Analysis of Shrinkage Defect in Sand Casting by Using Six Sigma Method with Taguchi Technique

M A Omprakas*, M Muthukumar¹, S P Saran¹, D Ranjithkumar¹, C M Shantha kumar¹, S Thiruppathi Venkatesh¹ and M Sengottuvelan²

¹ Department of Mechanical Engineering, Nandha Engineering College, Erode – 638052, Tamilnadu, India.
² Department of Mechatronics Engineering, Bannari Amman Institute of Technology, Sathyamangalam - 638401, Tamilnadu, India

omprakasangappan@gmail.com

Abstract. Casting industries play a major role in the field of manufacturing. The production of complex shape and size products is manufactured in a single process, which cannot be produced in other manufacturing processes. Because the other process needs more than one step to convert a raw material into a product. When producing the casting, the quality of the casting should be maintained without defects. This is not possible as we can’t produce a cent percentage of accuracy. But the percentage of defects can be reduced with the help of certain quality control tools and techniques. In this paper, the main focus is to reduce the shrinkage defect which occurs in the External Bearing Ring of ductile cast iron which is produced in the leading casting industry in Coimbatore. The data have been collected from the industry for the six months and the defects have been identified with the help of the Six-Sigma DMAIC (Define, Measure, Analyze, Improve, Control) technique. The quality control tools are applied in different stages of the DMAIC technique for identifying and controlling the defects. Also, the Taguchi technique is applied for creating the L9 orthogonal array from the Minitab software. Finally, the best possible solution is obtained and it is suggested to the industry for defects reduction.

Keywords: Casting defects; Six-sigma; DMAIC process; Taguchi; ductile iron.

1 Introduction
Casting is one of the oldest techniques in the days around 4000 B.C. The casting process was used for manufacturing of gold ornaments. Few years later, it was used for the production of weapons and tools with metals like copper as materials. Then after, the casting has been used for the production of products which were having different shapes from small to complex shape and size of products and different materials like cast iron and ductile iron, etc. Due to its major benefits and needs, the casting production plays a major role in the field of manufacturing. The occurrence of defects in the casting affected the casting industry economically. So, the defect occurrences should be reduced and the quality of the casting should be improved for which the application of some techniques like six-sigma and quality tools can be used. The defect in the particular area is identified and some changes are made to reduce the defects. In this paper, the External Bearing Ring made of ductile cast iron which is one of the main components in the windmill is considered for analysis. The leading casting industry in Coimbatore are facing this shrinkage defect on this particular product as high in numbers. So, this shrinkage defects are reduced by applying the six-sigma technique and quality control tools, with the help of Minitab software.
The Six-Sigma DMAIC technique is used, for the reduction of defect. In a metal casting industry, the casting production is made by using green sand-casting process. Here the misrun defect is reduced from 31% to 4% [1]. The Six-Sigma DMAIC technique is used in the small-scale industry as a case study. To reduce the rejection and rework of leaf spring manufacturing process. As a result, the overall rejection rate is reduced from 48.33% to 0.79% [2]. The Six-Sigma DMAIC technique is used to improve the efficiency and profitability of all the operations as a business strategy. The Blow holes, Misrun, Slag inclusion, Rough surface defects are reduced in the sand casting process. The percentage of rejection is reduced from 6.98% to 3.10% and made a profit of Rs.2.35 lakhs appx [3]. The performance level and efficiency of the casting process was improved by adopting the Six-Sigma technique. DMAIC approach is applied here. The process parameters of the green sand casting are optimized here, which contributes to diminish the casting defect, this is the conclusion of this case study. The optimized parameter levels for melt shop process are ferromanganese (3.5 kg), ferrosilicon (5 kg), ferrochrome (1.2 kg), pig iron (195 kg), steel (48 kg) and cast iron (350 kg) [4].

The steel casting manufacturing process is affected by shrinkage defect and gas defect, it is reduced by using the Taguchi’s DoE (Design of Experiments). Totally nine experiments are made and four parameters are chosen. The four parameters are sand-binder ratio, mould moisture, pouring temperature, and amount of de-oxidant material added to the melt. In this the experiment six is selected as a best parameter [6]. The Six-Sigma technique is applied to the flywheel manufacturing casting industry, to reduce the defect percentage. The process map, cause-and-effect matrix and the failure mode effective analysis are used as a primary tool. The working parameters, namely moisture content, green strength, permeability, and loss on ignition on sand preparation are measured. The experimental results were analyzed and modelled through response surface methodology (RSM). The optimized process parameters are taken from the experiment [7].

The first phase of Six-Sigma (DMAIC) is the Define phase. In this phase, a thorough study is carried out in the leading foundry industry located in Coimbatore, India where the ductile cast iron products are produced. The data was collected from the industry for the last six months and are tabulated in Table 1. From the number of products and quantity of rejection in the data, the percentage of good casting and the percentage of rejection are calculated.

2 Materials and Methods

Six-sigma is one of the best quality control techniques, for improving the quality of the casting by reducing the defects. In six-sigma, we can produce 3.4 defects per million opportunities. The Define, Measure, Analysis, Improve, and Control are the different stages of the DMAIC technique, which is used for the identification of the defect and the root cause of the defects. This is to reduce the defect with the help of Taguchi technique by forming the orthogonal array.

The minimization of cold shunt defect in an automobile cylinder block of gray cast iron grade FG150. The seven quality control tools, check sheet, pareto analysis, cause effect diagram, flow chart, scatter diagram, histogram and control chart are used here. The defects are reduced by controlling the pouring temperature and alloy composition [10].
The second phase in Six-Sigma (DMAIC) is the Measure phase. In this phase, the maximum number of defects occurred on the particular product is identified with the help of a histogram as shown in Figure 1 using Table 1.

| S. No. | Product Name       | Total Quantity of Product | Quantity of Rejection | Good Casting Produced | % of Good Casting | % of Rejection |
|-------|--------------------|---------------------------|-----------------------|-----------------------|------------------|----------------|
| 1     | HUB                | 1577                      | 23                    | 1554                  | 98.54%           | 1.45%          |
| 2     | FAN HUB            | 2341                      | 112                   | 2229                  | 95.21%           | 4.78%          |
| 3     | BASE TRUNNION      | 564                       | 8                     | 556                   | 98.58%           | 1.41%          |
| 4     | CLAW BEAM ASSEMBLY | 1945                      | 45                    | 1900                  | 97.68%           | 2.31%          |
| 5     | STEERING BRACKET   | 2014                      | 32                    | 1982                  | 98.41%           | 1.58%          |
| 6     | MOTOR COVER        | 854                       | 20                    | 834                   | 97.65%           | 2.34%          |
| 7     | COLLAR             | 1245                      | 26                    | 1219                  | 97.91%           | 2.08%          |
| 8     | SUSPENSION LEG     | 1120                      | 61                    | 1059                  | 94.55%           | 5.44%          |
| 9     | EXTERNAL BEARING RING | 3099                      | 400                   | 2699                  | 87.09%           | 12.90%         |
| 10    | PISTON             | 1743                      | 23                    | 1720                  | 98.68%           | 1.31%          |
| 11    | SUSPENSION        | 865                       | 26                    | 839                   | 96.99%           | 3.00%          |
| 12    | BEARING COVER      | 991                       | 40                    | 951                   | 95.96%           | 4.03%          |
| 13    | RETAINING RING     | 1121                      | 45                    | 1076                  | 95.98%           | 4.01%          |
| 14    | PLANETARY FIN      | 1467                      | 71                    | 1396                  | 95.16%           | 4.83%          |
| 15    | AXLE CASING        | 743                       | 36                    | 707                   | 95.15%           | 4.84%          |
In Figure 1, it is clearly shown that the External Bearing Ring product is having a higher rejection rate of 400 out of 3099 products. So, the External Bearing Ring product is taken and the different defects in it are tabulated in Table 2.

Table 2. Products with different kind of defects

| S. No. | Product Name           | Defects |
|--------|------------------------|---------|
|        |                        | Shrinkage | Sand Drop | Pin Hole | Sand Inclusion | Scabbing |
| 1      | HUB                    | 7        | 4         | 0        | 3             | 1        |
| 2      | FAN HUB                | 18       | 25        | 4        | 5             | 2        |
| 3      | BASE TRUNNION          | 1        | 1         | 0        | 0             | 3        |
| 4      | CLAW BEAM ASSEMBLY     | 0        | 14        | 9        | 0             | 4        |
| 5      | STEERING BRACKET       | 24       | 0         | 0        | 8             | 5        |
| 6      | MOTOR COVER            | 2        | 7         | 3        | 0             | 6        |
| 7      | COLLAR                 | 16       | 4         | 2        | 2             | 7        |
| 8      | SUSPENSION LEG         | 5        | 7         | 18       | 2             | 8        |
| 9      | EXTERNAL BEARING RING  | 187      | 27        | 18       | 23            | 9        |
| 10     | PISTON                 | 0        | 8         | 9        | 0             | 10       |
| 11     | SUSPENSION             | 4        | 9         | 6        | 2             | 11       |
| 12     | BEARING COVER          | 7        | 8         | 12       | 0             | 12       |
| 13     | RETAINING RING         | 9        | 12        | 3        | 5             | 13       |
| 14     | PLANETARY FIN          | 0        | 21        | 18       | 0             | 14       |
| 15     | AXLE CASING            | 7        | 6         | 3        | 5             | 15       |
When compared to all other products, the External Bearing Ring is only having 400 rejections out of 3099 products as already discussed in the define phase. In Figure 2, the External Bearing Ring product is having 187 shrinkage defect, 27 sand drop defect, 18 pinhole defect, 23 sand inclusion defect and 9 scabbing defect. The major defect in this product is shrinkage, as it is having 187 out of 400 defects. When compared to all other defects, its rate is high. So, the shrinkage defect is alone taken and an attempt is made to reduce the percentage of shrinkage defect.

The third phase in Six-sigma (DMAIC) is the Analyze phase. In this phase, the possible causes for the occurrence of shrinkage defect are identified using the cause and effect diagram as shown in Figure 3. The six different areas in the cause and effect diagram are measurement, materials, machine, environment, manpower, and method. Using this, the major parameter for the occurrence of defect can be identified in that particular area. This is the brainstorming process which is carried out with the help of company employees and standard values.
In Figure 3, the different parameters for the occurrence of the shrinkage defect are identified. The majorly affecting parameter is taken with the help of experienced persons from the casting industry and also referred the standard conditions for the shrinkage defects. Three parameters are taken from the Figure 3 namely, mould hardness, tapping temperature and pouring temperature.

The fourth phase in Six-sigma (DMAIC) is the Improve phase. In this phase, the parameters are taken from Figure 3, along with their range of values from high to low, are tabulated in Table 3. Three level of values for each parameter are considered. Taguchi technique is applied for the formation of L9 orthogonal array as shown in Table 4 using the Minitab software. In Table 5, the three-level range of values are applied in the L9 orthogonal array.

| Factors Designation | Control Factors | Range     | Level 1 | Level 2 | Level 3 |
|---------------------|-----------------|-----------|---------|---------|---------|
| A                   | Mould Hardness (nu) | 80 - 50   | 75      | 65      | 55      |
| B                   | Tapping Temperature (°C) | 1570 – 1560 | 1570    | 1565    | 1560    |
| C                   | Pouring Temperature (°C) | 440 - 1380 | 1430    | 1400    | 1370    |

| Trial 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   |

From Table 5, for each combination 30 castings produced, the output (or) result is based on the number of defects occurred during the casting process. Shrinkage defect is majorly focused and other defects are neglected. Also, there are no other defects are occurred majorly during this identification. In Table 6, the result of the produced casting is tabulated in percentage, for each combination of values the percentage of defect is shown in result column. The Taguchi analysis is made for the output with the
parameters A, B, C shown in Table 7, taking ‘smaller is better’. Figure 4, is the signal to noise ratio graph where ‘smaller is better’ is taken.

| Trial No. | A  | B  | C  | Result (O/P) |
|-----------|----|----|----|--------------|
| 1         | 75 | 1570 | 1430 | 13.33        |
| 2         | 75 | 1565 | 1400 | 20.00        |
| 3         | 75 | 1560 | 1370 | 33.33        |
| 4         | 65 | 1570 | 1400 | 26.67        |
| 5         | 65 | 1565 | 1370 | 40.00        |
| 6         | 65 | 1560 | 1430 | 20.00        |
| 7         | 55 | 1570 | 1370 | 46.67        |
| 8         | 55 | 1565 | 1430 | 20.00        |
| 9         | 55 | 1560 | 1400 | 26.67        |

Table 6. Result for the combination of Orthogonal Array

Taguchi Analysis: O/P versus A, B, C:

Smaller is better

| Level | A       | B       | C       |
|-------|---------|---------|---------|
| 1     | -29.31  | -28.33  | -31.96  |
| 2     | -28.86  | -28.03  | -27.69  |
| 3     | -26.33  | -28.13  | -24.85  |
| Delta | 2.98    | 0.31    | 7.11    |
| Rank  | 2       | 3       | 1       |

Table 7. Response Table for Signal to Noise Ratios

Table 8 shows the Response table for Means. In Figure 5, the mean effect plot for mean graph is made and ‘smaller is better’ is chosen. Because the defect percentage only needs to be reduced, from the Figure 4, Figure 5, Table 7 and Table 8 based on the rank the combination of parameters chosen which have the best possible solution for shrinkage defect reduction. Using regression test, it is checked whether the obtained combination is correct with the help of regression analysis from the output value verses the parameters A, B, C. Table 9 shows the coefficients. The R-sq (adj) obtained in Table 10, is 89.36% which is more than the satisfactory condition of 85%. So, the obtained value combination is
the best possible solution. The obtained combination is Mould Hardness of 75 Nu, Tapping Temperature of 1570°C and Pouring Temperature of 1430°C.

Table 8. Response Table for Means

| Level | A   | B   | C   |
|-------|-----|-----|-----|
| 1     | 31.11 | 26.67 | 40.00 |
| 2     | 28.89 | 26.67 | 24.44 |
| 3     | 22.22 | 28.89 | 17.78 |
| Delta | 8.89  | 2.22  | 22.22 |
| Rank  | 2     | 3     | 1    |

Figure 5. Main Effects Plot for Means

Regression Analysis: O/P versus A, B, C

Regression Equation

\[ O / P = 227 - 0.444 \, A + 0.222 \, B - 0.3704 \, C \]

Table 9. Coefficients

| Term | Coef  | SE Coef | T-Value | P-Value | VIF |
|------|-------|---------|---------|---------|-----|
| Constant | 227   | 454     | 0.50    | 0.638   | 1.00 |
| A     | -0.444| 0.143   | -3.10   | 0.027   | 1.00 |
| B     | 0.222 | 0.287   | 0.77    | 0.474   | 1.00 |
| C     | -0.3704 | 0.0478 | -7.75   | 0.001   | 1.00 |

Table 10. Model Summary

| S      | R-sq  | R-sq(adj) | R-sq(pred) |
|--------|-------|-----------|------------|
| 3.51364 | 93.35% | 89.36%    | 77.97%     |
The fifth and final phase of the Six-sigma (DMAIC) is Control phase. In this phase, the obtained combination of Mould Hardness of 75 nu, Tapping Temperature of 1570 °C and Pouring Temperature of 1430 °C from the improve phase for the External Bearing Ring product, are once again checked, by making 50 castings. From the pouring of 50 castings, it is found that the shrinkage defect count is only 3 and remaining defects are also minimal when compared to the previous defect count. Hence, in this control phase, the defects are controlled and maintained with the obtained combination values. The obtained percentage of rejection is 6%, which is less when compared to initial percentage of 12.90%. So, in the upcoming days the defect percentage will be in control.

3 Conclusion

The optimum combination of value obtained with the help of Six-Sigma (DMAIC) technique. In define phase, data are collected for six months and found that the good casting is 95.54% and the amount of rejection rate is high as 4.46% out of the total production count of 21689. Data are tabulated and histogram is plotted from that values, the most affected product is identified which is the External Bearing Ring product. While producing the External Bearing Ring product in casting, the amount of rejection is 12.90%. In measure phase, the different defects in External Bearing Ring product are identified and the majorly occurring defect is taken. Majorly occurring defect is shrinkage defect. Because the defect count is 187 out of 400 rejections out of 3099 total products produced. In analyze phase, the cause and effect diagram is used to identify the different parameters which is the possible one for the occurrence of the shrinkage defect. The chosen parameters are Mould Hardness in nu, Tapping Temperature in °C, Pouring Temperature in °C. These parameters are identified with the help of journals and experienced persons from the industry. In the improve phase, the parameter ranges are identified and three level of values are chosen with the help of Taguchi technique and Minitab software. The L9 (3^3) orthogonal array is formed and the chosen range values are tabulated in it. For this combination the output is taken like 30 casting in each combination. With the help of Signal to Noise ratio, the smaller value is chosen and it is checked with the Regression equation. The obtained optimum solution is Mould Hardness of 75 nu, Tapping Temperature of 1570 °C and Pouring Temperature of 1430 °C. Also, the Regression Value R-sq (adj) is 89.36%. It satisfied the condition because the R-sq (adj) value must be above 85%. In the final phase, the combination of values obtained from the improve stage is tested again for 50 products and the got the number of rejections as 3. The obtained percentage of rejection is 6%, which is less when compared to initial percentage of 12.90%. With the help of Six-sigma, it is possible to reduce the defect percentage and the Taguchi technique which is used to form the orthogonal array and from this combination, the optimal values are obtained.

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