each experimental run is calculated for each defect using equations 4.1

$$\frac{S}{N}\ Casting\ Defects = -10\ Log\ 1/n\left(\sum_{i=1}^{n} Yi^2\right) \quad (4.1)$$

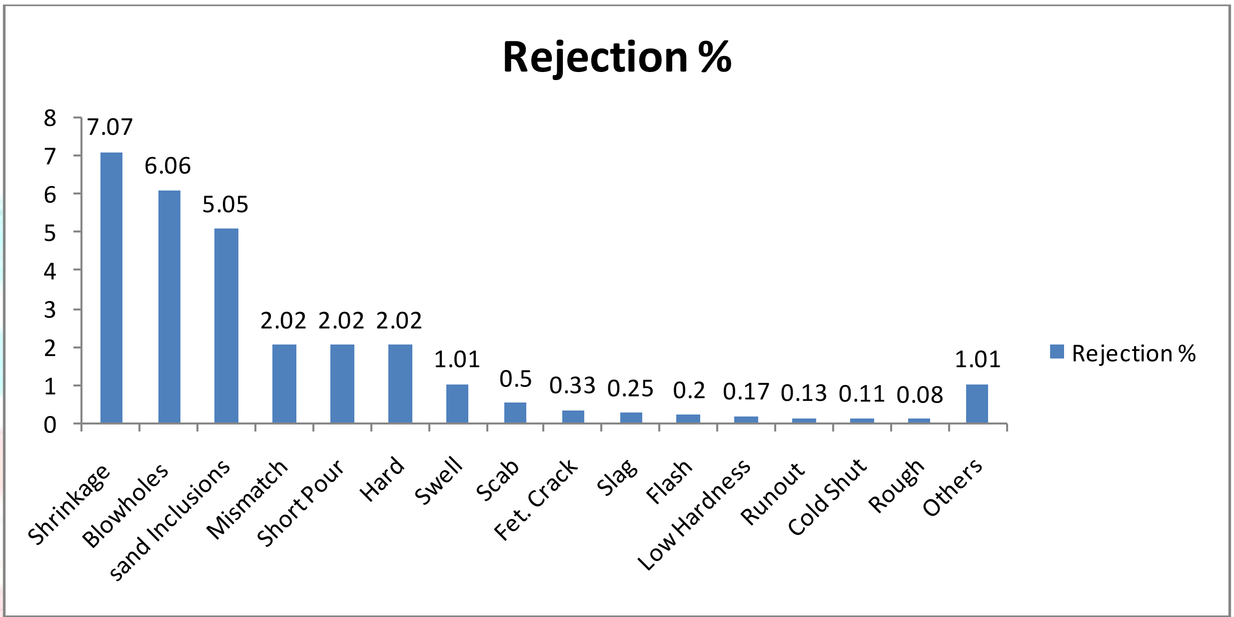

Figure 1 Pareto diagram to identify most occurred casting defects

Name	Shrinkage
Appearance	Irregular Shaped Cavities/Depressions
Defect Size	Medium to large
Location	External, surface
Consistency	Varying size, shape, location
Discovery at	Finish Machining
Inspection	Visual
Type	Geometric discontinuity

Causes	Design Parameters	Material Parameters	Process Parameters
Volumetric Contraction	Size of feeder	Carbon Equivalent	Pouring temperature
Insufficient Metal Poured	Number of feeder		
	Location of feeder		
	Size of Feeder neck		

Figure 2 Categorization of a defect – shrinkage

Name	Blow hole
Type	Geometric discontinuity
Appearance	Blue Gray Colour,Sperical,Flattened Elongated Cavities
Defect Size	Medium to large
Location	External, surface
Consistency	Varying size, shape, location
Discovery at	Shake-out
Inspection	Visual

Causes	Design Parameters	Material Parameters	Process Parameters
Poor Venting System	Insufficient Height of Runner and Riser	Core Material	Pouring Temperature
High Moisture Content	vents, locations	Moisture of Sand	Mold Permeability
Lower permeability	Gate location, size	Binding Material	Return Sand temprature
	Core Location	Permeability of Sand	Pouring Time

Figure 3 Categorization of a defect - Blow holes

Name	Sand Inclusions
Type	Geometric discontinuity
Appearance	Holes on Casting Surface filled with Sand/Sand Particles Dislodged
Defect Size	Medium to large
Location	External, surface
Consistency	Varying size, shape, location
Discovery at	Ejection / shake-out
Inspection	Visual

Causes	Design Parameters	Material Parameters	Process Parameters
High Pouring Rate	Gate location, size	Dead Clay in return sand	Hot return sand
Low Moisture and Green Strength		Compatibility of Sand	Mould hardness
Improper Core Setting		Green compressive strength of sand	
High Fluidly		A.F.S. number of Sand	

Figure 4.Categorization of a defect - Sand Inclusions

4.2 Grey Relational Analysis

Some Parameters reduces the defect level of one defect but same parameter which may increase defect level of other is the major challenge faced by foundymen. In such typical scenario , grey relational analysis (GRA) used in the present study is to obtain the single optimum process parameters set which control rejection level of occurred major casting defects. In GRA, data pre-processing is first performed in order to normalize the raw data for analysis. A normalization of the S/N ratio is performed to prepare raw data for analysis where the original sequence is transferred to a comparable sequence. A normalization of the S/N ratio in the range between zero and one is also called as the grey relational generation (Lin,2002). The larger the better, smaller-the-better and nominal-the-better, characteristics have identical levels to compare with each other. Depending on the characteristics of data sequence, linear normalization can be performed by different methodologies. If the smaller-the-better is the characteristic used. in the original sequence, then it should be normalized as given by Equation 4. 2. S/N ratios of all major casting defects used which were obtained from each trail. The deviation sequence, $\Delta Oi(k)$ is the absolute difference between the reference sequence $x_o^*\ (k)$ and the comparability sequence $x_1^*\ (k)$ after normalization. It is determined using Equation 4.3. Grey relation coefficient (GRC)for all the sequences gives the relationship between the ideal (best) and actual normalized S/N ratio.If the two sequences agree at all points, then their GRC is 1.The GRC γ ($x0(k)$, xi (k)) can be expressed by Equation 4.4 (Devid,1994). The value of ζ can be adjusted with the orderly actual need and defined in the range between 0 and 1. Generally it is considered as 0.5 (Devid,1994,Tosun,2006). The overall assessment of the multiple performance characteristics is based on the grey relational grade (GRG). The grey relational grade is an average sum of the GRC, and is calculated using equation 4.5(Lin,2002).

$$x_i^*(k) = \frac{max\ xi^{(a)}(k) - xi^{(a)}(k)}{max\ xi^{(a)}(k) - min\ xi^{(a)}(k)} \quad (4.2)$$

$$\Delta 0i(k) = |x_o^*(k) - x_1^*(k)| \quad (4.3)$$

$$\Upsilon(xo(k), xi(k) = \frac{\Delta \min + \zeta\Delta max}{\Delta oi(k) + \zeta\Delta max} \quad (4.4)$$

Where Where, Δmin is the smallest value of $\Delta 0i(k)$ min$i$min$k$ $|x_o^*(k) - x_1^*(k)|$ and Δmax is the largest value of $\Delta 0i(k)$ = max$i$max $|x_o^*(k) - x_1^*(k)|$, $x_o^*(k)$ is the ideal normalized S/N ratio, $x_1^*(k)$ is the normalized comparability sequence and ζ is the distinguishing coefficient.

$$\Upsilon(xo, xi) = \frac{1}{m}\sum_{i=1}^{m} \Upsilon(xo(k), xi(k)) \quad (4.5)$$

Where, γ ($x0$, xi) is GRG for the j^{th} experiment and m^{th} number of performance characteristics. After evaluating the optimal parameter settings, the next step is to predict and verify the improvement of quality characteristics using the optimal parametric combination. The predicted GRG γˆ using the optimal level of the machining parameters can be calculated as given by equation 4.6.

$$\Upsilon predicted = \Upsilon m + \sum_{i=1}^{q}(\Upsilon i - \Upsilon m) \quad (4.6)$$

Where, $\Upsilon mean$ is the total mean GRG, Υi is the mean GRG at the optimal level, and q is the number of parameters influencing the quality characteristics.

5. CASE STUDY

In the present work, automobile part was selected for investigation of FG 300 cast iron grade used for two wheelers and produced by green sand casting process. Foundry faced more high that is than 25 % rejections and observed major defect such as shrinkage, blow holes and sand inclusions shown by pareto diagram figure1.Major defects such as shrinkage, blow holes and sand inclusions were characterized and identified process parameters associated with each defect as shown in figure 2,3 and 4. An experimental design was based on taguchi based L_{16} (2^{13}) orthogonal array with 16 experimental runs were selected (Degrees of freedom=16-1=15).These parameters has been selected because of they were simple to manipulate and control. In each moulding box 11 parts were cast and total 99 parts were cast with help of 9 moulding boxes for each combination on high pressure moulding machine. The selected casting process parameters and their different levels are shown in table1.

An experimental design was formed and employed factorial arrangements that is all probable combinations of process parameters considered at two level. Table 2 shows actual values for each parameter investigated.

Table 1 Process parameters with their levels

Process Parameters	Notation	Unit	Range	Level 1	Level 2
Green compressive Strength	A	gm/cm²	1201-1500	1201-1350	1351-1500
Permeability	B	Number	111-140	111-125	126-140
Loss on ignition	C	%	4.1-4.6	4.1-4.3	4.4-4.6
Carbon equivalent	D	%	3.6-4.5	3.6-4.0	4.1-4.5
Volatile data in return sand	E	%	3.1-4..8	3.1-3.9	4.0-4.8
Pouring temperature	F	^{0}C	1391-1450	1391-1420	1421-1450
A.F.S. number	G	%	41-72	41-56	57-72
Mould Hardness	H	Number	80-95	80-87	88-95
Return sand temperature	I	^{0}C	31-50	31-40	41-50
Active clay	J	%	7.0-12.0	7.0-9.0	10.0-12.0
Dead Clay	K	%	3.1-4.0	3.1-3.5	3.6-4.0
Moisture content	L	%	3.1-3.6	3.1-3.3	3.4-3.6
Compatibility	M	cm	32-45	32-38	39-45

5.1 Results and discussion

The quality assessment of automobile casting parts was carried out by measuring casting defects that occur in each experiment conditions. The values of casting defects was determined for each experiment as shown in table 3.S/N ratios of all major casting defects such as (i)shrinkage, (ii) blow holes and (iii) sand inclusions in this experiments calculated by equation 4.1 and presented in table 3. . The deviation sequence $\Delta Oi(k)$ and GRC for each experiment were determined by using equation 4.3 and equation 4.4 respectively. The grey relation grade is an average sum of GRC was calculated by using equation 4.5.Te order of experiments according to the magnitude of GRG is presented in table 4.

Table 2 Control factors for each experimental combination

Expt.	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1201-1350	111-125	4.1-4.3	3.6-4.0	3.1-3.9	1391-1420	41-56	80-87	31-40	7-9	3.1-3.5	3.1-3.3	32-38
2	1201-1350	111-125	4.1-4.3	3.6-4.0	3.1-3.9	1391-1420	41-56	88-95	41-50	10-12	3.6-4.0	3.4-3.6	39-45
3	1201-1350	111-125	4.1-4.3	4.1-4.5	4.0-4.8	1421-1450	57-72	80-87	31-40	7.-9	3.1-3.5	3.4-3.6	39-45
4	1201-1350	111-125	4.1-4.3	4.1-4.5	4.0-4.8	1421-1450	57-72	88-95	41-50	10-12	3.6-4.0	3.1-3.3	32-38
5	1201-1350	126-140	4.4-4.6	3.6-4.0	3.1-3.9	1421-1450	57-72	80-87	31-40	10-12	3.6-4.0	3.1-3.3	32-38
6	1201-1350	126-140	4.4-4.6	3.6-4.0	3.1-3.9	1421-1450	57-72	88-95	41-50	7-9	3.1-3.5	3.4-3.6	39-45
7	1201-1350	126-140	4.4-4.6	4.1-4.5	4.0-4.8	1391-1420	41-56	80-87	31-40	10-12	3.6-4.0	3.4-3.6	39-45
8	1201-1350	126-140	4.4-4.6	4.1-4.5	4.0-4.8	1391-1420	41-56	88-95	41-50	7-9	3.1-3.5	3.1-3.3	32-38
9	1351-1500	111-125	4.4-4.6	3.6-4.0	4.0-4.8	1391-1420	57-72	80-87	41-50	7-9	3.6-4.0	3.1-3.3	39-45
10	1351-1500	111-125	4.4-4.6	3.6-4.0	4.0-4.8	1391-1420	57-72	88-95	31-40	10-12	3.1-3.5	3.4-3.6	32-38
11	1351-1500	111-125	4.4-4.6	4.1-4.5	3.1-3.9	1421-1450	41-56	80-87	41-50	7-9	3.6-4.0	3.4-3.6	32-38
12	1351-1500	111-125	4.4-4.6	4.1-4.5	3.1-3.9	1421-1450	41-56	88-95	31-40	10-12	3.1-3.5	3.1-3.3	39-45
13	1351-1500	126-140	4.1-4.3	3.6-4.0	4.0-4.8	1421-1450	41-56	80-87	41-50	10.-12	3.1-3.5	3.1-3.3	39-45
14	1351-1500	126-140	4.1-4.3	3.6-4.0	4.0-4.8	1421-1450	41-56	88-95	31-40	7-9	3.6-4.0	3.4-3.6	32-38
15	1351-1500	126-140	4.1-4.3	4.1-4.5	3.1-3.9	1391-1420	57-72	80-87	41-50	10-12	3.1-3.5	3.4-3.6	32-38
16	1351-1500	126-140	4.1-4.3	4.1-4.5	3.1-3.9	1391-1420	57-72	88-95	31-40	7-9.	3.6-4.0	3.1-3.3	39-45

Table 3 Major casting defects values and signal-to-noise (S/N) ratio against experiment number

Expt.No.	Percentage defects in experiment				S/N Ratio (dB) for defects		
	Shrinkage	Blow hole	Sand Inclusions	Total	Shrinkage	Blow hole	Sand Inclusions
1	0.0707071	0.030303	0.040404	0.1414141	23.010743	30.370287	27.87151275
2	0.040404	0.050505	0.050505	0.141414	27.871513	25.933312	25.93331249
3	0.020202	0.030303	0.030303	0.080808	33.892104	30.370287	30.37028748
4	0.040404	0.030303	0.030303	0.10101	27.871513	30.370287	30.37028748
5	0.040404	0.020202	0.050505	0.111111	27.871513	33.892104	25.93331249
6	0.020202	0.030303	0.050505	0.10101	33.892104	30.370287	25.93331249
7	0.050505	0.040404	0.020202	0.111111	25.933312	27.871513	33.89211266
8	0.0606061	0.030303	0.040404	0.1313131	24.349679	30.370287	27.87151275
9	0.0606061	0.0606061	0.080808	0.2020201	24.349679	24.349679	21.85091284
10	0.0707071	0.0707071	0.040404	0.1818181	23.010743	23.010743	27.87151275
11	0.0606061	0.030303	0.030303	0.1212121	24.349679	30.370287	30.37028748
12	0.0808081	0.040404	0.050505	0.1717171	21.850904	27.871513	25.93331249
13	0.020202	0.030303	0.050505	0.10101	33.892104	30.370287	25.93331249
14	0.020202	0.040404	0.060606	0.121212	33.892104	27.871513	24.34968757
15	0.0606061	0.020202	0.060606	0.1414141	24.349679	33.892104	24.34968757
16	0.0707071	0.030303	0.060606	0.1616161	23.010743	30.370287	24.34968757

5.2 Determination of optimal parameters

The GRG calculated for each run is taken as response for the additional analysis. The larger-the-better quality characteristic has been used for analysis, since it indicates the better performance of the process. The GRG obtained is analyzed by analysis of mean

(AOM) plots shown in figure 5. The response table 4 of Taguchi method was employed here to calculate the average GRG for each factor level. In this, the grouping of the GRGs was done initially by parameter level for each column in the orthogonal array and then by averaging them. The average sum of these values will be the corresponding response grade shown in table 5.

5.3 Study the results of analysis of variance (ANOVA)

In order to investigate the significance of casting process parameters ANOVA based on values of GRG from table 4 was performed. Table 7 shows the p values and percentage contribution of each casting process parameters. It is possible to conclude, with 95 % of confidence that pouring temperature, permeability, mould hardness, green compressive strength and mould hardness affect the rejection level of major casting defects such as shrinkage, blow holes and sand inclusions of casting part under study. The values of percentage of contribution are shown in figure 6.

5.4 Prediction and Validation Grey relation grade of optimum results

The predicted GRG using the optimal level of the casting process parameters can be calculated as given by equation 4.6. The results of the confirmation experiments using the optimal casting process parameters are presented in Tables 8. It is found that there is a good agreement between predicted and experimental GRG and improvement in grey relation grade by 0.0441. After implementation of optimal casting process parameters reduced rejection level of automobile casting component had reduced from 18.18 to 11.11 and ensured the usefulness of grey relational approach.

Table 4 Grey relation grades and their order

Expt.No.	GRG	Order
1	0.487752272	11
2	0.445571283	13
3	0.701877014	1
4	0.579326581	8
5	0.643558973	4
6	0.664634074	3
7	0.635126038	5
8	0.497967479	10
9	0.378942137	16
10	0.396513507	15
11	0.54161073	9
12	0.412903727	14
13	0.679242062	2
14	0.62051796	6
15	0.591235133	7
16	0.450036469	12

Table 5 Mean response table for grey relation grade

Levels	A	B	C	D	E	F	G	H	I	J	K	L	M
1	0.582	0.4931	0.5694	0.5396	0.5297	0.4854	0.5401	0.5824	0.5435	0.5429	0.5540	0.5162	0.5448
2	0.5089	0.5978	0.5214	0.5513	0.5612	0.6055	0.5508	0.5084	0.5473	0.5479	0.5368	0.5746	0.546
Max-Min	0.0731	0.1047	0.480	0.0117	0.0315	0.1201	0.0107	0.0740	0.0038	0.0050	0.0172	0.054	0.0012
Ranking	4	2	6	9	7	1	10	3	12	11	8	5	13

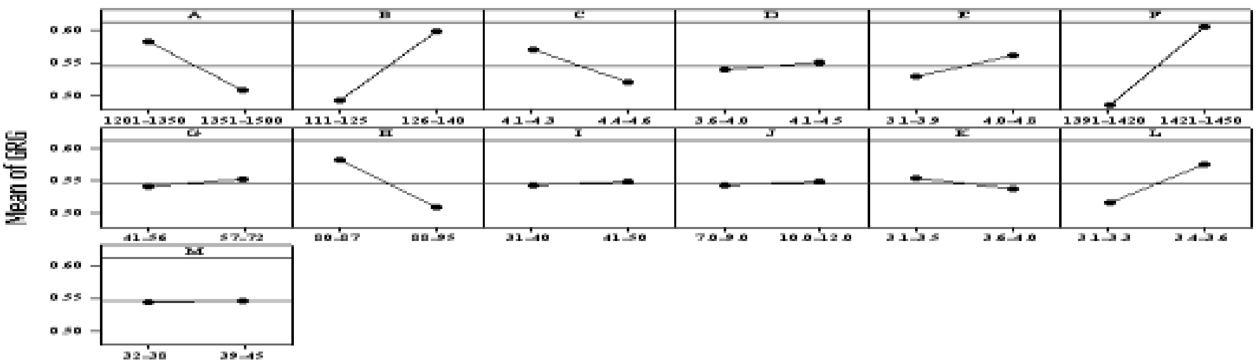

Figure 5.Analysis of mean plots for grey relation grades

Table 6 Optimized casting process parameters achieve better results using grey relation analysis

A	B	C	D	E	F	G	H	I	J	K	L	M
1201-1350	126-140	4.1-4.3	4.1-4.5	4.0-4.8	1421-1450	57-72	80-87	41-50	10-12	3.1-3.5	3.4-3.6	39-45

Table 7 Summarized F and P values of ANOVA

Process Parameters	Notation	DOF	Seq SS	Adj SS	Adj MS	F	P
Green compressive Strength	A	1	0.021375	0.021375	0.021375	33.75	**0.028**
Permeability	B	1	0.043871	0.043871	0.043871	69.27	**0.014**
Loss on ignition	C	1	0.009231	0.009231	0.009231	14.57	0.062
Carbon equivalent	D	1	0.000545	0.000545	0.000545	0.86	0.452
Volatile data in return sand	E	1	0.003976	0.003976	0.003976	6.28	0.129
Pouring temperature	F	1	0.057663	0.057663	0.057663	91.04	**0.011**
A.F.S. number	G	1	0.000456	0.000456	0.000456	0.72	0.485
Mould Hardness	H	1	0.021895	0.021895	0.021895	34.57	**0.028**
Return sand temperature	I	1	0.000057	0.000057	0.000057	0.09	0.792
Active clay	J	1	0.000101	0.000101	0.000101	0.16	0.729
Dead Clay	K	1	0.001181	0.001181	0.001181	1.86	0.305
Moisture content	L	1	0.013651	0.013651	0.013651	21.55	**0.043**
Compatibility	M	1	0.000006	0.000006	0.000006	0.01	0.931
Error		2	0.001267	0.001267	0.001267		
Total		15	0.175274				
			S = 0.0251666	R-Sq = 99.28%		R-Sq(adj) = 94.58%	

Table 8 Results of process performance using initial and optimal casting process parameters

Setting Level	Notation	Initial parameter Setting	Optimum parameter level Prediction	Optimum parameter level Experimental
Process Parameters	Notation	A1 B1C1D2 E2 F2 G2 H1 I1 J1 K1 L2 M2	A1 B2C1D2 E2 F2 G2 H1 I2 J2 K1 L2 M2	A1 B2C1D2 E2 F2 G2 H1 I2 J2 K1 L2 M2
Green compressive Strength	A	1201-1350		1201-1350
Permeability	B	111-125		126-140
Loss on ignition	C	4.1-4.3		4.1-4.3
Carbon equivalent	D	4.1-4.5		4.1-4.5
Volatile data in return sand	E	4.0-4.8		4.0-4.8
Pouring temperature	F	1421-1450		1421-1450
A.F.S. number	G	57-72		57-72
Mould Hardness	H	80-87		80-87
Return sand temperature	I	31-40		41-50
Active clay	J	7.0-9.0		10.0-12.0
Dead Clay	K	3.1-3.5		3.1-3.5
Moisture content	L	3.4-3.6		3.4-3.6
Compatibility	M	39-45		39-45
GRG		0.701877	0.82508842	0.745993319
Improvement in grey relation grade=0.044116305				

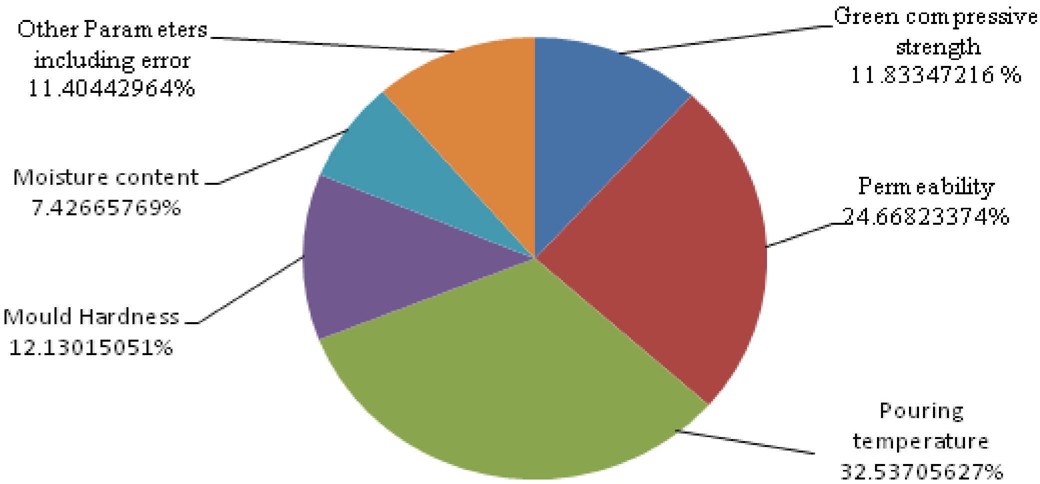

Figure 6.Percentage of contribution

VI.CONCLUSIONS

In this work casting process parameters optimization for reducing rejection level of major casting defects such as shrinkage, blow holes and sand inclusion by using grey relation analysis based on an orthogonal array of the taguchi method in median size cast iron foundry. The main findings of this investigation are:

1.Grey relation analysis based on taguchi method is an effective combination tool to evaluate multiple performance characteristics and increase the stability of process. Hence ,this tool greatly simplify the optimum procedure to solve chronological problems faced by industries.

2 Characterization of of major casting defects gave pave way for finding correct causes of defect as well as identifying process parameters causing defects.

3.The best optimized set of casting process parameters to achieve better results of rejection level of automobile casting part is use of green compressive strength 1201-1350 gm/cm^2,permeability126-140, loss on ignition4.1-4.3, carbon equivalent4.1-4.5 %, volatile data in return sand4.0-4.8%, pouring temperature1421-1450 ^{o}C, A.F.S .number 57-72, mould hardness 80-87, return sand temperature 41-50 ^{o}C, active clay10-12, dead clay 3.1-3.5, moisture content 3.4-3.6 and compatibility 39-45cm.Optimum parameters setting reduced rejection level from 18.18 to 11.11.

4. Pouring temperature 32.54%, permeability 24.67%, mould hardness 12.13%, green compressive strength 11.83% and mould hardness 7.43 % have significant influence on major casting defects such as shrinkage, blow holes and sand inclusions.

5. Significant process parameters identified based on this study will further analyzed at smaller range of levels will extend this work to define robust process routes towards zero rejection in foundries.

6.This work also give innovative idea to Develop an integrated algorithm of grade relation analysis with support of computer program which will applicable for any casting part for determination of optimal values of process parameters to avoid use of costly simulation software.

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