# Introduction of Statistical Process Control System in a Ductile Iron Pipe Manufacturing Plant for Export Promotion

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ABSTRACT *This study illustrates how a system of statistical process control consisting of appropriate statistical techniques is introduced in an Indian organization that manufactures ductile iron pipes, with a view to expanding the market for export promotion. This is a part of corporate business strategy of the organization. The statistical system is introduced by taking into account certain critical-to-quality product characteristics of some processes, which have been identified by the auditors of the Korean Standards Association (KSA). The specific recommendations with regard to the introduction of the statistical system are based on an extensive assessment of the existing performance of the identified processes by the authors. Successful implementation of the recommendations enabled the Indian organization to export to Korea in a big way.*

KEY WORDS: Ductile iron, eutectic point, X-MR chart, box whisker plot, process capability

## Introduction

An Indian ductile iron pipe manufacturing plant wanted to introduce a statistical system for exercising day-to-day control over its processes with a critical focus on export promotion. These pipes are primarily used for distribution of water, petroleum gas and sewage. It may not be out of place to mention here that in order to export to countries like Korea, stringent macro process control is necessary to enhance product quality, product performance and competitive performance. The auditors of the Korean Standards Association (KSA) identified the Critical to Quality (CTQ) product characteristics of these macro processes.

Accordingly, at the outset, a study has been carried out to assess the macro processes and their outputs. The following characteristics have been studied.

(a) *Chemical composition* is studied at Mini Blast Furnace (MBF), Mini Heel Furnace (MHF), and Converter (Magnesium treatment). It is worth mentioning here that MBF is a melting furnace where iron is extracted by melting through combustion of coke with air. MHF is an induction furnace for controlling the composition of cast iron under liquid condition. And a converter is a closed ladle to facilitate Magnesium (Mg) treatment for promoting graphitization in the form of spheroidal nodules during solidification. The Mg causes the graphite in the iron to precipitate in the form of microscopic spheres rather than the flakes found in ordinary cast iron. The spheroidal graphite in iron improves the properties of ductile iron. For details see Appendix 6 and White (1999).

(b) *Pipe thickness* is studied along the length of pipe starting from the socket end to the spigot end. It may be noted that the socket end of the pipe has a larger diameter compared with the spigot end. The configuration of the socket end is different from the spigot end. The socket end of one pipe is joined with the spigot end of another pipe by a flexible joint in which a rubber gasket is located in the socket and the joint assembly is effected by entering the spigot through the rubber gasket into the socket. The joint is called a 'push on joint'.

(c) *Sieve analysis* of sand, meant for cement lining of pipes, is studied. Sieve analysis has been done both for the incoming sand, supplied from a single source as well as for the final processed sand, obtained after sieving through a mesh of size 6 (ASTM Standard) and controlling moisture subsequent to processing through a Kiln.

## Objective

The statistical system has been introduced with the following objectives:

- Suggesting methods for day-to-day control over chemical composition at MBF, MHF and Converter.
- Providing guidance for taking appropriate corrective action to reduce thickness variation along pipe length.
- Recommending corrective action for controlling particle size of final sand after Kiln operation. It may be recalled that this processed sand is used for cement lining of pipes. As far as the particle size of incoming sand is concerned, hardly any action can be taken since there remains only one natural source of such sand in the country for supplying to the organization.

## Background Information

This study can be considered as one of the demonstrative evidences to highlight the usefulness of introducing Statistical Process Control (SPC) for key product characteristics. Since the company wants to explore overseas market expansion, application of SPC as an ongoing decision-making procedure, instead of taking decisions on arbitrary basis, becomes worthwhile. This is particularly important for exporting to country like Korea where application of SPC for day-to-day decision making procedure is a must.

## Technical Specifications based on Metallurgical and Usage Criteria

The technical specifications are given in Tables 1 and 2.

**Table 1.** Specification for chemical composition of liquid metal

| Chemical composition | Mini blast furnace | Mini heel furnace | Casting hopper after converter operation or Mg treatment |
|---|---|---|---|
| %C | 3.5–4.4 | 3.80–3.95 | 3.80–3.95 |
| %Si | 1.0–2.5 | 1.75–1.90 | 1.75–1.90 |
| %S | 0.15 Max | 0.15 Max | 0.02 Max |
| %P | 0.12 Max | 0.12 Max | 0.12 Max |
| %Mn | 0.50 Max | 0.50 Max | 0.50 Max |
| %Mg | Not Applicable | Not Applicable | 0.02–0.06 |
| Carbon Equivalent (CE) | $4.3 \pm 0.1$ | $4.3 \pm 0.1$ | $4.3 \pm 0.1$ |

Note 1: CE = C% + 1/3 (Si% + P%). The eutectic point is attained at 4.3. It is worthwhile to note here that in eutectic reaction, a liquid phase decomposes isothermally on cooling into two solid phases. The corresponding equilibrium point consisting of fixed temperature and composition of two phases is called eutectic point under invariant reaction $L \rightleftharpoons \alpha + \beta$

Note 2: Appendix 6 describes the impact of chemical composition on spheroidal graphitic cast iron material.

### *Particle Size of Sand*

At first, let us consider what is meant by the ASTM mesh size of a sieve. Thereafter specification for particle size of sand will be given – see Tables 3–5.

## Data

The statistical analyses in this study have been done corresponding to the data collected and compiled for the quality characteristics given in Table 6.

The chemical composition of liquid metal is analysed by the spectrographic method. For this purpose, samples are collected in the form of sample coins after every heat subsequent to MBF operation. At MHF, after attaining the requisite temperature, sample coins are collected just before sending the liquid metal to the converter. At the converter, every third

**Table 2.** Specification for pipe thickness

| Pipe diameter (mm) | Minimum thickness (mm) | Nominal thickness (mm) |
|---|---|---|
| 80, 100, 150 | 4.7 | 6.0 |
| 200 | 4.8 | 6.3 |
| 250 | 5.2 | 6.8 |
| 300 | 5.6 | 7.2 |
| 350 | 6.0 | 7.7 |
| 400 | 6.4 | 8.1 |
| 450 | 6.8 | 8.6 |
| 500 | 7.2 | 9.0 |
| 600 | 8.0 | 9.9 |
| 700 | 8.8 | 10.8 |
| 750 | 9.2 | 11.3 |
| 800 | 9.6 | 11.7 |
| 900 | 10.4 | 12.6 |
| 1000 | 11.2 | 13.5 |

**Table 3.** Sand grading

| ASTM sieve size | Side of the square of a sieve in mm |
|---|---|
| 6 | 3.350 |
| 12 | 1.700 |
| 20 | 0.850 |
| 30 | 0.600 |
| 40 | 0.425 |
| 50 | 0.300 |
| 70 | 0.212 |
| 100 | 0.150 |
| 140 | 0.106 |
| 200 | 0.075 |
| 270 | 0.053 |

ladle is considered for collection of sample coins at the casting hopper before casting the last pipe from that hopper.

The thickness of pipes is measured by an ultrasonic method along the length of pipes at 0.1 m, 1 m, 2 m, 3 m, 4 m, 5 m, 5.5 m and 6 m from the socket end in general.

The particle size of sand is determined by doing Sieve Analysis. The final sand is processed at the Kiln for control of moisture and particle size by sieving with ASTM sieve size 6 (i.e. 3.350 mm side of the square of a sieve).

## Analysis

Based on techno-economic considerations it has been decided that control will be exercised on the following chemical constituents at the relevant stages.

| Stage | Control will be exercised on |
|---|---|
| MBF | C%, Si%, S%, CE |
| MHF or Induction Furnace | C%, Si%, S%, Mn%, CE |
| Converter or Mg treatment | C%, Si%, Mg%, CE |

A control chart for individual observations along with moving range chart (X – MR Chart) is thought to be appropriate for this purpose. For a day-to-day process control purpose, control limits have been suggested corresponding to the respective target values of C, Si, Mg and CE. However, for S and Mn since there remains only upper specification

**Table 4.** Particle size of incoming sand

| ASTM sieve size | Retention % |
|---|---|
| 20, 30, 40 and 50 | 50.0 (Minimum) |
| −6/+12 (Means 6 pass but retention on 12) | 10.0 (Maximum) |
| −140 (Means 140 pass but retention on 200 and pan) | 10.0 (Maximum) |
| −200 (Means 200 pass but retention on pan) | 1.5 (Maximum) |

**Table 5.** Particle size of processed sand

| ASTM sieve size | Retention % |
|---|---|
| 20, 30, 40 and 50 | 50.0 (Minimum) |
| −6/+12 (Means 6 pass but retention on 12) | 5.0 (Maximum) |
| −100 (Means 100 pass but retention on 140, 200 and pan | 10.0 (Maximum) |
| −200 (Means 200 pass but retention on pan only) | 2.0 (Maximum) |

**Table 6.** The quality characteristics considered for data collection and compilation

| Quality characteristic |
|---|
| Chemical composition at MBF |
| Chemical composition at MHF |
| Chemical composition after Mg treatment, done by converter |
| Pipe thickness |
| Pipe thickness v/s pipe weight |
| Particle size for incoming sand for cement lining of pipes |
| Particle size for final sand for cement lining of pipes |

limits, control limits have been suggested corresponding to the respective average values. In order to compare actual performance of the process with the tolerance, Process Capability Indices (PCI) have been computed. A sample X-MR chart and Histogram are given in Appendix 1 for Sulphur percentage after MBF operation. For the X-MR chart the upper line indicates $UCL_X$, the central line indicates the process average and the lower line indicates the $LCL_X$ (Montgomery, 1991).

For analysing data on pipe thickness along the length of pipe, Box Whisker plots (Montgomery, 1997) are done. A small write-up has been given in Appendix 5 about Box Whisker plots to facilitate better understanding. The sample plots have been given in Appendix 2.

For particle size of sand (both incoming and processed sand) Run-Charts are provided in Appendix 3 (for incoming sand) and Appendix 4 (for processed sand). For all Run-Charts related to the sand analysis, the straight line running parallel to the horizontal axis indicates the specification limit.

## Results and Conclusion

For the results see Tables 7–9. Box–Whisker plots for pipe thickness (see Appendix 2) revealed clearly that except for 900 mm diameter and 600 mm diameter pipes, there was a tendency to produce a lower thickness in the middle portion of the pipes compared to the two ends of pipes – namely the socket end and the spigot end. In this context 900 mm diameter and 600 mm diameter pipes can be considered as internal benchmarks. Performance with respect to both central tendency and dispersion of pipe thickness across the length of pipes calls for adequate technical attention.

An attempt was made to establish the relationship between pipe weight and difference between maximum and minimum thickness of pipes. However, application of regression analysis produced no worthwhile result (see Tables 10 and 11).

**Table 7.** Results for chemical composition at MBF

| Ingredient | Specification | $N$ | $\bar{X}$ | Min | Max | Inherent process $\hat{\sigma}$ | Off-specification % <LSL | >USL | Total | Process Capability Index $C_p$ | $C_{pm}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C% | 3.95 ± 0.45 (3.5 to 4.4) | 329 | 4.25 | 3.22 | 4.44 | 0.0662 | 0.6 | 0.6 | 1.2 | 2.27 | 0.49 |
| Si% | 1.75 ± 0.75 (1.0 to 2.5) | 331 | 1.51 | 0.22 | 5.94 | 0.1702 | 13.6 | 0.0 | 13.6 | 1.47 | 0.85 |
| S% | 0.15 Max | 331 | 0.054 | 0.008 | 0.168 | 0.0112 | – | 0.3 | 0.3 | 2.86 | – |
| CE | 4.3 ± 0.1 (4.2 to 4.4) | 329 | 4.76 | 3.43 | 5.54 | 0.0805 | 4.0 | 93.0 | 97.0 | 0.41 | 0.07 |

## Recommendation

In order to control the chemical composition of liquid metal, the following control limits are suggested for application of X-MR control chart. These limits are based on the inherent variability of the process under the existing techno-economic set up (see Tables 12–14).

Root causes of pipe thickness variation along the pipe length are to be explored by conducting brainstorming session. In particular, the role of certain process parameters at the horizontal centrifugal casting stage is crucial for pipe thickness variation along the pipe length. Technically the potential parameters are mould r.p.m., rate of traverse of mould and metal temperature.

As far as the particle size of processed sand is concerned, there is scope for improving process capability with regard to percentage retention on −6/+12 ASTM sieve, provided the sieve attached to the Kiln (ASTM sieve size 6) is adequately straightened near the joints of two sheets of the sieve and at the edges. It is also to be seen whether the sieve size has become larger than the desired size of ASTM 6 because of prolonged usage.

**Table 8.** Results for chemical composition at MHF

| Ingredient | Specification | $N$ | $\bar{X}$ | Min | Max | Inherent process $\hat{\sigma}$ | Off-specification % <LSL | >USL | Total | Process Capability Index $C_p$ | $C_{pm}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| C% | 3.875 ± 0.075 (3.80 to 3.95) | 561 | 3.87 | 3.55 | 4.12 | 0.0616 | 19.8 | 20.3 | 40.1 | 0.41 | 0.40 |
| Si% | 1.825 ± 0.075 (1.75 to 1.90) | 561 | 1.82 | 1.36 | 2.30 | 0.0987 | 22.6 | 22.6 | 45.2 | 0.25 | 0.25 |
| S% | 0.15 Max | 561 | 0.061 | 0.012 | 0.125 | 0.0068 | – | 0.0 | 0.0 | 4.36 | – |
| Mn% | 0.50 Max | 561 | 0.29 | 0.17 | 0.44 | 0.0230 | – | 0.0 | 0.0 | 3.04 | – |
| CE | 4.3 ± 0.1 (4.2 to 4.4) | 561 | 4.50 | 4.09 | 4.79 | 0.0661 | 0.4 | 81.8 | 82.2 | 0.50 | 0.16 |

**Table 9.** Results for chemical composition at the Converter

| | | | | | | | Off-specification % | | | Process Capability Index | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Ingredient | Specification | $N$ | $\bar{X}$ | Min | Max | Inherent process $\hat{\sigma}$ | <LSL | >USL | Total | $C_p$ | $C_{pm}$ |
| C% | 3.875 ± 0.075 (3.80 to 3.95) | 1134 | 3.75 | 3.43 | 3.96 | 0.0378 | 72.1 | 0.1 | 72.2 | 0.66 | 0.19 |
| Si% | 1.825 ± 0.075 (1.75 to1.90) | 1134 | 1.89 | 1.51 | 2.31 | 0.0450 | 6.0 | 41.6 | 47.6 | 0.56 | 0.32 |
| Mg% | 0.04 ± 0.02 (0.02 to 0.06) | 1134 | 0.045 | 0.005 | 0.089 | 0.0070 | 0.7 | 6.2 | 6.9 | 0.95 | 0.77 |
| CE | 4.3 ± 0.1 (4.2 to 4.4) | 1134 | 4.39 | 4.12 | 4.63 | 0.0432 | 1.1 | 45.9 | 47.0 | 0.77 | 0.33 |

Note 1: For two-sided specification $C_p = (\text{USL} - \text{LSL})/6\hat{\sigma}$ and $C_{pm} = (\text{USL} - \text{LSL})/(6\sqrt{\hat{\sigma}^2 + (\bar{X} - \text{Target})^2})$.

If $\bar{X}$ and Target coincide, $C_p = C_{pm}$. The higher is the deviation between $\bar{X}$ and Target, the less will be the $C_{pm}$ compared with the corresponding $C_p$ value.

Note 2: For upper-sided specification, only $C_p$ is calculated as $(\text{USL} - \bar{X})/3\hat{\sigma}$

Note 3: For satisfactory process performance $C_p$ or $C_{pm}$ should be at least one.

**Table 10.** Incoming sand particle size

| Characteristic | Specification | Min | Max | $\bar{X}$ | $\hat{\sigma}_{n-1}$ | $C_p$ |
|---|---|---|---|---|---|---|
| %Retention [20, 30, 40 & 50 ASTM sieve] | 50.0 (Minimum) | 49.20 | 78.00 | 68.0372 | 7.2658 | 0.83 |
| %Retention [−6/+12 ASTM sieve] | 10.0 (Maximum) | 0.00 | 37.00 | 1.6395 | 4.7085 | 0.59 |
| %Retention [−140 ASTM sieve] | 10.0 (Maximum) | 0.60 | 6.80 | 2.3174 | 0.9001 | 2.85 |
| %Retention [−200 ASTM sieve] | 1.5 (Maximum) | 0.20 | 2.20 | 1.0140 | 0.3720 | 0.44 |

Note: Total number of observations is 86.

**Table 11.** Particle size of processed sand

| Characteristic | Specification | Min | Max | $\bar{X}$ | $\hat{\sigma}_{n-1}$ | $C_p$ |
|---|---|---|---|---|---|---|
| %Retention [20, 30, 40 & 50 ASTM sieve] | 50.0 (Minimum) | 45.60 | 88.40 | 71.7026 | 6.7200 | 1.08 |
| %Retention [−6/+12 ASTM sieve] | 5.0 (Maximum) | 0.00 | 30.40 | 1.2151 | 4.1720 | 0.30 |
| %Retention [−100 ASTM sieve] | 10.0 (Maximum) | 0.80 | 16.40 | 5.9868 | 2.3117 | 0.58 |
| %Retention [−200 ASTM sieve] | 2.0 (Maximum) | 0.20 | 1.60 | 0.8151 | 0.2241 | 1.76 |

Note 1: total number of observations is 53.
Note 2: $C_p = (\mathrm{USL} - \overline{X})/3\hat{\sigma}$ or $(\overline{X} - \mathrm{LSL})/3\hat{\sigma}$ for one-sided specification.
Note 3: For satisfactory performance $C_p$ should be at least one.

**Table 12.** Control limits at MBF

| Chemical composition | $\overline{\mathrm{MR}}$ | $\mathrm{UCL}_{\mathrm{MR}}$ | Target | $\mathrm{LCL}_X$ | $\mathrm{UCL}_x$ |
|---|---|---|---|---|---|
| C% | 0.07470 | 0.24399 | 3.950 | 3.7510 | 4.1490 |
| Si% | 0.19203 | 0.62727 | 1.750 | 1.2390 | 2.2610 |
| S% | 0.01258 | 0.04110 | 0.054 | 0.0204 | 0.0876 |
| CE | 0.09085 | 0.29678 | 4.300 | 4.0580 | 4.5420 |

**Table 13.** Control limits at MHF

| Chemical composition | $\overline{\mathrm{MR}}$ | $\mathrm{UCL}_{\mathrm{MR}}$ | Target | $\mathrm{LCL}_X$ | $\mathrm{UCL}_x$ |
|---|---|---|---|---|---|
| C% | 0.06943 | 0.22679 | 3.875 | 3.6900 | 4.0600 |
| Si% | 0.11129 | 0.36352 | 1.825 | 1.5290 | 2.1210 |
| S% | 0.00765 | 0.02499 | 0.061 | 0.0406 | 0.0814 |
| Mn% | 0.02598 | 0.08487 | 0.290 | 0.2210 | 0.3590 |
| CE | 0.07452 | 0.24341 | 4.300 | 4.1020 | 4.4980 |

**Table 14.** Control limits at converter

| Chemical composition | $\overline{\mathrm{MR}}$ | $\mathrm{UCL}_{\mathrm{MR}}$ | Target | $\mathrm{LCL}_X$ | $\mathrm{UCL}_x$ |
|---|---|---|---|---|---|
| C% | 0.04259 | 0.13914 | 3.875 | 3.762 | 3.988 |
| Si% | 0.05074 | 0.16575 | 1.825 | 1.690 | 1.960 |
| Mg% | 0.00791 | 0.02584 | 0.04 | 0.0190 | 0.0610 |
| CE | 0.04868 | 0.15903 | 4.3 | 4.170 | 4.430 |

Note 1: For moving range (MR) of two successive observations ($n = 2$), $\mathrm{D}_4 = 3.267$ and $\mathrm{UCL}_{\mathrm{MR}} = \mathrm{D}_4\overline{\mathrm{MR}}$. For $n = 2$, $\mathrm{D}_3 = 0$ and hence $\mathrm{LCL}_{\mathrm{MR}} = \mathrm{D}_3\overline{\mathrm{MR}} = 0$.

Note 2: For $n = 2$, $d_2 = 1.128$ and $\hat{\sigma} = \overline{\mathrm{MR}}/1.128$. Thus, $\mathrm{LCL}_x = \mathrm{Target} - 3\hat{\sigma}$, $\mathrm{UCL}_x = \mathrm{Target} + 3\hat{\sigma}$.

**Table 15.** Results of implementation

| | Before implementation | | | After implementation | | | |
|---|---|---|---|---|---|---|---|
| Pipe diameter in mm | No. pipes inspected | No. pipes rejected | % Rejection | No. pipes inspected | No. pipes rejected | % Rejection | % Reduction of rejection |
| 150 | 205 | 30 | 14.63 | 3231 | 185 | 5.73 | 60.83 |
| 200 | 1322 | 130 | 9.83 | 1744 | 75 | 4.30 | 56.26 |
| 250 | 1617 | 158 | 9.77 | 1922 | 61 | 3.17 | 67.55 |
| 300 | 1465 | 136 | 9.28 | 1575 | 72 | 4.57 | 50.75 |
| 350 | 2660 | 225 | 8.46 | 1302 | 75 | 5.76 | 31.91 |
| 450 | 447 | 42 | 9.40 | 562 | 26 | 4.63 | 50.74 |
| 500 | 2055 | 197 | 9.59 | 1106 | 53 | 4.79 | 50.05 |
| 600 | 178 | 19 | 10.67 | 1127 | 44 | 3.90 | 63.45 |

## Impact of the Study

The study impacted positively in terms of earning more foreign currency in dollar value. This enhanced the profit turnover of the organization substantially. Reduction of rejection of pipes by adopting the process approach of ‘doing the right thing right the first time’, enabled reducing the cycle time of pipe manufacturing process appreciably.

Successful implementation of the above recommendations led the organization to capture the export market – particularly the export market in Korea. Installation of a sound statistical system at some key technical processes consolidated the process of day-to-day decision making. The extent of the reduction in rejection percentage for different pipe diameters can be seen in Table 15.

## References

Montgomery, D. C. (1991) *Introduction to Statistical Quality Control* (Wiley).

Montgomery, D. C. (1997) *Design and Analysis of Experiments* (Wiley).

White, M. A. (1999) *Properties of Materials* (Oxford University Press).

## Appendix 1. X - MR chart for Sulphur Percentage at Mini Blast Furnace Operation

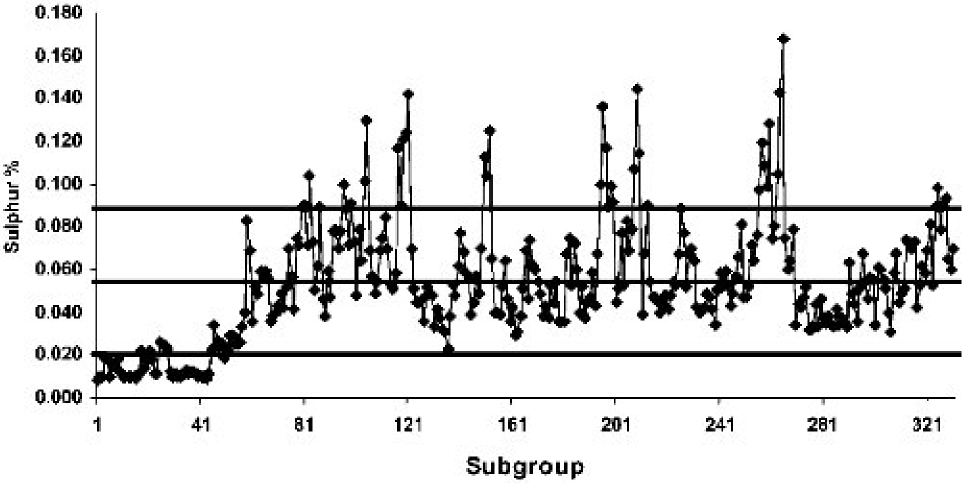


**Figure 1.** X chart

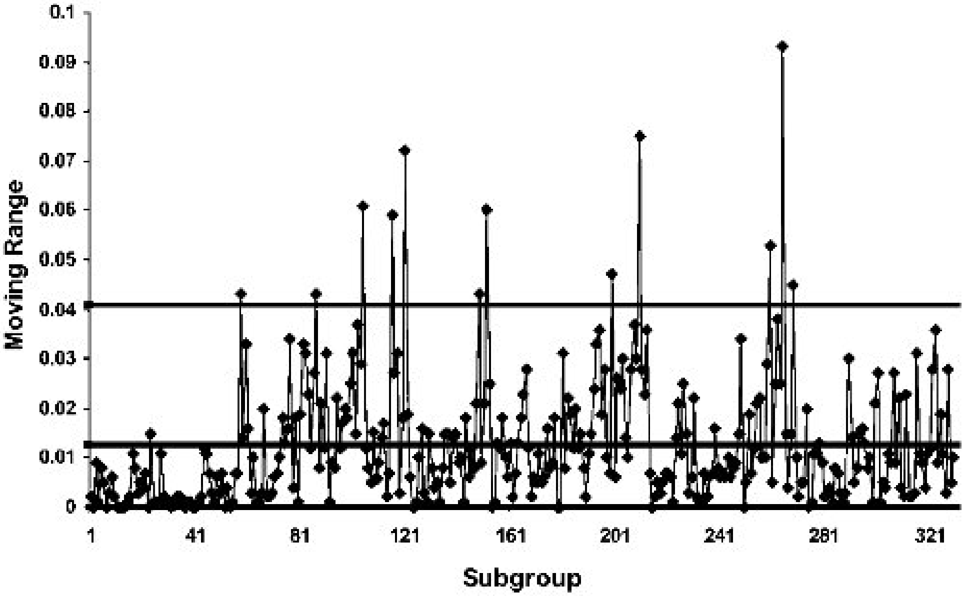


**Figure 2.** MR chart

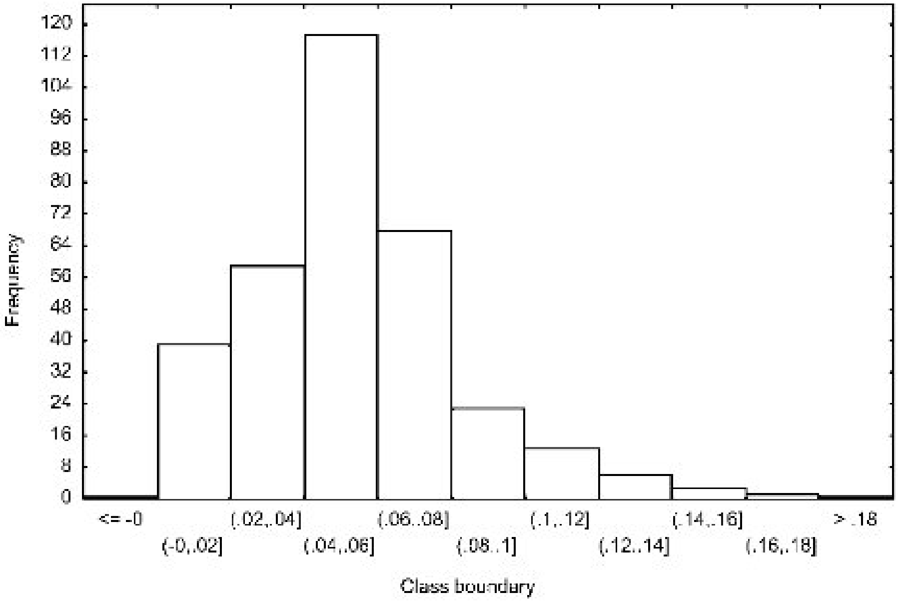


**Figure 3.** Histogram of Sulphur % at MBF operation

## Appendix 2. Box–Whisker Plot

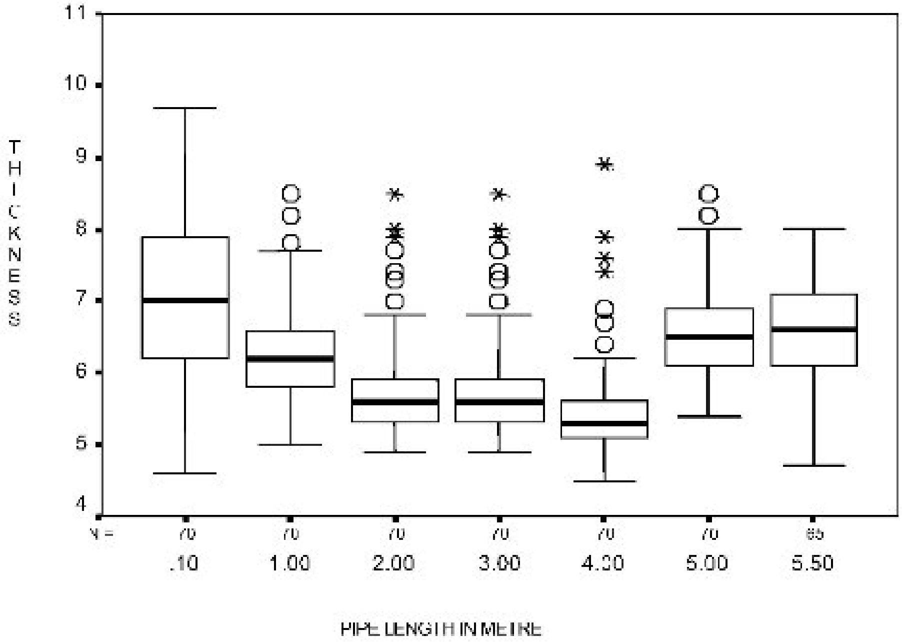


**Figure 4.** Box plot for 100 mm. diameter pipe thickness

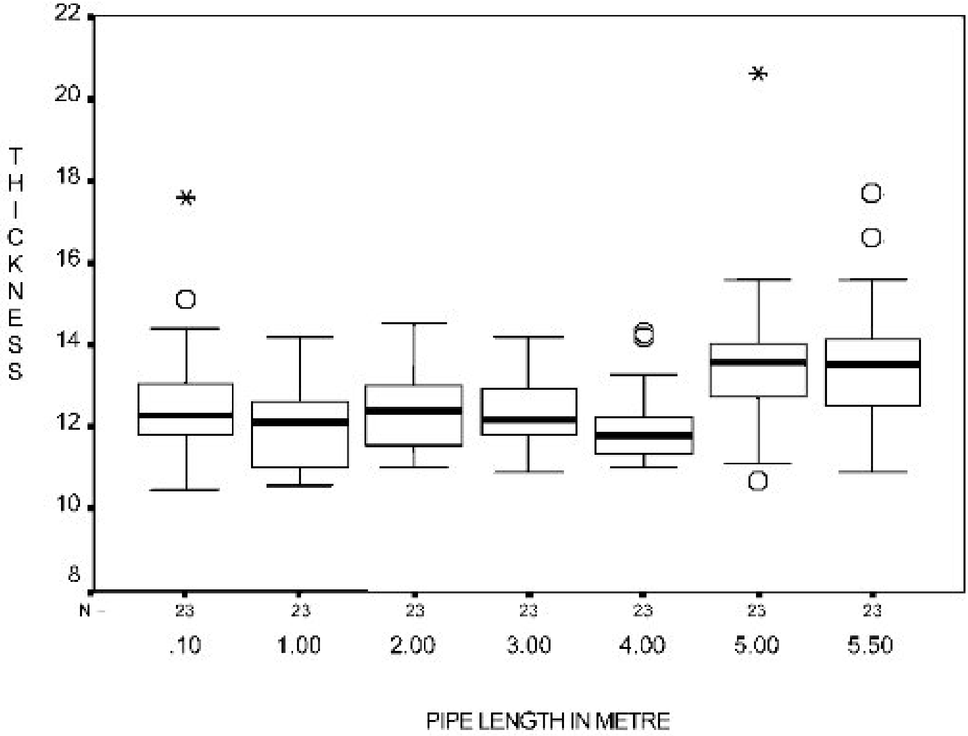


**Figure 5.** Box plot for 900 mm. diameter pipe thickness

## Appendix 3. Analysis on Percentage Retention of Incoming Sand for Cement Mortar Lining

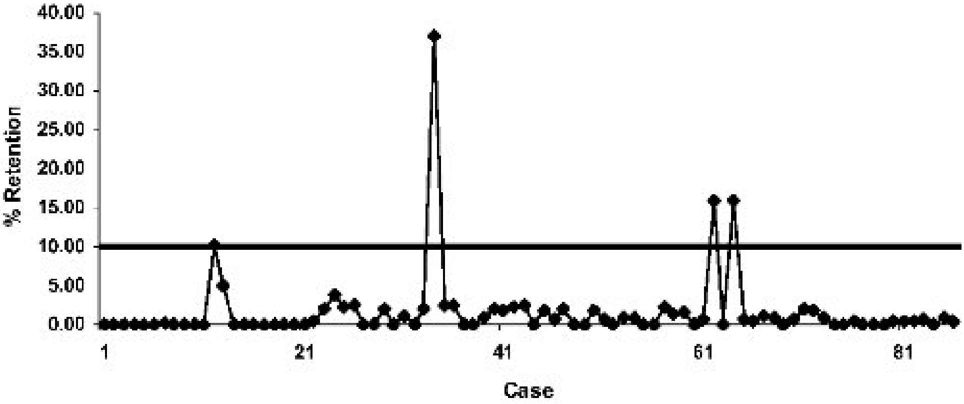


**Figure 6.** Percent retention on $-6/+12$ ASTM sieve of incoming sand

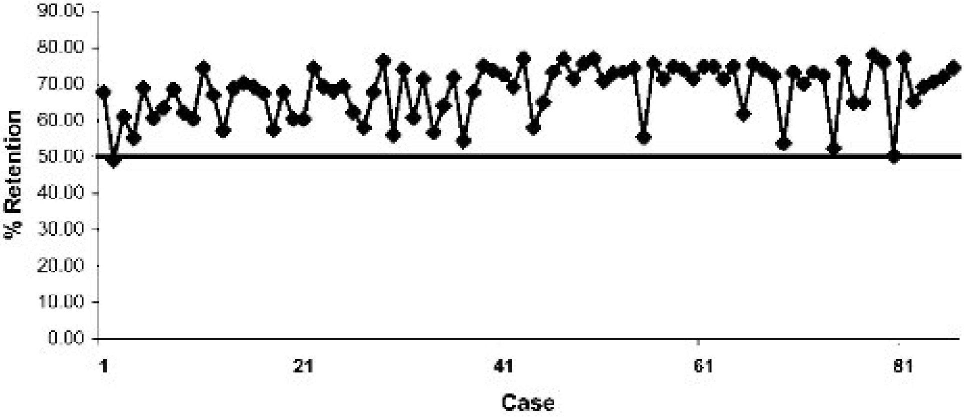


**Figure 7.** Percent retention on 20, 30, 40 & 50 ASTM sieve of incoming sand

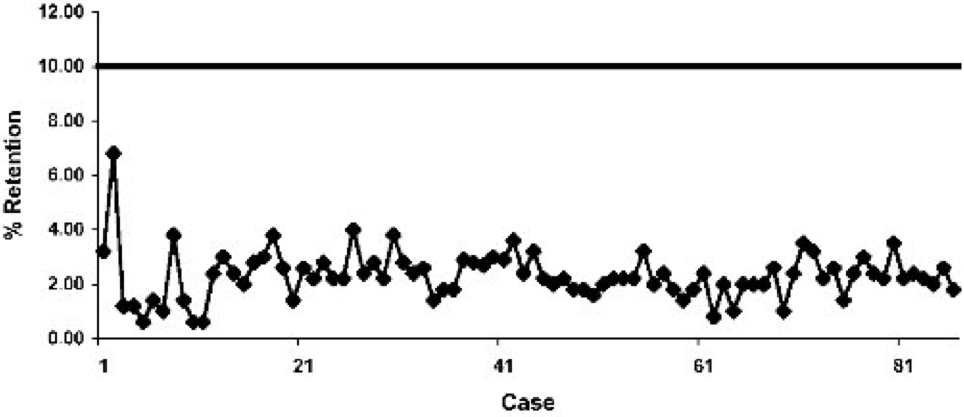


**Figure 8.** Percentage retention on −140 ASTM sieve of incoming sand

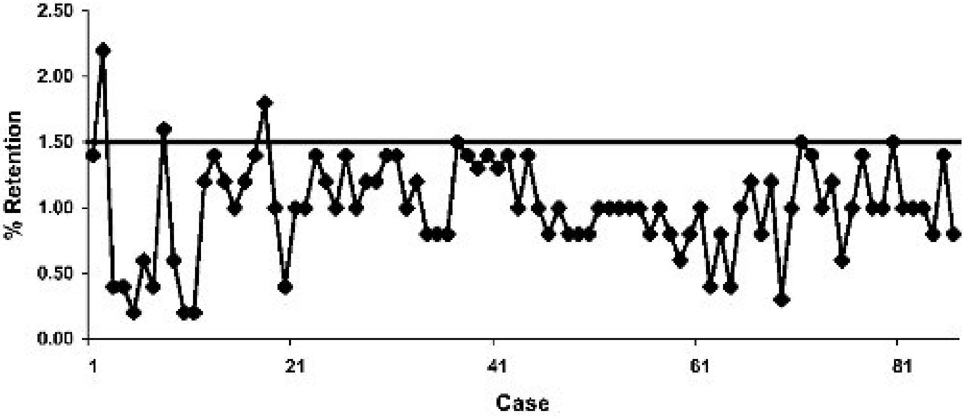


**Figure 9.** Percent retention on −200 ASTM sieve of incoming sand

## Appendix 4, Analysis of Percentage Retention of Processed Sand used in Cement Mortar Lining

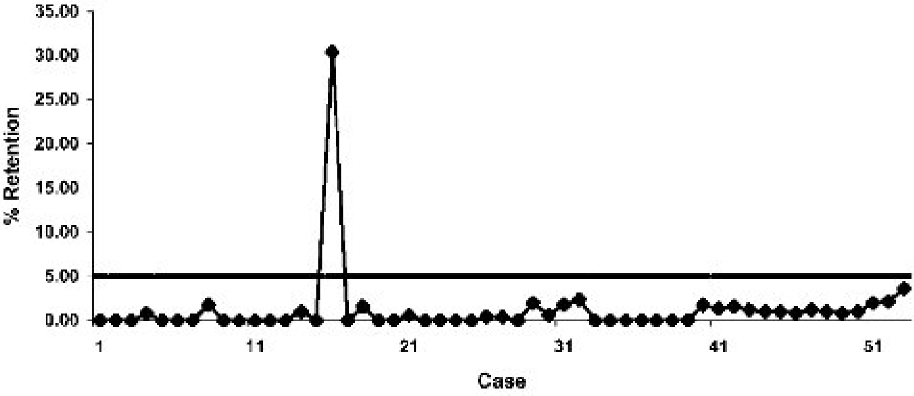


**Figure 10.** Percent retention on −6/+12 ASTM sieve of processed sand

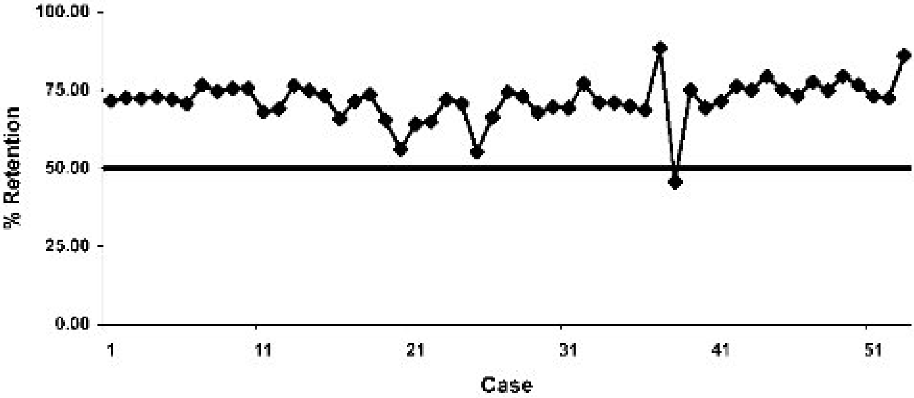


**Figure 11.** Percent retention on 20, 30, 40 and 50 ASTM sieve of processed sand

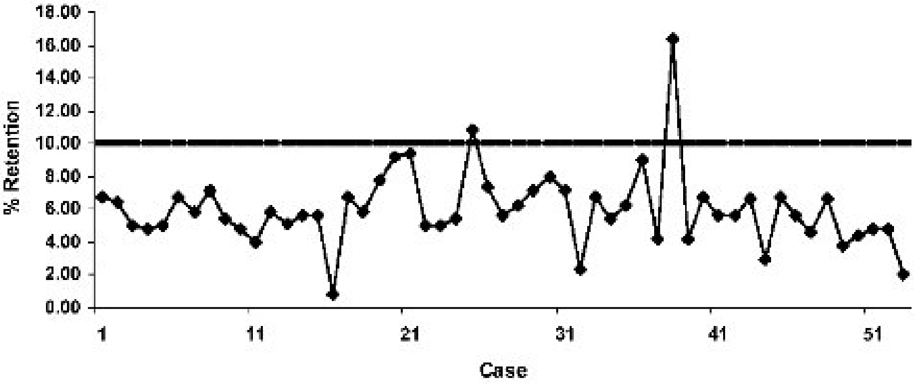


**Figure 12.** Percent retention on −100 ASTM sieve of processed sand

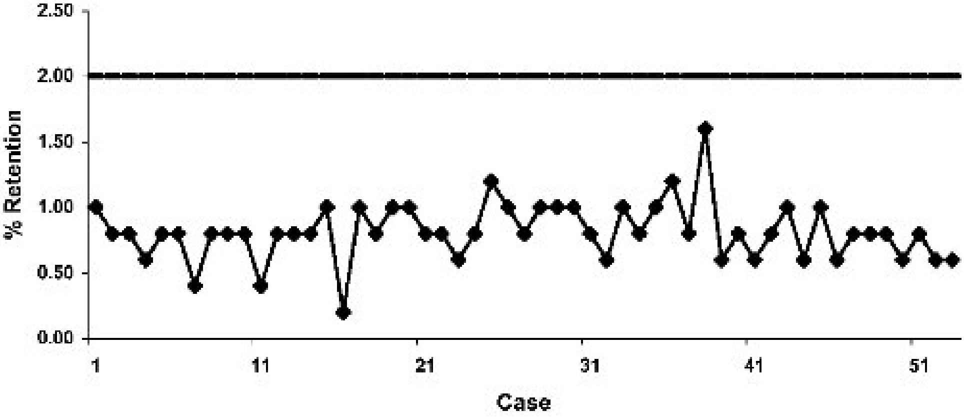
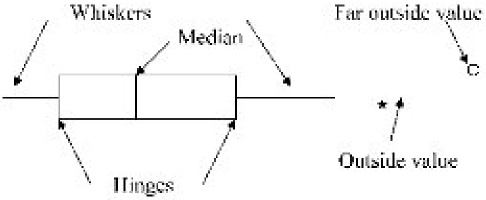


**Figure 13.** Percent retention on −200 ASTM sieve of processed sand

## Appendix 5. Write-up on Box –Whisker plot

In a box plot, the centre vertical line marks the median of the sample. The length of each box shows the range within which the central 50% of the values fall, with the box edges (called hinges) at the first and third quartiles. The whiskers show the range of values that fall within the inner fences (but does not necessarily extend all the way to the inner fences). Values between the inner and outer fences are plotted with asterisks. Values outside the outer fence are plotted with empty circles.



The fences are defined as follows:

Lower inner fence = lower hinge − (1.5 (median – lower hinge))
Upper inner fence = upper hinge + (1.5 (upper hinge – median))
Lower outer fence = lower hinge − (3 (median – lower hinge))
Upper outer fence = upper hinge + (3(upper hinge – median))

*Hspread* is comparable to the inter-quartile range or midrange. It is the absolute value of the difference between the values of the two hinges. The *Whiskers* show the range of values that fall within 1.5 Hspreads of the hinges. They do not necessarily extend to the inner fences. Values outside the inner fences are plotted with asterisks. Values outside the outer fences, called *far outside values*, are plotted with empty circles.

## Appendix 6. Impact of Chemical Composition on Spheroidal Graphitic Cast Iron Material

| Chemical composition % | Impact on the higher side | Impact on the lower side |
|---|---|---|
| Silicon [Si] | Leads to high Carbon Equivalent (CE) and higher melting point and affects casting parameters. Results in less growth after heat treatment. Also leads to graphite agglomeration. | Leads to crack generation. Creates problem in heat treatment due to formation of more carbide resulting in low elongation %. |
| Carbon [C] | Leads to high CE and high melting point of metal (hyper eutectic) and affects casting parameters. Increases brittleness and lowers tensile strength. | Nodule count decreases and as a result ductility will decrease. |
| Manganese [Mn] | Increases the tensile strength and toughness. However, very high Mn affects diffusion characteristics of Carbon and increases annealing cost due to requirement of high temperature. | Material becomes soft and generates ovality particularly for pipes of higher diameter. |
| Phosphorus [P] | Increases fluidity and generates brittleness due to iron phosphite ($Fe_3P$) formation. | It's good but cost of manufacture increases due to its reduction. |
| Sulphur [S] | Results in high slag and dross generation due to MgS, CaS and FeS formation. | Retards MgS generation and increases the nucleation sites of graphite resulting in low ductility. |
| Magnesium [Mg] | Leads to brittleness due to Magnesium Phosphite formation in cold regions on the earth. | Results in lower ductility. |
| Titanium [Ti] | Above 0.06% generates Titanium Carbide and increases the requirement of high temperature for annealing. | Up to 0.06% is ferritizer. And that's good. |