Optimization of sand-defects process parameters for reducing its defect using taguchi technique

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Abstract. Foundry or casting manufacturing process is largely used in manufacturing of automobile and general-purpose machine components. Still this method is popular due to low cost, easiness in manufacturing and easy availability of input materials and resources. It involves a number of processes like sand preparation, pattern making, melting, pouring, cooling etc. Due to influence of so many factors defect arises by one factor or many factors. Still trial and error method are used by casting units to remove defects. Therefore, a more disciplined approach is required to find the root cause of problem. In this paper taguchi’s method and design of experiment is used to analyze sand and mould related defects. Standardization (optimization) attempt is done to obtain optimum values of process parameters by taguchi’s method whose experimental approach of design is robust. The parameters affecting the process are chosen as sand grain size, clay content, moisture percentage, pouring temperature, green strength, permability, mould hardness, number of vent holes, number of ramming etc. An orthogonal array L₂⁷ is selected which is based on taguchi. In this study a cast iron alloy (FG260) retainer used in tractor is focused.

1. Introduction
Sand casting is a centuries old manufacturing process. It successfully serves the requirements of industries. In the last few decades so many different types of casting are fulfilling different demands of transportation and agricultural sector. This process can manufacture a very complex shape with great accuracy. Various components manufactured by green sand casting are affected by different parameters. These parameters influence the quality of product. Parameters are of two types one is controllable parameter while another is uncontrollable also called noise factor.

Kassie A A and Assfaw S B [1] have focused gas and shrinkage defect to optimize. In process parameters binder ratio, mold permeability, pouring temperature and deoxidant are studied. Here factorial experiment is used. Various inspection done are process inspection, visual inspection, chemical composition inspection etc. Muzammil M et al [2] have optimized gear blank casting by taguchi’s robust design technique. The parameters selected are moisture content, sand grain size, fluidity of metal, gating design ramming & clay content. Kumaravadivel A and Natarajan U [3] used process window approach for optimization of control factors. They have taken help of taguchi’s method for analyzing critical parameters influencing the process. The results are confirmed in foundry which were obtained by taguchi’s method & RSM. Process window approach helps in approving final process parameters. Dabade U A and Bhedasgaonkar R C [4] optimized the process parameters of a casted part is done which
is casted through green sand molding process. Different critical parameters selected are mould hardness (horizontal), green compression strength, permeability & moisture content. For experimentation Taguchi method is adopted having L18 orthogonal array. ANOVA is used for analysis. Minitab software helps in analysis of means plot also. Different types of defects i.e., sand related defect, method related defect, solidification and filling related defects are optimized. Change in design of gating & feeding reduces shrinkage porosity by 15%. Kumar S et al [5] have used six sigma approach to reduce green sand-casting defects. The methodology used is in sequence of defining, measuring, analyzing, improving & controlling Six sigma approach helps in defect minimization at minimum cost. It also gives optimal levels of factors for which responses are affected by noise factors. Manikanda Prasath K et al [6] have used simulation and taguchi experimental design for better yield of casting. In the second section, the gating system was optimized to reduce the shrinkage defect and weight of the gating system. Tiwari S K et al [7] studied the castings process of mild steel used in big foundry. Quality concerns are improved by optimization of process parameters of green sand casting. Signal to noise ratio in ANOVA analysis helps in finding optimum value of parameter. Also, each factor’s contribution towards defects is determined. Choudhari C M et al [8] have studied about casting of cover plate (square shaped) which is suffering from shrinkage defect. Simulation is done for improvement in feeding and other important areas using a software known as AUTOCAST-X, the cover plate material was LM6 and silica sand was taken as mould material. Designing of pattern, gating and feeder is done. Solidification related defects such as hot spots etc are identified. Bentonite is used which helps in retaining moisture and also holds sand firmly. Reilly C et al [9] have studied about oxide formation on the free surface of castings and their modeling. Optimization is done by software related to computational fluid dynamics. Defects are modeled and quantified. This study is helpful in complex shaped products. This relates to porosity defect causes analysis. Nimbulkar S L and Dalu R S [10] studied defects like porosity and incomplete filling gating and riser system design is done. Then it is numerically simulated using AUTO-CAST X1 software. Then validated with experimental results. After that ultrasonic testing is done and results are compared. Simulation showing the process of solidification gives stages of freezing from inner region of casting to external environment. It also helps to identify regions solidified in last. It also identifies metal flow rates, hot spots etc., and vertical gating and feeding systems are not up to the mark for thick castings because of many defects of solidification present in the casting. In their proposed work the horizontal gating and feeding systems and the riser are placed symmetrically, and the flow is uniform and the gases escape comfortably into the environment. Khandelwal H and Ravi B [11] have investigated and optimized chemically bonded sand than green sand. Through the lab experimentation they have decided the effect on mechanical properties such as core hardness, compression strength and shear strength by the size of sand grain, percentage of binder and the curing time according to the three different levels of given parameters. Raghupathy R and Amirthagadeswaran K S [12] completed the optimization of process parameters of a grey cast pump adapter is done by DOE and CAE. optimized parameters are mold hardness, moisture content, clay content etc. each parameter is having is having three levels. Feeding and gating parameters are redesigned by using a simulation software PROCAST.

A plethora of research on the impact of process parameters on sand casting defects have been published in literature surveys. A research gap is an unfilled area where the previous research has not paid attention. It may be the method of research, method of collecting the data, selection of factors, method of sampling, selection of software etc. Sand casting is affected by so many parameters such as pouring temperature, pouring time etc. In this study some more significant parameters and selection of levels are considered for better output. Here signal to noise ratio of taguchi’s method helps in determining effect of uncontrollable factors or noise factors. In this paper design of experiment is used to identify causes of defects in a product called retainer used in tractor’s axle. Also, optimum values of parameters are found out.

2. Experimental Details
Among the different types of defects analysis methodologies taguchi method which comes from design of experiments is selected for analysis purpose. Here different defects of different nature and types i.e.
gas related defects, sand related defects and mould related defects are analyzed. Taguchi method of design of experiments is suitable when a number of process parameters is involved. Taguchi method is considered as robust as in this method variations are minimum and it is not affected by variation in component or outside conditions [13]. The success of taguchi’s method lies in proper selection of control factors and their levels. A set of experiments is done with the help of orthogonal arrays. In this research work defects of a product named “Retainer” used in escort tractors is studied. This involves different parameters at different levels which affects the quality. In sand casting different types of defects such as gas defect or sand related defects are observed. The percentage rejection is reduced by setting different process parameters at different levels and optimum values are found.

2.1 Material selection and problem identification
The company Pragati Techno cast is a private limited company, which is the manufacturer and supplier of tractor parts. There is one of the tractor parts called as retainer made of cast iron (FG 260). The nominal composition of FG 260 is: Carbon-3.5%, Silicon- 1.8%, Sulphur- 0.15%, Phosphorous-0.15, Manganese- 0.9%. The total number of retainers produced in a single day is approximately 40 and an average of 4 retainers got rejected due to defects as shown in Figure 1. Due to this the productivity and the quality of this retainer was low. So, there is a need to reduce the number of rejections of retainers.

2.2 Setting the control factors with their levels
Finding the important factors affecting the process with suitable range of levels is the next step in defect analysis, based on the brainstorming with the group of people like lab-in-charge, quality manager, furnace supervisor, workers working at furnace and mold checking supervisor. The parameters affecting the process and their significance in the green sand moulding and casting of “Retainer” is illustrated as follows in Table 1.

| Control Factors | Range of Factors | First Level | Second Level | Third Level |
|-----------------|-----------------|-------------|--------------|-------------|
| Water Content (A) | 4-8 | 4 | 6 | 8 |
| Sand grain size (B) | 60-70 | 60 | 65 | 70 |
| Clay Content (C) | 12-20 | 12 | 16 | 20 |
| Pouring Temp. (D) | 1385-1430 | 1385 | 1410 | 1430 |
| Pouring Time (E) | 20-25 | 20 | 23 | 25 |
| Green Strength (F) | 1000-1500 | 1000 | 1250 | 1500 |
| Permeability (G) | 230-270 | 230 | 250 | 270 |
| Mold Hardness (H) | 65-80 | 65 | 75 | 80 |
| Vent Holes (I) | 8-10 | 8 | 9 | 10 |
| Ramming (J) | 2-6 | 2 | 4 | 6 |

Figure 1. Retainer
2.3 Experimental Design
Orthogonal arrays give the no. of experimentations. In factorial design no. experiments becomes very large. Hence fractional factorial suggested by taguchi is followed. In full factorial design if x factors are considered at y levels, then total number of experiments are y^x. Orthogonal arrays conduct a limited number of experimentations to know the most important factors affecting the process. It is calculated by equation 1:

\[ X = 1 + Y \times (L-1) \]

where X is no. of experiments to be conducted. Y = no. of parameters. L = no. of levels.

Based on calculation orthogonal array is selected. After selecting orthogonal array experiments are conducted. Here \( L_{27} \) orthogonal array is selected as per calculations. Table 2 shows the orthogonal array \( L_{27} \). [14]

| Table 2. Design of Experiment with \( L_{27} \) Orthogonal array |
|-----------------|---|---|---|---|---|---|---|---|---|---|---|
| Trial no.      | (A)| (B)| (C)| (D)| (E)| (F)| (G)| (H)| (I)| (J)| % |
| 1              | 4 | 40| 12| 1385| 20| 1000| 230| 68| 8 | 2 | 7.77 |
| 2              | 4 | 40| 12| 1385| 23| 1250| 250| 75| 9 | 4 | 7.51 |
| 3              | 4 | 40| 12| 1385| 25| 1350| 270| 80| 10| 6 | 7.34 |
| 4              | 4 | 64| 16| 1410| 20| 1000| 230| 75| 9 | 4 | 7.40 |
| 5              | 4 | 64| 16| 1410| 23| 1250| 250| 80| 10| 6 | 5.64 |
| 6              | 4 | 64| 16| 1410| 25| 1350| 270| 68| 8 | 2 | 8.64 |
| 7              | 4 | 70| 19| 1430| 20| 1000| 230| 80| 10| 6 | 6.20 |
| 8              | 4 | 70| 19| 1430| 23| 1250| 250| 68| 8 | 2 | 7.55 |
| 9              | 4 | 70| 19| 1430| 25| 1350| 270| 75| 9 | 4 | 6.90 |
| 10             | 6 | 60| 16| 1430| 20| 1250| 270| 68| 9 | 6 | 6.80 |
| 11             | 6 | 60| 16| 1430| 23| 1350| 230| 75| 10| 2 | 6.80 |
| 12             | 6 | 60| 16| 1430| 25| 1000| 250| 80| 8 | 4 | 7.40 |
| 13             | 6 | 64| 19| 1385| 20| 1250| 270| 75| 10| 2 | 6.30 |
| 14             | 6 | 64| 19| 1385| 23| 1350| 230| 80| 8 | 4 | 6.90 |
| 15             | 6 | 64| 19| 1385| 25| 1000| 250| 68| 9 | 6 | 8.10 |
| 16             | 6 | 70| 12| 1410| 20| 1250| 270| 80| 8 | 4 | 6.30 |
| 17             | 6 | 70| 12| 1410| 23| 1350| 230| 68| 9 | 6 | 8.07 |
| 18             | 6 | 70| 12| 1410| 25| 1000| 250| 75| 10| 2 | 8.40 |
| 19             | 8 | 60| 19| 1410| 20| 1350| 250| 68| 10| 4 | 7.97 |
| 20             | 8 | 60| 19| 1410| 23| 1000| 270| 75| 8 | 6 | 7.11 |
| 21             | 8 | 60| 19| 1410| 25| 1250| 230| 80| 9 | 2 | 7.30 |
| 22             | 8 | 64| 12| 1430| 20| 1350| 250| 75| 8 | 6 | 7.01 |
| 23             | 8 | 64| 12| 1430| 23| 1000| 270| 80| 9 | 2 | 8.07 |
| 24             | 8 | 64| 12| 1430| 25| 1250| 230| 68| 10| 4 | 7.90 |
| 25             | 8 | 70| 16| 1385| 20| 1350| 250| 80| 9 | 2 | 6.90 |
| 26             | 8 | 70| 16| 1385| 23| 1000| 270| 68| 10| 4 | 7.54 |
| 27             | 8 | 70| 16| 1385| 25| 1250| 230| 75| 8 | 6 | 7.42 |

3. Results and discussion
Experimental works has been carried out in a foundry unit which is engaged in manufacturing cast iron products for different automobile and other sectors. From discussion with factory personnel the average rejection per month in the foundry is 8-10%. The rejection in the product retainer is not visible after casting but holes are observed after machining on lathe machine. Here small cavities are observed during machining.
3.1 Analysis of Signal–to-Noise ratio

The robustness of design is indicated by ‘Signal to noise ratio’. Target value is given by signal while unwanted value is noise. System’s robustness is evaluated by higher ‘S/N ratio’. It is also a measure of good quality product. The table below shows signal to noise ratio values for different factors. Taking “lower the better” the ‘signal to noise ratio’ is calculated by equation 2 [15]:

\[
S/N = -10 \log x (\sum (1/Y_i^2)/n)
\]  

(2)

Where, \(n\) = Number of repetitions and \(Y_i\) = value of quality characteristics at ith experimental run. The S/N ratio and mean for 27 trials are shown in Table 3.

| Trial no. | A | B | C | D | E | F | G | H | I | J | K | S/N ratio | Mean |
|-----------|---|---|---|---|---|---|---|---|---|---|---|-----------|------|
| 1         | 4 | 6 | 0 | 12| 1380| 20| 1000| 230| 68 | 8  | 2  | 7.77      | -17.8084 | 7.77   |
| 2         | 4 | 6 | 0 | 12| 1380| 23| 1200| 250| 75 | 9  | 4  | 7.51      | -17.5128 | 7.51   |
| 3         | 4 | 6 | 0 | 12| 1380| 26| 1400| 270| 82 | 10 | 6  | 7.34      | -17.3139 | 7.34   |
| 4         | 4 | 64| 16| 1410| 20| 1000| 230| 75 | 9  | 4  | 7.40      | -17.3846 | 7.40   |
| 5         | 4 | 64| 16| 1410| 23| 1200| 250| 82 | 10 | 6  | 5.64      | -15.0256 | 5.64   |
| 6         | 4 | 64| 16| 1410| 26| 1400| 270| 68 | 8  | 2  | 8.64      | -18.7303 | 8.64   |
| 7         | 4 | 68| 20| 1440| 20| 1000| 230| 82 | 10 | 6  | 6.20      | -15.8478 | 6.20   |
| 8         | 4 | 68| 20| 1440| 23| 1200| 250| 68 | 8  | 2  | 7.55      | -17.5589 | 7.55   |
| 9         | 4 | 68| 20| 1440| 26| 1400| 270| 75 | 9  | 4  | 6.90      | -16.7770 | 6.90   |
| 10        | 6 | 60| 16| 1440| 26| 1400| 270| 68 | 9  | 6  | 6.80      | -16.6502 | 6.80   |
| 11        | 6 | 60| 16| 1440| 23| 1400| 230| 75 | 10 | 2  | 6.80      | -16.6502 | 6.80   |
| 12        | 6 | 60| 16| 1440| 26| 1000| 250| 82 | 8  | 4  | 7.40      | -17.3846 | 7.40   |
| 13        | 6 | 64| 20| 1380| 20| 1200| 270| 75 | 10 | 2  | 6.30      | -15.9868 | 6.30   |
| 14        | 6 | 64| 20| 1380| 23| 1400| 230| 82 | 8  | 4  | 6.90      | -16.7770 | 6.90   |
| 15        | 6 | 64| 20| 1380| 26| 1000| 250| 68 | 9  | 6  | 8.10      | -18.1697 | 8.10   |
| 16        | 6 | 68| 12| 1410| 26| 1200| 270| 82 | 8  | 4  | 6.30      | -15.9868 | 6.30   |
| 17        | 6 | 68| 12| 1410| 23| 1400| 230| 68 | 9  | 6  | 8.07      | -18.1375 | 8.07   |
| 18        | 6 | 68| 12| 1410| 26| 1000| 250| 75 | 10 | 2  | 8.40      | -18.4856 | 8.40   |
| 19        | 8 | 60| 20| 1410| 20| 1400| 250| 68 | 10 | 4  | 7.97      | -18.0292 | 7.97   |
| 20        | 8 | 60| 20| 1410| 23| 1000| 270| 75 | 8  | 6  | 7.11      | -17.0374 | 7.11   |
| 21        | 8 | 60| 20| 1410| 26| 1200| 230| 82 | 9  | 2  | 7.30      | -17.2665 | 7.30   |
| 22        | 8 | 64| 12| 1440| 20| 1400| 250| 75 | 8  | 6  | 7.01      | -16.9144 | 7.01   |
| 23        | 8 | 64| 12| 1440| 23| 1000| 270| 82 | 9  | 2  | 8.07      | -18.1375 | 8.07   |
| 24        | 8 | 64| 12| 1440| 26| 1200| 230| 68 | 10 | 4  | 7.90      | -17.9526 | 7.90   |
| 25        | 8 | 68| 16| 1380| 20| 1400| 250| 82 | 9  | 2  | 6.90      | -16.7770 | 6.90   |
| 26        | 8 | 68| 16| 1380| 23| 1000| 270| 68 | 10 | 4  | 7.54      | -17.5474 | 7.54   |
| 27        | 8 | 68| 16| 1380| 26| 1200| 230| 75 | 8  | 6  | 7.42      | -17.4081 | 7.42   |

The response table for means is shown in Table 4.
### Table 4. Response Table for Means

| Level | A   | B   | C   | D   | E   | F   | G   | H   | I   | J   |
|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1     | 7.217 | 7.333 | 7.597 | 7.309 | 6.961 | 7.554 | 7.307 | 7.816 | 7.344 | 7.526 |
| 2     | 7.230 | 7.329 | 7.171 | 7.426 | 7.243 | 6.969 | 7.387 | 7.206 | 7.450 | 7.313 |
| 3     | 7.469 | 7.253 | 7.148 | 7.181 | 7.711 | 7.392 | 7.222 | 6.894 | 7.121 | 7.077 |
| Delta | 0.252 | 0.080 | 0.449 | 0.244 | 0.750 | 0.586 | 0.164 | 0.921 | 0.329 | 0.449 |
| Rank  | 7    | 10   | 5    | 8    | 2    | 3    | 9    | 1    | 6    | 4    |

#### 3.2 ANOVA Analysis

Analysis of variance (ANOVA) gives relative effect of different parameters. Contribution of each factor on the response collectively is calculated by ANOVA. F-ratio gives contribution of each factor & its importance compared to other factors. F – Test value at 95% confidence level helps in deciding important parameters controlling or influencing the process. The F-Statistics is defined as the ratio of variation between the samples to the variations within the sample. The F statistic is dependent on the proportion of the average square. The term "average square" can be more confounding, but it is only an estimate of population differences that accounts for the degrees of freedom (DOF) used to calculate that estimate.

### Table 5. Rejection analysis at 95% confidence limit using ANOVA

| Factors | DOF | SS   | MS   | F ratio | P value | Contribution | Best level |
|---------|-----|------|------|---------|---------|--------------|------------|
| A       | 2   | 0.3626 | 0.18129 | 0.68 | 0.540 | Significant | 4%         |
| B       | 2   | 0.0364 | 0.01819 | 0.07 | 0.934 | Non-significant |            |
| C       | 2   | 1.1494 | 0.57471 | 2.17 | 0.196 | Significant | 20%        |
| D       | 2   | 0.2691 | 0.13454 | 0.51 | 0.626 | Non-significant |            |
| E       | 2   | 2.5829 | 1.29145 | 4.87 | 0.055 | Significant | 20 sec     |
| F       | 2   | 1.6452 | 0.82260 | 3.10 | 0.119 | Significant | 1200 kg/cm² |
| G       | 2   | 0.1217 | 0.06086 | 0.23 | 0.802 | Non-significant |            |
| H       | 2   | 3.9520 | 1.97600 | 7.45 | 0.024 | Significant | 82         |
| I       | 2   | 0.5076 | 0.25378 | 0.96 | 0.436 | Significant | 10         |
| J       | 2   | 0.9077 | 0.45383 | 1.71 | 0.258 | Non-significant |            |
| Error   | 6   | 1.5920 | 0.26533 |      |       |              |            |
| Total   | 26  | 13.1265 |        |       |       |              |            |

Higher value of F-value informs that change in the process parameters have a good influence on performance characteristic and more significant the parameter will be. In the ANOVA at a given confidence level if a particular factor’s value becomes below tabulated F-value for that confidence level, then that factor or parameter is not important and that parameter is pooled. The rejection analysis at 95% confidence level is shown in Table 5. The significant and non-significant process parameters may be separated out on the basis of Table 5.

The plots of S-N ratio have been represented in the Figure 2. The greater values of S/N ratio identify the controlling factors which mitigates the effects of the noise factors. A two-stage optimization process offered by Taguchi experiments. The signal-to-noise ratio are identified the control factors which decreases the variability stage 1. The various controlling factors are identified which move the mean to target and have a negligible effect on the S/N ratio in stage 2. Under different noise conditions, the S/N ratio decides how the response varies relative to the nominal or target value.
Figure 2. S-N ratio plots

There are 10 process parameters and each process parameter has 3 different levels. Figure 2 depicts the variation in process parameters along with the level. According to the Figure 2, the moisture content reduces as the level increases. It is clear that the moisture content is a significant factor in sand-casting process as the value of S/N ratio decreases the percentage composition of moisture content is also decreasing. From level 1 to 2, the moisture content decreases slowly but from level 2 to level 3, the moisture content reduces drastically. In this study, smaller is the better is taken for S/N ratio. From the above figure it can be concluded that level 3 is best for moisture content. The sand grain size increases as its level increases. The clay content increases from level 1 to level 2 and from level 2 to level 3, it is almost regular as it can be observed that the S/N ratio increases from level 1 to level 2. It is also observed that initially the pouring temperature decreases and then increases. The similar effect has been observed on the green strength also, initially from level 1 to level 2, the green strength is increasing then after it is decreasing from level 2 to level 3. In the case of clay content level 1 is found to be the best. In the case of pouring time the level 3 is most accepted. Similarly, the variation in each process parameter can be explained with the change in its level.

4. Conclusions

There are two types of finding in this study. First one is to sort out the contributing and non-contributing process parameters and the second one is the optimized process parameters to minimize the sand casting defects. The results of this study, show that water content, clay content, pouring time, Green strength, mould hardness and ventholes are the contributing parameters while sand grain size, pouring temp, permeability and ramming are the non-contributing factors and the optimized values of process parameters of the sand found by taguchi method are: Moisture content-4%, sand particle size – 70, clay content-18%, pouring temperature-1430°C, pouring time- 20 seconds, green strength- 1350 g/cm², number of vent holes- 10, number of ramming- 6. By adopting taguchi optimization method, the percentage rejection of castings is reduced from 8 % to 5.095%.

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