Leveraging Six Sigma Disciplines to Reduce Scrap in Indian Foundry SMEs

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Abstract:

The study focuses on scrap reduction in foundries and tries to find out the reasons of low productivity index among Indian subcontinent. It briefly discusses some facts and figures about foundry scenario in world and in the India. The Indian foundry industry is the fourth largest in the world. There are more than 70,000 foundries in India and most foundries (nearly 95%) fall under small and medium scale category. For global competitiveness, Indian industries need overall operational and service excellence and are extensively engaged in Quality Circles, TQM and ISO Certifications. However, these methods have failed to deliver required performance over the last decade or so. The average growth rate of productivity for Indian SMEs has been 4.95% in comparison to 7.31% for China, 9.45% for Singapore and 8.65% for Pakistan. It seems a comprehensive quality approach like ‘Six Sigma’ is not fully explored among Indian industries. This paper tends to shatter the various phobias of SMEs in context of Six Sigma concepts and its implementation by validating the compatibility of it by performing a case study in an Indian environment itself. In present case, overall sigma level has been raised by 0.24 by reducing the scrap of a non-ferrous piston foundry from 22% to 10% after successfully implementing the DMAIC (Define-Measure-Analyse-Improve-Control) methodology of Six Sigma.

Keywords: Productivity, Non-Ferrous Foundry, DMAIC, Susceptible Sources of Variations (SSVs), Analysis of Variance (ANOVA), Design of Experiments (DOE)

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INTRODUCTION

India has around 5500 foundries, producing about 3.24 MT of castings worth ten millions (Government of India, 2002). These units are mostly located in clusters with numbers varying from less than 100 to around 400 per cluster. Some of the notable clusters in this regard are Agra, Howrah, Batala, Coimbatore, Kolhapur, Rajkot and Belgaum (Chhabilendra and Roul, 2001). The foundry produces a wide variety of castings such as manhole covers, pipe and pipe fittings, sanitary items, tube well body, metric weights, automobile components, railway parts, electric motor, fan body etc. 90% of the castings produced are from the Small Scale Industry sector (Government of India, 2006). India has exported castings worth USD 131.35 Million and sanitary castings worth USD 55.39 in 1999-2000, mainly to USA and Europe (Alistair Nolan, 2003).

LITERATURE REVIEW

In India, productivity levels of SMEs are alarmingly low due to host of problems (Director of Industries, 2003). For higher productivity in SMEs, ‘Defects reduction’ will be one of the most promising and viable strategy and it will also be capable to cope up the emerging future challenges (Antony et al., 2005). Six Sigma concept has been widely used in manufacturing sector from last 25 years as company like Motorola has been improving its processes since 1986 by using its defect reduction approach (Eckes, 2001). Similarly manufacturing giants like General Electric and Honey Well have been using it as cycle time reduction tool, since 1996 (Zu et al., 2011). Other well-known companies like Ford, Caterpillar, Our lady of Lourdes medical centre, LG and Samsung etc. are also practicing Six Sigma as a quality improvement technique in their respective manufacturing processes from 1999. Table 1 cites major works of the researchers related to application of Six Sigma in manufacturing sector during the past decade.

After analyzing significant contribution of Six Sigma approach among SMEs, an effort has been made to implement DMAIC methodology in non-ferrous (medium scale) foundry, without ignoring its existing Indian constraints. It further demystifies various myths regarding Six Sigma and SMEs, specifically for the foundry units.
## Table-1: Application of Six Sigma in Manufacturing Sector

<table>
<thead>
<tr>
<th>SN</th>
<th>Author(s)</th>
<th>Company / Unit</th>
<th>Parameters</th>
<th>Achievements</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.</td>
<td>Ingle and Roe (2001)</td>
<td>Medium sized welding unit</td>
<td>Optimization of welding process parameters</td>
<td>Joint strength is increased by 26% and scrap work is reduced by 3%</td>
</tr>
<tr>
<td>3.</td>
<td>Does et al. (2002)</td>
<td>A bulb manufacturing SME</td>
<td>Improve the process and reduced the shell cracking of bulbs</td>
<td>Sigma level increased from 3.1 to 4.5</td>
</tr>
<tr>
<td>6.</td>
<td>Hollenstein (2005)</td>
<td>A medium scale IC engine manufacturing unit</td>
<td>Improve the Cpk</td>
<td>Process capability improved from 1.1 to 2.9</td>
</tr>
<tr>
<td>7.</td>
<td>Andersson et al. (2006)</td>
<td>A gravity die casting unit</td>
<td>Casting scrap reduced from 23% to 11%</td>
<td>40% reduction in manufacturing cost with annual savings of $72000 p.a.</td>
</tr>
<tr>
<td>8.</td>
<td>Lin et al. (2008)</td>
<td>Cranberry Drinks Ltd.</td>
<td>Improvement in packing process.</td>
<td>DPMS level improved from 3011 to 178 only. 17% reduction in packing time.</td>
</tr>
<tr>
<td>9.</td>
<td>Antony and Desai (2009)</td>
<td>Wilson Tools</td>
<td>Shorten the heat treatment time</td>
<td>Roughly $10000 per year savings. 2% reduction in overall Lead time</td>
</tr>
<tr>
<td>10.</td>
<td>Singh and Khanduja (2010)</td>
<td>A copper wire manufacturing plant</td>
<td>Quality improvement in rolling operation</td>
<td>Defect are decreased by 19% within nine months of DMAIC project</td>
</tr>
</tbody>
</table>

### PROBLEM FORMULATION

In India, manufacturing industries like foundries do not enjoy monopoly but they have to face competition (Chaganti and Greene, 2002). To overcome this problem and to retain the share of the market, it is necessary to constantly improve the quality of the cast product without increasing price of the products. The price is influenced by the cost of production, which in turn is influenced by rework or rejection. Attention to quality assurance can reduce the wasteful rework. Aiming for quality in the first instance can reduce the cost of casting production. This quality production results in the company’s growth and profitability. Among various reasons responsible for this malady, low utilization of productive capacity is the major reason, which should cause concern for production planning and for this capacity waste, rejection and scrap accounts for a major share (Hollenstein, 2005). The technology gap is alarming and a company in India spends less than 0.6% on average, of its turnover on R&D as against the world average of 2.5% (Coronado and Antony, 2002). In a small unit, where investment in plant and machinery is less than Rs.10 million, productivity and profitability are indispensable to assess
the performance of such an organization. Arita and McCann (2002) in their study have observed that reduction in cost and product rejection rate are among the main pressures on small units. The main barriers for these units to be competitive are inadequate technologies causing lot of defects, poor human expertise and scarcity of resources impairs their ability to become internationalized (Lucas, 2002).

**METHODOLOGY ADOPTED**

For global competitiveness, Indian industries are working hard to achieve overall operational excellence in their business (Zu et al., 2011). Six Sigma has evolved into a powerful business improvement methodology in many Indian industries and its importance is growing (Voelkel, 2002). Within Indian SMEs, this paper has validated the concept of Six Sigma successfully by unveiling a tested DIMAC methodology for foundry SMEs. In the present market, competitors are looking for flexibility and shorter production lead times because only such a configuration of production system can fulfil the ever-changing demands of customers (Antony, 2004). But for this it is necessary to have less scrap as it is well known that this will result into economic production (Eckes, 2001). To handle these challenges, competitors are forced to move towards such strategies/techniques which can make production less costly and of optimum quality. Wright and Basu (2008) highlight that by Scrap reduction, one can have maximum utilization of machine or equipment, which will obviously enhance the production rate and make the overall production more feasible. This can be remarkably tackled by inculcating above cited DMAIC approach uniformly in the given foundry conditions, particularly in foundry SMEs of India. Six Sigma is a highly structured program developed by Motorola and used to improve quality world widely (Singh and Khanduja, 2010). This contains a number of management and statistical tools and techniques in its respective phases (Lin et al., 2008). There is always a risk of choosing wrong tools due to negligence or production constraints for performing improvements, that ultimately leads to failure of this approach and it only bounds to produce paper work projects that are far away from real world savings. The proposed work tries to simplify the phases of Six Sigma and categories the given tools/techniques with respect to their utility and further successfully validates its effectiveness by conducting a successful case study in a non-ferrous foundry.

Literature review also shows that Six Sigma research has been mostly empirical in nature which reinforces the use of real-world data. Case study was the dominant approach in Six Sigma research and this is perhaps due to the fact that quality problems in manufacturing and service contexts are usually treated as a case in terms of documentation and analysis. Figure 1.9 defines the growing gap over the years between case study method and other research methods, particularly survey research. Case study method is used to document and analyze Six Sigma implementation in particular contexts; industry, service, process or phase of a specific project. In addition, the lack of implementing Six Sigma tools and methodologies across a wide range of processes or organizations makes the use of survey approach impractical. The graph in figure 1 shows that case study based approach has been well acceptable and successful since 1992, as far as Six Sigma concept and its implementation are concerned. From 2004 to 2008, researchers seem to be using this approach exponentially as compared to survey based and
review based frameworks by analyzing the benefits and authenticity of case study based works in the field of Six Sigma.

Figure-1: Historical Trend of Six Sigma Implementations

![Historical Trend of Six Sigma Implementations](Source; Aboelmaged, 2009)

The present work has taken this case study based approach to achieve the pre-defined goals and objectives relating to Six Sigma implementation in Indian foundries.

A CASE STUDY

A case study has been carried out in a non-ferrous foundry at Federal Mogul India Limited Bhadurgarh, Patiala (Punjab) which casts around 9.5 million pistons annually. Foundry has a covered area of about 50144 m² and was established in 1954. It is a medium scale unit used to cast pistons for export to US and uses mostly semi-automatic die casting machines. Dies of different types of pistons have been installed on machines as per the monthly planning/scheduling and pouring of metal is performed manually by operators. Foundry under consideration is used to cast piston of diameter ranging from 30mm to 300mm and capable to manufacture 13 million pistons per annum. In July 2010, a six months Six Sigma project was initiated to reduce the scrap of export-pistons (form 22% to 10% approximately). The main five phases of project (Define, Measure, Analyse, Improve and Control) have been executed in the given foundry environment to make the Six Sigma implementation more compatible with the present dynamic environments of foundry industry.
Define phase

The first step was to precisely define the problem, keeping in mind business objectives, customer needs and feedback (Singh and Khanduja, 2012a). This involves identification of Critical to Quality (CTQ) issues and other items that have an impact on quality and customer satisfaction.


**Findings:** The house of quality was generated to hear the voice of customers effectively and ‘reduction in casting scrap’ has been adopted as the most critical issue (refer figure 2). To define the problem of large scrap quantitatively, previous six month’s data was collected regarding scrap and good pieces from production reports. It was found that H-749 pistons had around 20% to 24% of scrap, which was causing substantial financial and non-financial losses. The impact of high rejection became clearly obvious as net rejection cost came out to be around Rs.30,70,000/- per annum and is substantial for a medium scale foundry. For intense focusing on the foundry. The whole process was mapped (refer figure 3). Key process input variables at each operation were found out and further classified into three categories; Noise Variables, Critic Variables and Controlled Variables respectively.

Measure phase

Measure phase is the second step after defining the problem which involves measurement system analysis, capability studies and finding performance gaps for the identified problem (Singh and Khanduja, 2012c).

**Major Tools Used:** Sigma Calculator, Pareto Charts, Cause and Effect Matrix, Gauge R&R study, Bias Checking and Stability Test.

**Findings:** The existing sigma level of casting process has been calculated by a sigma calculator that works on the principle of DPMO and this was calculated as 3.43 for the process. The existing foundry process has been mapped minutely and drawn as in figure 3 ahead. Pareto chart has defined all the 20% factors that are causing 80% of the problem (see figure 4). In the present case shrinkage at ring zone and skirt, bottom thickness (BT) variation, blow holes in ring zone and bottom, cold lap and porosity are emerging as the prime reasons of high casting scrap in H-749 pistons.
**Figure-2: House of Quality**

### VOC (Machine Shop)

<table>
<thead>
<tr>
<th>Importance to Customer</th>
<th>Target Direction</th>
<th>Completeness Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Importance to Customer</td>
<td>Meet Deadlines/Schedules</td>
<td>M M H H M H M M L M 230</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Reduction in Production Cost</td>
<td>M M M N M L H H L M N 150</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Satisfy Quality Initiatives (Overall Quality of the Product)</td>
<td>N M L H L L H M M 128</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Cycle Time Reduction</td>
<td>L M H N N M M M N 155</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Reduce Rework</td>
<td>5 15 45 0 0 15 15 15 15 0 125</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Strong Information System</td>
<td>L L N N N L H H L 48</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Accountability of Supplied Product</td>
<td>H M H M N M M M M L 117</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Less Dimensional Problems</td>
<td>M H L N H M M N N 130</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Develop Closer Supplier Relations</td>
<td>M M H N L M L M N M 78</td>
</tr>
<tr>
<td>Importance to Customer</td>
<td>Reduce Waste</td>
<td>M M H L M M M H H 230</td>
</tr>
</tbody>
</table>

**TARGET VALUE OF CTC (Critical to Customer) FACTOR**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Relationship Between X &amp; Y</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Strong (H)</td>
<td>9</td>
</tr>
<tr>
<td>M</td>
<td>Medium (M)</td>
<td>3</td>
</tr>
<tr>
<td>L</td>
<td>Weak (W)</td>
<td>1</td>
</tr>
<tr>
<td>N</td>
<td>No Relation (N)</td>
<td>0</td>
</tr>
</tbody>
</table>

**Target Directions**

- More is Better
- Less is Better
- Specific Amount

10%
Figure-3: Process Mapping with Key Performance Input Variables (KPIVs)

Step 5:
- Die preparation
- Ingots transportation to foundry
- Ingots storage (in Cell)
- Molten metal temperature
- Aging
- Degassing and flux treatment
- Input Classification
- Holding time and impurity flotation
- Pouring
- Density Index (ID)
- Furnace charge relation
- Croppers
- Time
- Die coating
- Microstructure
- Heat Treatment
- Controlled
- Hardness
- Pouring speed
- Water cooling Time
- Water cooling temp.
- AQFD
- Scrap
- Time
- Scrap
- Die temperature
- Die coating density
- Spray gun
- Free of humidity
- Free of slag
- Change relation (50 Ingot:40 scrap)
- Metal Temp.
- N2 Flow RPM
- Time
- ID=1.5 max.
- Time
- Ingate separation
- Separate in baskets by defects
- Free of visual defects
- Soft in baskets by savy

CTQ's
A.- Die coating
B.- Furnace charge relation
C.- Molten metal temperature
D.- Density Index (ID)
E.- Cycle time
F.- Pouring speed
G.- AQFD
H.- Without visual defects
I.- Aging
J.- Microstructure
K.- Hardness
L.- Chemical analysis

Figure-4: Pareto Chart for Defect Analysis

Pareto Chart of H-749

- NUMBERS
- DEFECTS
- Percent
- Cum %

NUMBERS
426 203 133 99 98 52 40 32 26 19 52
Percent
36.1 17.2 11.3 8.4 8.3 4.4 3.4 2.7 2.2 1.6 4.4
Cum %
36.1 53.3 64.6 73.0 81.3 85.7 89.1 91.8 94.0 95.6 100.0
By conducting Cause & effect Analysis, Process parameters (SSVs) like; In-gate Design, Die Temperature, Die Coating Thickness, Alloy Temperature, Discharge of Cooling Water, Shift Dependency and Delay during Casting have been measured as the main reasons of the above defects in piston castings. The next crucial step in the measurement phase is the measurement of the accuracy and precision of already ‘in-use’ measuring equipments or gauges. In the present case, it was decided to validate the calibration by conducting Gage R&R study for bottom thickness gauge (BT gauge), bias checking of immersion pyrometer and stability test of Vac-tester (metal density checker) respectively.

**Analyze phase**

At the end of Measure Phase, seven critical to quality (CTQ) process parameters were short listed and these seemed to be the major reasons for high scrap. As per DMAIC methodology, before targeting these susceptible sources of variations (SSVs) through ‘Improve Phase’, the authenticity and impact realization of each SSV on scrap, is required to be judged by conducting suitable investigation under Analyse Phase. This phase helps to focus improvement efforts on those SSVs which can be highly significant (Singh and Khanduja, 2011a).

**Major tools used:** Table 2 gives a summary of various quantitative and qualitative techniques/tools used for analyzing the measured critical to quality (CTQ) process parameters.

**Tables-2: Identifying Analytical Tools for Each SSV**

<table>
<thead>
<tr>
<th>Analysis Technique</th>
<th>Tool</th>
<th>SSV Analyzed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis Testing (OFAT)</td>
<td>Chi Square Test</td>
<td>Analysis of Shift dependency</td>
</tr>
<tr>
<td></td>
<td>One Way ANOVA</td>
<td>Die Coating thickness</td>
</tr>
<tr>
<td></td>
<td>Two Sample t-Test</td>
<td>In gate design</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge of cooling water</td>
</tr>
<tr>
<td>MFAT</td>
<td>Multi Regression</td>
<td>Alloy temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Die temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Delay time</td>
</tr>
</tbody>
</table>

Findings: After this phase, it is amply clear that out of the seven susceptible sources of variations (SSVs), only four are actually responsible for high value of scrap and these are: Ingate Design, Die Temperature, Delay Time and Discharge of Cooling Water. Unwanted SSVs have been omitted which seems to be vital for being focused on serious issues for reducing the scrap significantly. Outcomes of this phase have been summarized in table 3.
Table-3: Out Comes of Analyse Phase

**Analysis of Shift Dependency:** The overall chi-square value is coming out to be 6.150 and value of \( p \) is 0.908 at 12 degrees of freedom. As it is higher than 0.005. The null hypothesis cannot be rejected at 5\% significance level. Therefore there is no difference between the mean scrap value of morning, afternoon and night shift. Hence it makes clear that this factor does not contribute to scrap in the shop-floor and can be dropped here only.

**Effect of Die Coating Thickness:** Under given temperature and time conditions, die has been made to run with various coating thicknesses (i.e. at 50 microns, 80 microns 110 microns and 140 microns) separately. After giving input of above data, Minitab has compiled Analysis of Variance for all the four groups and generated \( p \) value as 0.932 at 95\% confidence level. It implies again that the null hypothesis is acceptable. The graph drawn shows less variation among the mean of all populations. Hence this factor seems to be less significant in context of high casting scrap.

**Impact of In-gate Design:** This analysis contains two groups and each has samples less than 30, hence 2-sample t-test is best for such type of data populations. For this analysis, two piston dies of H-749 have been selected, one has existing runner riser volume (i.e. 250-260 cm\(^3\)) and other is modified to the volume of runner riser up to 260-270 cm\(^3\) (by altering the gate design). \( t \)-value is coming out to be 4.63 and probability value \( (p) \) is 0.001, which is less than 0.05 \( (\text{value of } \beta \text{ at } 95\% \text{ confidence}) \). It concludes that the null hypothesis has been rejected in the favour of alternate hypothesis for the given two populations.

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It implies that with increase in runner and riser volume (or altering In-gate design) casting defects are reducing.

**Discharge of Cooling Water:** The p value for this factor is less than 0.05 while conducting the 2 sample t-test. So, Discharge of cooling water has also erupted as major factor for casting defects as null hypothesis of no affect has been rejected.

**Analysis of Process Parameters:** In the present study, three process parameters (namely; Alloy temperature, Die temperature and Delay time) have been measured as more critical as far as question of high casting scrap of piston castings is raised. In order to verify their dependability on dependent output variable (scrap), the Six Sigma team has decided to perform Multi-regression analysis. The regression calculations and results have been quoted in sideline figure. From the calculated p values, it represents Alloy temperature is in control conditions and only Delay in-between casting process and Die temperature are impacting casting scrap seriously.

**Improve phase**

In this phase actions are piloted and real tolerances are established to deliver desired performance (Singh and Khanduja, 2011b). Various suggestions and new activities have been added during optimization of the out-put variable.

**Major Tools Used:** Design of Experiments (DOE).

**Findings:** Scrap reduction is the main problem which depends upon four selected casting process variables (factors). Each factor is defined in terms of high and low values of levels (refer to table 4). To realize the effect of each factor or their interactional impact on scrap, ‘full factorial design’ has been selected for optimizing the process in-put factors. No blocking

---

**Regression Analysis:** %age of Scrap versus Alloy Temp., Stoppage (in secs) & Die Temp.

The regression equation is
\[
\%age\ of\ Scrap = 114 + 0.118\ Alloy\ Temperature + 0.306\ Stoppage\ (in\ Sec) - 0.745\ Die\ Temp
\]

<table>
<thead>
<tr>
<th>Predictor</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>114.4</td>
<td>476.2</td>
<td>0.24</td>
<td>0.822</td>
</tr>
<tr>
<td>Alloy Temperature</td>
<td>0.1184</td>
<td>0.6554</td>
<td>0.18</td>
<td>0.865</td>
</tr>
<tr>
<td>Stoppage (IN Sec)</td>
<td>0.30615</td>
<td>0.08153</td>
<td>3.76</td>
<td>0.020</td>
</tr>
<tr>
<td>Die Temp</td>
<td>-0.7454</td>
<td>0.2130</td>
<td>-3.50</td>
<td>0.025</td>
</tr>
</tbody>
</table>

\[ S = 7.70734 \quad R^2 = 83.5\% \quad R^2(adj) = 71.1\%
\]

**Analysis of Variance**

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regression</td>
<td>3</td>
<td>1200.75</td>
<td>400.25</td>
<td>6.74</td>
<td>0.048</td>
</tr>
<tr>
<td>Residual Error</td>
<td>4</td>
<td>237.61</td>
<td>59.40</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>1438.37</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As P>0.05 for Alloy temp. It implies it is already in control.

As P<0.05 for Stoppage or Delay. It effects Scrap positively.

As P<0.05 for Die temperature. It also effects Scrap.

As P<0.05 for overall regression. It implies input variables have impact on dependent variables.
is used and experiments were replicated twice for suitable accuracy. So it requires $2^4$ experiments and for generating effective impacts of each factor over the response, random repetition of 16 experiments or total 32 runs were performed.

Table-4 Two Levels of each Critical Factor

<table>
<thead>
<tr>
<th>Factors/Levels</th>
<th>(A) Die Temp (in Degrees)</th>
<th>(B) Discharge of Water (Liter Per Minute)</th>
<th>(C) Delay (Seconds)</th>
<th>(D) Volume of R &amp; R ($cm^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>250</td>
<td>7</td>
<td>60</td>
<td>260</td>
</tr>
<tr>
<td>High</td>
<td>330</td>
<td>10</td>
<td>180</td>
<td>285</td>
</tr>
</tbody>
</table>

Scrap value has been calculated for each run. Figure 5 shows the analysis of the orthogonal matrix of experiments through Minitab Statistical Software.

Figure-5: DOE Statistics

Factorial Fit: Scrap (%) versus Die Temp, Discharge of water,

Estimated Effects and Coefficients for Scrap (%) (coded units)

<table>
<thead>
<tr>
<th>Term</th>
<th>Effect</th>
<th>Coef</th>
<th>SE Coef</th>
<th>T</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>14.281</td>
<td>0.1362</td>
<td>104.84</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Die Temp</td>
<td>3.937</td>
<td>1.969</td>
<td>0.1362</td>
<td>14.45</td>
<td>0.000</td>
</tr>
<tr>
<td>Discharge of water</td>
<td>-1.813</td>
<td>-0.906</td>
<td>0.1362</td>
<td>-6.65</td>
<td>0.001</td>
</tr>
<tr>
<td>Delay</td>
<td>0.438</td>
<td>0.219</td>
<td>0.1362</td>
<td>1.61</td>
<td>0.128</td>
</tr>
<tr>
<td>Volume of R&amp;R</td>
<td>-4.313</td>
<td>-2.156</td>
<td>0.1362</td>
<td>-15.83</td>
<td>0.002</td>
</tr>
<tr>
<td>Die Temp*Discharge of water</td>
<td>0.062</td>
<td>0.031</td>
<td>0.1362</td>
<td>0.23</td>
<td>0.821</td>
</tr>
<tr>
<td>Die Temp*Delay</td>
<td>-0.187</td>
<td>-0.094</td>
<td>0.1362</td>
<td>-0.69</td>
<td>0.501</td>
</tr>
<tr>
<td>Die Temp*Volume of R&amp;R</td>
<td>0.563</td>
<td>0.281</td>
<td>0.1362</td>
<td>2.06</td>
<td>0.056</td>
</tr>
<tr>
<td>Discharge of water*Delay</td>
<td>-0.687</td>
<td>-0.344</td>
<td>0.1362</td>
<td>-2.52</td>
<td>0.026</td>
</tr>
<tr>
<td>Discharge of water*Volume of R&amp;R</td>
<td>0.312</td>
<td>0.156</td>
<td>0.1362</td>
<td>1.15</td>
<td>0.268</td>
</tr>
<tr>
<td>Delay*Volume of R&amp;R</td>
<td>-0.187</td>
<td>-0.094</td>
<td>0.1362</td>
<td>-0.69</td>
<td>0.501</td>
</tr>
<tr>
<td>Die Temp<em>Discharge of water</em>Delay</td>
<td>0.187</td>
<td>0.094</td>
<td>0.1362</td>
<td>0.69</td>
<td>0.501</td>
</tr>
<tr>
<td>Die Temp<em>Discharge of water</em>Volume of R&amp;R</td>
<td>-0.813</td>
<td>-0.406</td>
<td>0.1362</td>
<td>-2.98</td>
<td>0.009</td>
</tr>
<tr>
<td>Discharge of water<em>Delay</em>Volume of R&amp;R</td>
<td>-0.313</td>
<td>-0.156</td>
<td>0.1362</td>
<td>-1.15</td>
<td>0.268</td>
</tr>
<tr>
<td>Volume of R&amp;R</td>
<td>-0.313</td>
<td>-0.156</td>
<td>0.1362</td>
<td>-1.15</td>
<td>0.268</td>
</tr>
<tr>
<td>Die Temp<em>Discharge of water</em>Delay*Volume of R&amp;R</td>
<td>-0.437</td>
<td>-0.219</td>
<td>0.1362</td>
<td>-1.61</td>
<td>0.128</td>
</tr>
</tbody>
</table>

S = 0.770552   PRESS = 38
R-Sq = 97.09%   R-Sq(pred) = 88.36%   R-Sq(adj) = 94.36%
In the present case, it has been found that A, B, D, BC and ABD are more critical factors and factor interactions, that are affecting overall casting scrap substantially. These are dotted in red and lying far away from the normal plot line of standardized effects. Figure 6 represents the ‘relative percentage of significance’ for every factor responsible for scrap. The main effect plots have been drawn to describe the individual effect of each factor on the response. Figure 7 shows four factors plotted in between their respective two levels and against scrap to show their impact, independently. The slope of the main effect line in each plot represents the high impact of that factor on response.

**Figure-6: Normal Plot of Effects to Foreground CTQ Factors**

**Figure-7: Main-Effect Plot (OFAT)**
Plots for two-way interactions have been presented in figure 8. Graphically it is obvious that BC (or combined effect of discharge of cooling water and delay) has vital impact on scrap, as two effects are crossing with each other.

Similarly other interactions of delay with volume of R&R and die temperature are also affecting scrap up to a certain level but the main effect of delay was coming out to be less significant. Out of three two-way interactions of delay, the combination with discharge (C) seems to be more effective.

**Figure-8: Two-way Interactions (MFAT)**

<table>
<thead>
<tr>
<th>Interaction Plot for Scrap (%) Data Means</th>
</tr>
</thead>
<tbody>
<tr>
<td>Die Temp</td>
</tr>
<tr>
<td>Discharge of water</td>
</tr>
<tr>
<td>Delay</td>
</tr>
<tr>
<td>Volume of R&amp;R</td>
</tr>
</tbody>
</table>

Three-way interactions have also been analyzed but only the ABD interaction was significant, therefore a cube plot has been generated in figure 9 describing all possible three-way interactions of input process factors in the ABD group.

**Figure-9: Cube Plot for Critical Three Way Interaction (ABD)**
Response Optimizer or Overlaid Contour Plot has been used to obtain a numerical and graphical analysis. All the factors and their starting lower levels have been quoted in optimizer. The existing value and required target value of the response are fed with possible upper and lower values. The optimizer in Minitab software shows results at 99% desirability (see figure 10). The results are placed in the form of a solution to the problem and quoted in red colour. These optimized values of respective factors had reduced the piston scrap up to 10% as per the calculations of Minitab’s response optimizer tool.

Later, it was estimated that an approximate saving of Rs.16,78,000/- per annum has been achieved by reducing the scrap of H-749 pistons from around 22% to 10% (in first attempt). It is a great achievement for a medium scale non-ferrous Indian foundry.

**Control phase**

During this phase, process monitoring and corrective or preventive actions are documented and executed. Basically this phase tries to check and monitor the improved process and its parametric values.

**Major tools used:** Control Plan, p-Chart for overall scrap tracking.

**Findings:** In order to control the concerned parameters at their improved values, necessary modification in control plan of casting process has been done as per the output of DOE. After brainstorming, maximum tolerance limits for metal temperature, water temperature and cooling time etc were fixed. It is recommended to check 5-S condition of casting work station daily by visual inspection by the Production Supervisor. The overall sigma level has been raised by 0.24. The Runner & Riser volume has been increased permanently as per recommendations of DOE results. It was also decided to monitor the overall casting scrap due to other reasons and scrap is further controlled by drawing p-charts daily by inspection supervisor in general shift. The one month data for p charts has been collected and shown in figure 11, which predicts the day to day current status of scrap in piston foundry. These control measures have successfully run the piston foundry for consecutive two months at around 10.4 % scrap only.
The Control phase has been integrated to configure infrastructure (hardware and software) and to with-hold the settings, improvements, adjustments and optimizations performed during Six Sigma case-study, with passage of time. This phase may also include some Value-Engineering proposals for input parameters to resist changes in improved process variables, like:

Proper On-the-job training schedule for awareness of all the concerned shop floor staff, so that their code of conduct becomes positive and responsive to tackle responsibilities. For more awareness and to understand the significance of Six Sigma improvements, a ‘Six Sigma Corner’ should be developed in the middle of production floor that should usually be operated by a black belt champion.

A comprehensive check list to cover every factor of all phases could be helpful to related work force in reminding vital steps at the right time.

A Process-Indicator board (look figure 12) has been specifically designed to mitigate the execution of all the casting activities/set up activities of H-749 pistons in a desired sequence like die installation, setting of cooling time and emergency timer, installing of top frame of die with ram of machine, alignment of top and bottom frame of die, level of molten metal in the holding-furnace, metal temperature reading and checking of proper water supply connections with die top etc., before commencing regular production runs. It also supports important process variables like die temperature, cooling water temperature and control over cycle time with series of successive indicators, once the relevant check or activity has been performed or ensured successfully. Proper hooters have also been installed with the board to warn the machine operators in case of missing of any casting activity or its parameters settings. It really makes the whole die casting process well sustained and ensures optimisation of relevant variables efficiently and as per process requirements.

Three patrol teams of expert casting operators are constituted to vigil the critical foundry processes and their vital parameters, while patrolling in each shift.

To sustain the overall improvements acquired by DMAIC process, one executive level person to be deputed to have a round at least once a week on the production shop floor, so that value adding activities can be performed in a more controlled and consistent manner in future.
Audit sheets and work instructions to be displayed for sustaining proper execution of various foundry processes.

**Figure-12: Process Indicator Board**

Process to be supported suitably by an appropriate implementation of principle of 5-S, safety rules and good practices in the foundry.

The Control phase tends to support the improved process and ensures the process execution in between the controlled limits by total cultural improvement of given production environment. It leads to stability of the system, which ultimately causes the customer satisfaction. The Control phase has also raised future hopes for much more profitability by implementing such Six Sigma cases for other parts like; for domestic gasoline and diesel vehicle pistons etc.

**CONCLUSIONS**

Manuscript has significantly reaffirmed the efficacy of Six Sigma strategy in Indian foundry industry by reducing scrap/waste from the operations, thus greatly improving the production efficiency. ‘Project based’ approach for Six Sigma implementation (rather planning, training or investing in different phases of Six Sigma approach) is more motivating and helps a lot to demystify various fears on Six Sigma. A cadre with sound theoretical knowledge on different statistical tools and software needs to be built up in the management, so as to bridge the gap between the theory and practice of Six Sigma and appreciate its potential while bringing in business excellence (Singh and Khanduja, 2012b).

Beside non-ferrous foundries, Six Sigma approach can be explored for ferrous foundries to bring breakthrough in rejections and increase yield per annum. It can also be used in energy intensive units, as it not only enhances productivity by process improvement but also it is a step to create ‘zero defect units’ which indirectly reap huge energy/power savings. Apart from foundry industries, other manufacturing sectors like forging, forming, welding and machining industries can also take benefits to lean their respective business operations. Six Sigma should further be explored in service sector like; hospitals, offices, banking, traffic etc. Through an extensive literature search, it was observed that very little documentation exists in the application of Six Sigma to education sector. This approach will bring paradigm shifts in enterprises by inculcating high skill levels among their management personnel, managers, engineers, practitioners or even workers. The challenge for all organizations is to integrate Six Sigma into their core business processes and operations rather than managing it as a separate initiative. Six Sigma, a systematic framework for quality improvement and business excellence, has been widely publicized in recent years as the most effective means to
combat quality problems and win customer satisfaction but it is still at its infancy stage as far as Indian industries are concerned.

REFERENCE


Director of Industries (2003), “Data on Employment, Number of Units, Investment and Production of Industrial Sector”.


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