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EFFECT OF MOULDING SAND LAYERS ON STATISTICALLY CONTROLLED INVESTMENT CASTING SOLUTION FOR PLAIN CARBON STEEL

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Abstract

The purpose of the present investigations is to study the effect of moulding sand layers on statistically controlled investment casting solution (ICS) for plain carbon steel. Starting from the identification of component; investment castings (IC) were produced with different grades of silica slurry layers (coarse, medium and fine) over the patterns (in the form of a tree). The study highlights that for present case study 3(fine)-1(medium)-1(coarse) moulding sand layers combination is statistically controlled ICS and hence can be use for mass production. Further the cast components have been analysed based upon mechanical and metallurgical properties.

Keywords: *Moulding sand, statistically controlled, dimensional accuracy, plain carbon steel, investment casting.*

1. Introduction

IC is one of the precision, economical, mass-production casting processes (Wang et al., 2010). In this process wax patterns are converted into solid metal parts following a multi-step process (Rafique and Iqbal, 2009, Chattopadhyay, 2011). IC enables near net shaped metal parts containing complex geometries and features from a variety of metals, including difficult-to-machine or non-machine able alloys (Beeley and Smart, 1995, Lee et al., 2004, Cheah et al., 2005). One of the most important factor for cast component properties is the thermal conductivity of the mould material; the higher the conductivity, the higher the heat transfer and the greater the tendency for the fluid to solidify, hence possibly impeding the free flow of the molten metal (Sidhu et al., 2008, Mishra and Ranjana, 2010). Also, higher the cooling rate of the surfaces of the casting in contact with the mould, the larger the grain size and hence the higher the hardness (Jones and Yuan, 2003, Singh and Singh, 2013). The kind of surfaces created in the readiness of form materials may likewise be extraordinary. For instance, sand form surfaces are likely be rougher than those of metal shape whose surfaces can be set up to fluctuating degrees of unpleasantness, including the headings of harshness/lay (Singh and Singh, 2013). The writing audit uncovers that part of work has been accounted for on IC, its applications by various analysts (Horton, 1992, Cui and Yang, 2001, Hung et al., 2003, Kumar et al., 2006, Jiang and Liu, 2007, Norouzi et al., 2009, Dong et al., 2011, Konrad et al., 2011,). Be that as it may, not many researchers have given an account of technique for use of paints/ceramic slurry over the form in requested to get great quality castings (Jones and Yuan, 2003, Sidhu et al., 2008, Singh and Singh, 2013).

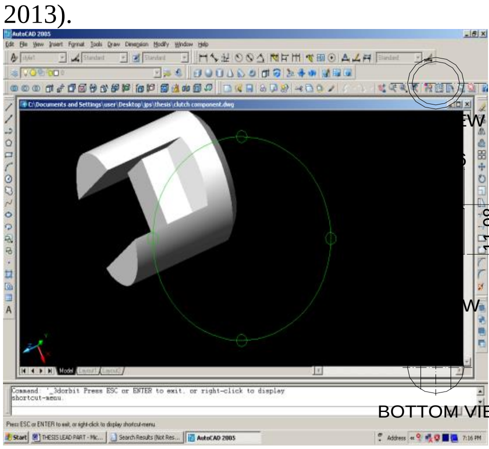

Figure1. 3D thrust pad (plain carbon steel benchmark)

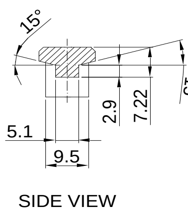

Figure2. Benchmark dimensional details

The primary goal of this exploration work is to consider the impact of number of layers (of zircon paint, colloidal silica) on measurably controlled IC arrangement. So as to achieve this goal, plain carbon steel castings have been picked as a benchmark (Ref. Figure 1-2). The segment chose is a bike's pushed cushion (vehicle part utilized in large scale manufacturing).

2. Experimentation

For pilot experimentation, three arrangements of earthenware shells distinguished as 'X1', 'X2' and 'X3' were set up in type of tree, with various layers of paints (Zircon flour+ Colloidal silica+ Distilled water) and slurry of various coarseness sizes (Ref. Table 1). The drying conditions were 27˚C temperature and humidity 60%.

Table 1. Pilot Experimentation

S. No.	Shell identification	No. of layers of ceramic sand	Drying time
1	X1	1 (80-100 mesh) 1 (50-80 mesh) 1 (30-50 mesh)	2 Hr/layer (6 Hr.)
2	X2	2 (80-100 mesh) 1 (50-80 mesh) 1 (30-50 mesh)	2 Hr/layer 8Hr.
3	X3	3 (80-100 mesh) 1 (50-80 mesh) 1 (30-50 mesh)	2 Hr./layer 10Hr.

During the procedure of shell development, it was seen from pilot experimentation that the shell with three layers as (X1) splits while de-waxing. The shell arranged with four layers as at (X2) gives more thickness however it has additionally demonstrated minor splits while warming the shell (after de-waxing) preceding pouring of metal. Again the shell was set up with five layers appeared (X3) gives acceptable outcomes. Based on the outcomes got as above it was chosen to set up the shell with least five layers. Consequently for definite experimentation ceramic shells with five numbers of layers were made distinguished as 'X4', ‘X5', ‘X6' (Ref. Table 2).

Table 2. Nomenclature for shell identification

S. No.	Shell designation	No. of layers of ceramic
1	X4	3 (80-100 grit) 1 (50-80 grit) 1 (30-50 grit)
2	X5	2 (80-100 grit) 2 (50-80 grit) 1 (30-50 grit)
3	X6	2 (80-100 grit) 1 (50-80 grit) 2 (30-50 grit)

In order to establish the appropriateness of ICS; the output parameters selected were: surface finish, hardness, dimensional accuracy and microstructure. The surface finish was measured at 0.8mm cut off length. Table 3 shows results of surface finish and hardness (as per ISO 6507-1 standard) based upon final experimentation.

Table 3. Influence of ceramic layer’s on surface finish and hardness

S. No.	Shell designation	Surface finish	HV
1.	X4	3.35 µm	205
2.	X5	6.02 µm	190
3.	X6	5.51 µm	180

3. Results and Discussion

In order to have more insight of mechanical and metallurgical properties, Figure 3-5 shows microstructure of IC prepared with respect to components; X4, X5 and X6. As observed from Figure 3-5; components marked as X4 shows uniformly distributed pearlite / ferrite structure, component marked as X5 shows coarse grain structure with ferritic grain boundaries & some area shows ferrite in patches and X6 shows non-uniform coarse grain structure of pearlite with ferritic grain boundaries. Based upon Table3 and Figure 3-5, it can be observed that component identified as X4 shows better results as compared to X5 and X6 (in terms of surface finish, hardness and microstructure). This may be because of better rate of cooling conditions attained with 3(80-100 mesh)-1(50-80 mesh)-1(30-50 mesh) layer combination

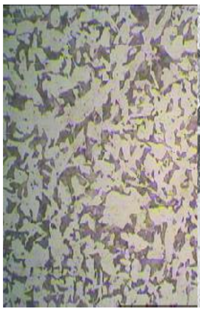

Figure 3. Photomicrographs for component X4 (x200)

Figure 4. Photomicrographs for component X5(x200)

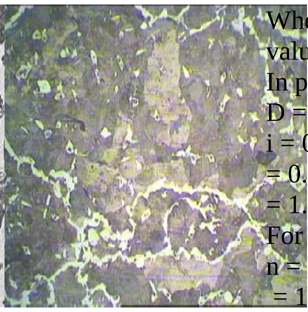

Figure 5. Photomicrographs for component X6(x200)

Finally, castings produced from plain carbon steel were measured for dimensional accuracy with the help of co-ordinate measuring machine (CMM). The readings were taken thrice. The average measurements are shown in Table 4.

Table 4. Measured dimensions (mm) for IC (Ref. Figure 2)

Nominal dimension	12.46	11.98	6.64	9.5	5.1
S. No	Measured dimension				
1	12.3012	11.682	6.91	9.09	4.89
2	12.4016	12.124	6.87	9.64	5.22
3	12.2011	12.043	6.88	9.12	5.23
4	12.1701	12.281	6.72	9.5	5.13
5	12.2021	12.28	6.92	9.23	4.95
6	12.3514	12.051	6.90	9.35	4.88
7	12.3521	12.651	6.87	9.17	5.23
8	12.2506	12.014	7.22	9.10	5.14
9	12.4100	12.157	6.87	9.40	4.94
10	12.3900	12.345	6.92	9.23	4.83

Now for a generic nominal dimension D_{JN}, the number of the tolerance units is evaluated as (Kaplas and Singh, 2008, Devor et al., 2005 and Bassoli et al., 2006):

$n= 1000(D_{JN} - D_{JM})/ i$,

Where D_{JM} is a measured dimension

Tolerance factor $i = 0.45 (D)^{1/3} + 0.001D$,

Where, D is the geometric mean of the limiting values.

In present case for nominal dimension (12.46mm):

$D = (10x\ 18)^{1/2} = 13.416$ mm

$i = 0.45 (D)^{1/3} + 0.001D$

$= 0.45 (13.416)^{1/3} + 0.001(13.416)$

$= 1.082964$µm

For casting obtained from 12mm shell thickness

$n = 1000(D_{JN} - D_{JM})/ i$

$= 1000(12.46-12.301)/1.082964$

$=147$

Based upon Table 4, IT grades for different dimensions were calculated (ISO, 1995, Singh, 2012). Table 5 shows IT grades for nominal dimension 12.46mm.

Table 5. IT grades for dimension 12.46mm for i =1.082964

S. No	D_{JM}	n	IT grade
1	12.3010	147	12
2	12.4016	54	10
3	12.2011	239	13
4	12.1701	268	13
5	12.2021	238	13
6	12.3514	100	11
7	12.3521	100	11
8	12.2506	193	13
9	12.4100	46	10
10	12.3900	65	10

Additionally IT grades for different dimensions were likewise determined. The part chose in present investigation is actually utilized in car and external width 12.46mm was picked for exhibit over the remainder of the measurements for the estimation and correlation reason since it is really mating/useful measurement in get together. It ought to be noticed that the outcomes depend on study performed on a straightforward geometry (Ref. Figure2), however similar outcomes are relevant to any complex geometry of comparative volume as on the grounds that hardening time relies on proportion of volume to surface region. Further (in view of perceptions of Table5), to comprehend whether the procedure is measurably controlled six samples of plain carbon steel pieces were casted. On estimation of external measurement with CMM, the dimensions are appeared Table 6. In light of Table 6, Figure 6 demonstrates run-chart of the outer diameter of external breadth of chose segment.

Table 6. Bench mark dimensional values

Exp. No,	Observed values	A/B mean	U/D
1	12.41010	B	-

2	12.40160	B	D
3	12.41510	B	U
4	12.42010	A	U
5	12.42030	A	U
6	12.42520	A	U
Mean	12.41540	Run=1	U and D=1

A=above the mean, B=below the mean, U=Up from previous reading, D=Down from previous reading

Now if the mean and standard of population that is having normal distribution is μ and σ respectively then for variable data X the standard normal deviate Z is defined as:

$$Z = \frac{(Xi - \mu)}{\sigma}$$

Where X_i is the variable data obtained, μ is the mean of data and σ is the standard deviation (Devor et al., 2005 and Singh, 2012).

3.1 Calculation for Z (standard normal deviate) above and below:

E (run) $_{AB} = (\frac{N}{2} + 1)$

Where N is the number of observations and E $(run)_{AB}$ is the expected number of run above and below

E (run) $_{AB} = (\frac{6}{2} + 1) = 4$

$\sigma_{AB} = \sqrt{(N - \frac{1}{4})}$

Where σ_{AB} is the standard deviation of above and below

$\sigma_{AB} = \sqrt{(6 - \frac{1}{4})} = 1.118$

$Z_{AB} = \{RUN_{AB} - E(run)_{AB}\} / \sigma_{AB}$

Where RUN_{AB} is the actual number of run obtained above and below

$Z_{AB} = \frac{(1-4)}{1.118} = -2.6834$

P_{AB} = NORMSDIST (Z) when the value of Z is negative (using Microsoft excel software)

P = 0.003645

For up and down calculations:

E (run) $_{UD} = \frac{2N - 1}{3}$

Where N is the number of observations and E $(run)_{UD}$ is the expected number of run up and down.

E $(run)_{UD} = \frac{2 \times 6 - 1}{3} = 3.667$

$\sigma_{UD} = \sqrt{(16N - 29/90)}$

Where σ_{UD} is the standard deviation for up and down

$\sigma_{UD} = \sqrt{(16 X 6 - 29/90)}$

$\sigma_{UD} = 0.8628$

$Z_{UD} = \{RUN_{UD} - E(run)_{UD}\} / \sigma_{UD}$

$Z_{UD} = (2-3.667)/0.8628$

$Z_{UD} = -1.5840$

P_{UD} = NORMSDIST (Z) when the value of z is negative (using Microsoft formula)

$P_{UD} = 0.056597$

Normally decision making is done with certain margin of error 'α' & taken as equal to 0.005 that is there can 5% chances in arriving at wrong conclusion.

3.2 Decision making:

If $P_{AB} > \alpha$ OR /& $P_{UD} > \alpha$ then non-random pattern exist.

In the present case $P_{UD} > \alpha$ indicates existence of non random pattern

Now exercise of anticipating different statistical or reaching determinations ought not be attempted except if the normal distribution has been checked. Regardless of whether one has an expansive information, superimposing of ordinary bend on the histogram it is more troublesome errand than it to be envisioned. For histogram one require least of 50 perceptions, anyway more the better and for evaluating whether the basic appropriation is ordinary or not turns out to be progressively troublesome when the quantity of perceptions is less. For aggregate probability plot (Pi):Pi = (S.N-0.5)/N

Where S.N is serial number of data observation arranged in ascending order, N is total number of observations in the data set. If the standard normal deviate follows normal distribution that has mean μ =0 and standard deviation σ =1, then:

$$f(Z) = 1/\sqrt{(2\Pi e^{\frac{z^2}{2}})}$$

The condition above pursues normal probability diagram and any date near it likewise pursues ordinary likelihood bend. The estimations of standard normal deviate off were determined utilizing normal probability and dimensional qualities were orchestrated in rising request as appeared in Table7.

In light of Table7 normal probability curve was attracted to foresee the probability as appeared in Figure7. As saw in Figure7, the previously mentioned information pursues random pattern and is under normal probability curve. Thus, there are solid shots that the procedure is under factual control anyway X-bar outline and R-bar graph can't be attracted because of less number of observational information. The co-proficient of assurance (R2) having esteem 0.94 states that the

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distance across observational qualities lies in normal probability curve

Table 7. Standard normal deviate and outer diameter in ascending order

S. No	Cumulative Probability	Standard Normal Deviate (Z)	Observed Dimensions (mm)
1	0.083	-1.38	12.401
2	0.250	-0.67	12.410
3	0.416	-0.210	12.415
4	0.583	0.210	12.420
5	0.750	0.674	12.423
6	0.916	1.382	12.425

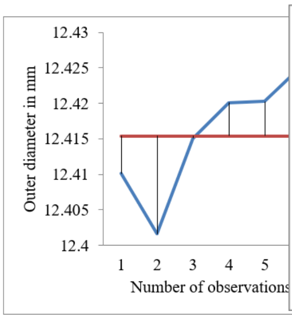

Figure 6. Run-chart of the measured values of outer diameter (benchmark)

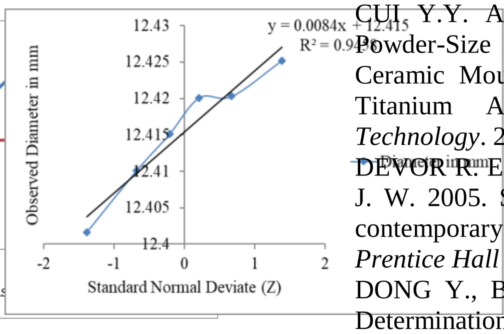

Figure 7. Normal probability curve (for selected IC)

4. Conclusions

In this research work application of layer by layer of paint and silica slurry of different grades (30-50, 50-80, 80-100 mesh) over the patterns (in the form of a tree) has been highlighted and compared for sound castings. Based upon the outcome this study following conclusions has been made for investigating the process capability analysis:

There is a consistency is observed in the tolerance grades of the IC produced with the permissible range of tolerance grades (IT grades) as per ISO standard UNI EN 20286-I (1995). For the improved mechanical and morphological characteristics, moulding sand layers combination as 3 (fine)-1(medium)-1(coarse) is coming out as better IC solution. This demonstrated procedure is superior for evidence of concept. Strong potential are observed for the process under statistical control for moulding sand layers combination as 3(fine)-1(medium)-1(coarse) as IC solution.

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