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Characteristics of Dimensional Variation and Shrinkage Analysis of Wax- Based Thin Walled Investment Casting in Hot Clay Mold for Batch Production

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***ABSTRACT** :The lost wax casting process in Hot Mold is a sophisticated tool to produce precision casting products. The overall shrinkage of cast products are depend on clay core shrinkage during drying, expansion clay mold over the wax pattern during heating and solidification of liquid metal in three stages: liquid- liquid, liquid- solid, and solid-solid contraction. Also the frequency distribution in six-sigma scale shows the discrepancy of dimensional accuracy for repetitive production.*
***KEYWORDS:** Lost Wax Casting Process, Hot Mold, Shrinkage, Frequency Distribution, Six Sigma.*

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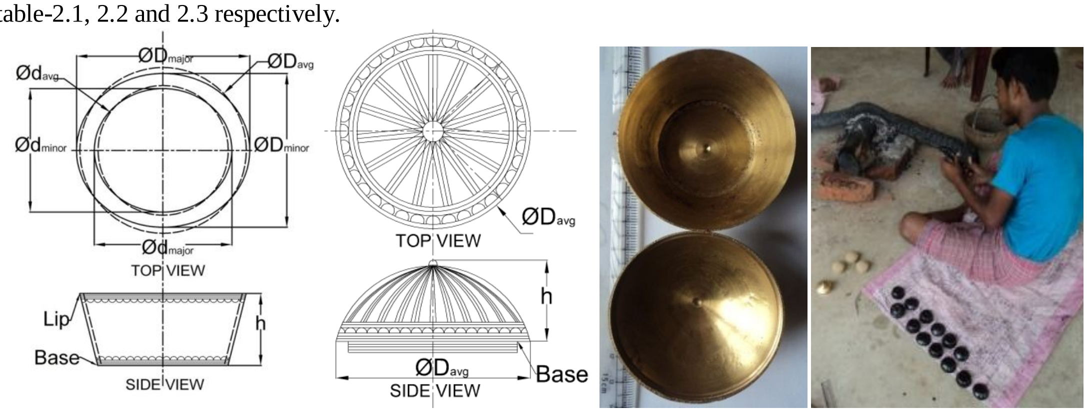
I. INTRODUCTION

For thin walled castings, liquid metal flow through the capillary mold is controlled by surface tension, capillary action, gas pressure inside the mold and many other factors . Due to these factors the liquid metal flow inside the capillary mold becomes non uniform and did not follow traditional fluid flow equation. Core and the thickness play a very important role in dimensional variation and shrinkage. The difference in dimensional variation and shrinkage between Restricted (with core, like Lip Diameter) and Un-restricted (without core, like Base Diameter) parts, thin and thick part, Radial and Longitudinal part of a casting was estimated.

II. PROCEDURE OF EXPERIMENT

A Batch of Cosmetic Cases and its Caps of same design (fig.-2.1. a, b) with same gating system were produced.
At first, clay cores were made using a given Truncated shaped Case and Hemispherical Cap (fig. 2.1.c) as a mold. Then thin wax sheet and wax threads are used to construct the desired shape. All the dimensions of all samples were noted in each step during the process according to fig.-(2.1.e to 2.1.q). A gate was attached with each of the samples and then all the wax pattern was covered with clay and kept for drying.
After casting all the pots were surface finished and the internal and external dimensions were tabulated according to diagram. The materials used for core, mold, pattern and the metal used for the casting is tabulated in table-2.1, 2.2 and 2.3 respectively.



(a) (b) (c) (d)

Fig.2.1: Steps of cosmetic case and cap casting: (a, b) Schematic diagram Cosmetics Case (Left) and its Cap (right), (c) Dies, (d) working artisan, (e, f)- core, (g, h)- Thin Walled Wax Pattern, (i) Gating on wax Pattern, (j) Primary Clay Coating, (k) clay mold with brass scrap, (l) Covered clay mold, (m) Fired mold- pouring of liquid metal also done, (l, m) Samples with Gating System, (p, q)- finished casting product.

Table-2.1 : Materials used for Core and Mold

	Type of Clay and Sand	Component
1.	Clay for core	Kaolinite + rice husk + Cow Dung
2.	Clay for first coating over wax pattern	Very fine Kaolinite
3.	Clay for next coating	Kaolinite + rice husk + Cow Dung + Jute cuttings + sand
4.	Sand	Silica Sand (Medium/Fine)

Table-2.2 : Materials used for Pattern

	Pattern Material	mix.- 1	mix.- 2	mix.- 3
1.	Petroleum tar (Pitch)	65%	-	-
2.	Sal Dammar resin	35%	40%	20%
3.	Bees wax	-	60%	20%
4.	Paraffin wax	-	-	40%

Table-2.3 : Chemical analysis of brass

	Element	Percentage
1.	Copper (Cu)	67.72
2.	Zinc (Zn)	31.76
3.	Lead (Pb)	0.05
4.	Tin (Sn)	0.37
5.	Iron (Fe)	0.07
6.	Nickel (Ni) and Others	0.02
Zn Equivalent		32.61
Cu: Zn Ratio		67:33

Table-3.1: Dimension of used Die

	Lip Dia	Base Dia	Height
Case	50	34.2	20.2
Cap	x	50.85	16.4

III. RESULT AND DISCUSSION

All the dimensions of clay core, wax and cast product were measured and then calculate to find out the discrepancy. The dimensions of the Die, used for making Core of Case and Cap is tabulated in Table-3.1.

3.1. Frequency Distribution of Dimensions

To determine the variation of dimensions Frequency distribution was calculated followed by the six-sigma scale. The rule of acceptance is: approx 68% of dimension should within 2σ region, 95% should be within 4σ and

99.99% should be within 6σ region. Variance (σ^2) and Standard Deviation (σ) are as follows [X= Individual population, X_m= Mean population, N = number of sample].

$$\sigma^2 = \frac{\sum_{i=1}^{N}(X - X_m)^2}{N} \qquad \sigma = \frac{\sum_{i=1}^{N}(X_i - X_m)}{N}$$

3.1.1. Dimensional Analysis of Cosmetic Case

From all the samples of Cosmetic Case, Distribution of Dimension, Deviation of Dimensions, Frequency Distribution of the Dimensions of Internal and External Lip diameter, Base Diameter and Height was calculated and analyzed.

3.1.1.1. Distribution of the Dimensions

Distribution of major, minor, average and mean diameter and height of different position is plotted in Fig.-3.1 for lip diameter, fig.3.2 for base diameter and fig.-3.3 for height.

3.1.1.2. Deviation of Dimensions

Upper lower and standard deviations were calculated (table-3.2 and 3.3) and plotted in fig.-3.4.

3.1.1.3. Frequency Distribution of Dimensions

Frequency distribution was plotted followed by six sigma scale in Fig.-3.5 and tabulated in table- 3.4.

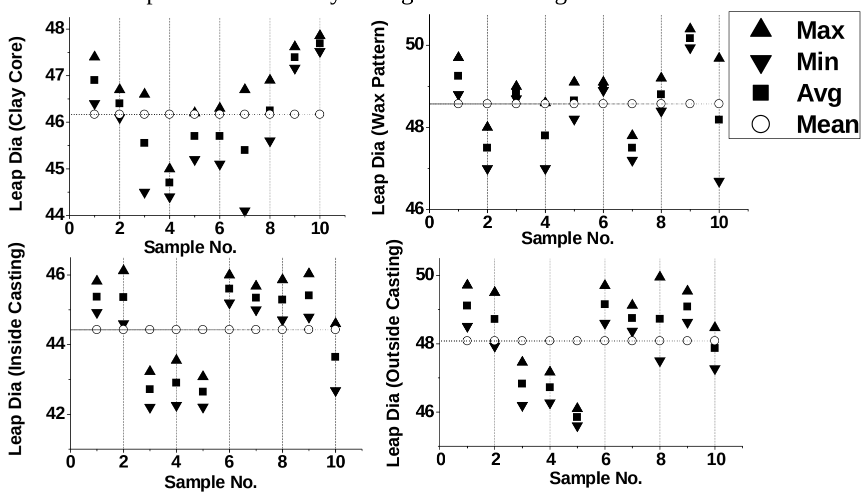


Fig.-3.1: Distribution of Major, Minor, Average and mean Diameter of Lip for Clay core, Wax Pattern, Inside and outside measurement of Cast products.

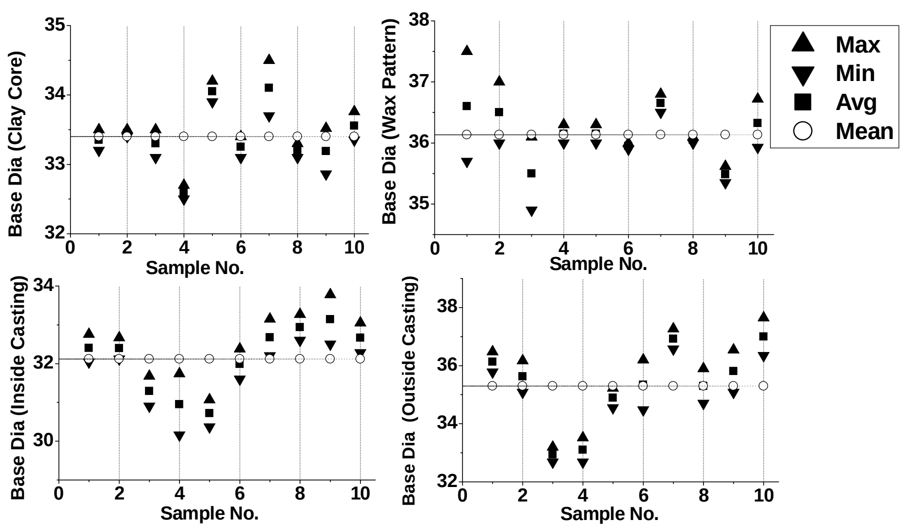


Fig.-3.2: Distribution of Major, Minor, Average and mean Diameter of Base for Clay core, Wax Pattern, Inside and outside measurement of Cast products.

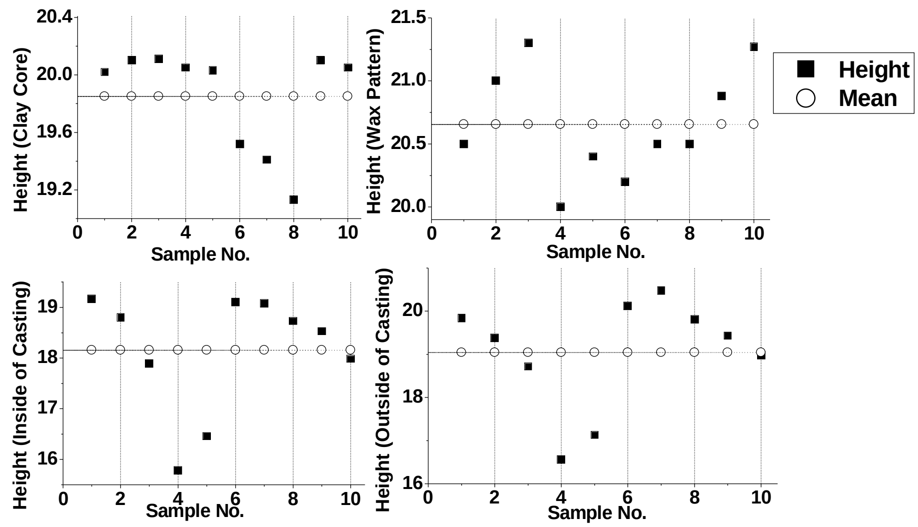


Fig.-3.3: Distribution of Height and mean height of Clay core, Wax Pattern, Inside and outside measurement of Cast product.

Table-3.2: Calculation of Deviation for Clay Core and Wax Pattern of the Cosmetics Case (mm)

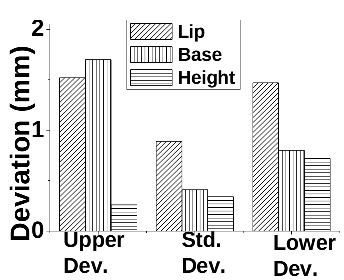
	Clay Core					Wax Pattern				
Position	**Mean Dia mm**	**Std. Dev. mm**	**Upper Dev. mm**	**Lower Dev. mm**	**Mean Variation mm**	**Mean Dia mm**	**Std. Dev. mm**	**Upper Dev. mm**	**Lower Dev. mm**	**Mean Variation mm**
Lip	46.17	0.89	1.52	1.47	1.12	48.57	0.8	1.6	1.07	0.98
Base	33.4	0.41	0.7	0.8	0.37	36.14	0.39	0.51	0.65	0.61
Height	19.85	0.34	0.26	0.72	X	20.65	.42	0.65	0.65	X

Table-3.3: Calculation of Inside and Outside Deviation of the Cosmetics Case after casting (mm)

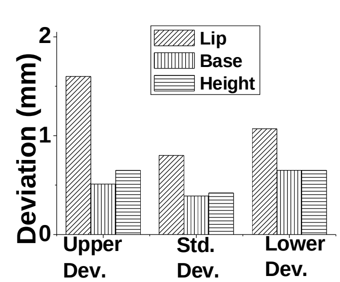
	Inside Measurements					Outside Measurements				
Position	**Mean Dia mm**	**Std. Dev. mm**	**Upper Dev. mm**	**Lower Dev. mm**	**Mean Variation mm**	**Mean Dia mm**	**Std. Dev. mm**	**Upper Dev. mm**	**Lower Dev. mm**	**Mean Variation mm**
Lip	44.27	1.15	1.17	1.78	1.14	48.08	1.13	1.07	2.23	1.18
Base	32.12	0.76	0.81	1.4	0.88	35.87	0.58	0.44	1.07	0.43
Height	18.15	1.1	1.02	2.77	1.14	19.04	1.2	2.32	1.59	X

Table-3.4: Frequency Distribution of Mean Diameter of Lip and Base, Height of Clay core, Wax Pattern, inside and outside dimensions of small powder case:

	Clay Core			Wax Pattern			Inside of Casting			Outside of Casting		
Position	**2σ (%)**	**4σ (%)**	**2σ (%)**	**4σ (%)**	**6σ (%)**	**6σ (%)**	**2σ (%)**	**4σ (%)**	**6σ (%)**	**2σ (%)**	**4σ (%)**	**6σ (%)**
Lip	70	100	70	100	100	100	60	100	100	70	100	100
Base	70	100	60	100	100	100	50	100	100	60	100	100
Height	90	100	60	100	100	100	70	90	100	70	90	100



Clay Core



Wax Pattern

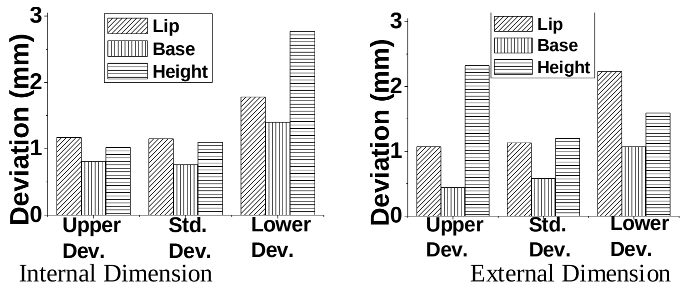


Fig.-3.4: Upper deviation, Lower deviation and Standard deviation of (a) clay core, (b) wax pattern, (c) Internal and (d) external dimensions of small powder case.

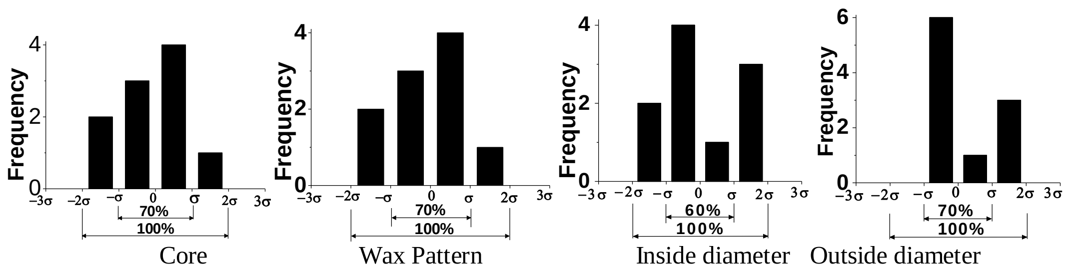


Fig.3.5. (a) Frequency Distribution of core, wax pattern, internal and external Lip Diameter

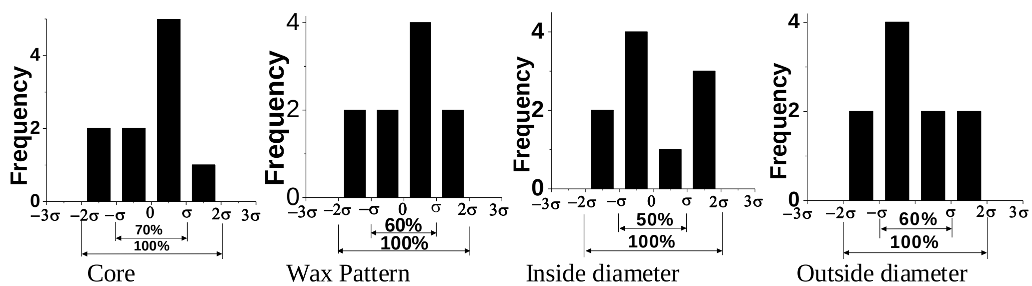


Fig. 3.5 (b) Frequency Distribution of core, wax pattern, internal and external Base Diameter

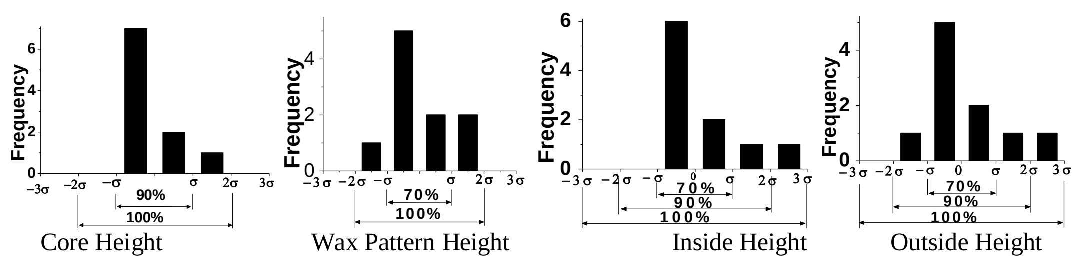


Fig. 3.5 (c) Frequency Distribution of Core, Wax pattern, Internal and External Height

Fig.- 3.5: Frequency distribution of the Internal and External diameters and heights of clay core, wax pattern, internal and external dimension of Cosmetic Case

3.1.2. Dimensional Analysis of Cosmetic Cap

From all the samples of Cosmetic Case, Distribution of Dimension, Deviation of Dimensions, Frequency Distribution of the Dimensions of Internal and External Lip diameter, Base Diameter and Height was calculated and analyzed.

3.1.2.1. Distribution of the Dimensions

Distribution of major, minor, average and mean diameter and height of different position is plotted in Fig.-3.6 and 3.7.

3.1.2. 2. Deviation of Dimensions

Upper, lower and standard deviations were calculated (table-3.5 and 3.6) and plotted in fig.-3.8.

3.1.2.3. Frequency Distribution of the Dimensions

Frequency distribution was plotted followed by six sigma scale in Fig.-3.9 and tabulated in table- 3.7.

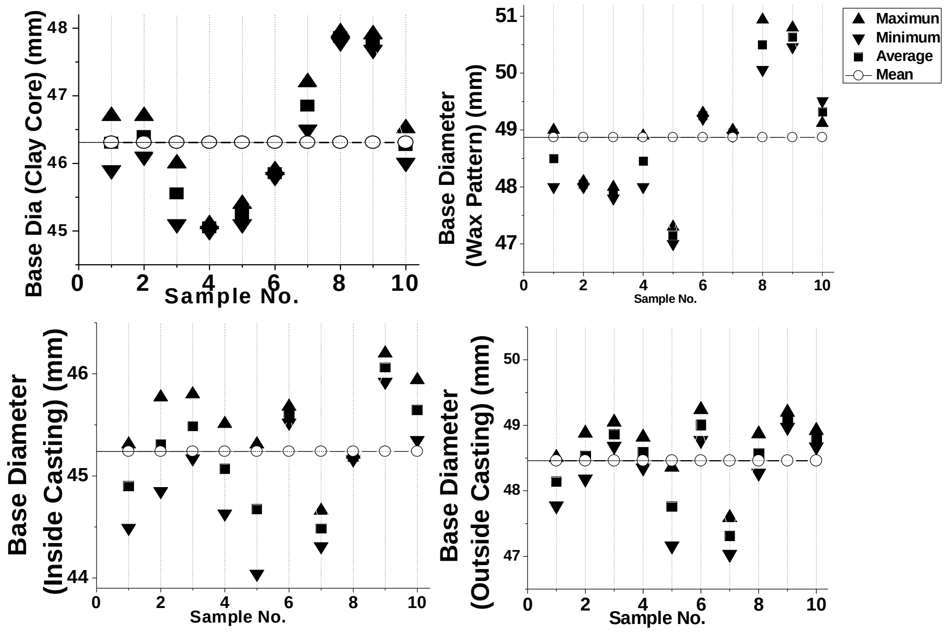


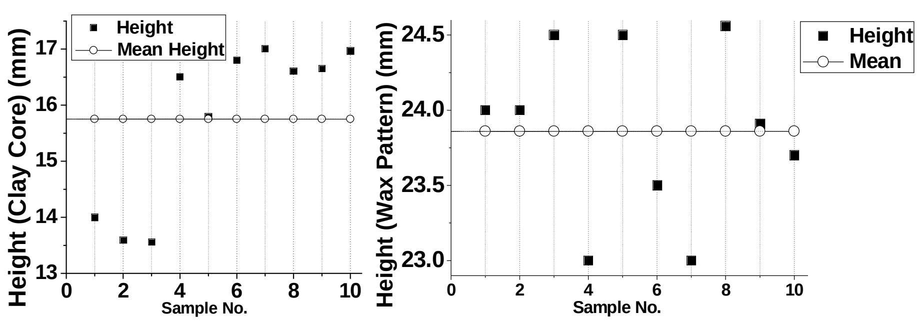
Fig.3.6: Distribution of Major, Minor, Average and mean Diameter of Base for Clay core, Wax Pattern, Inside and outside measurement of Cosmetics Cap

Table-3.5: Calculation of Deviation for Clay Core and Wax Pattern of the Cosmetics Cap (mm)

	Clay Core					Wax Pattern				
Position	Mean Dia mm	Std. Dev. mm	Upper Dev. mm	Lower Dev. mm	Mean Variation mm	Mean Dia mm	Std. Dev. mm	Upper Dev. mm	Lower Dev. mm	Mean Variation mm
Base	46.32	1.06	1.71	1.105	0.431	48.82	1.09	1.67	1.81	0.435
Height	15.75	1.37	2.22	1.23	X	23.88	0.57	0.88	0.67	X

Table-3.6: Calculation of Inside and Outside Deviation of the Cosmetics Case after casting (mm)

	Inside Measurements					Outside measurements				
Position	Mean Dia mm	Std. Dev. mm	Upper Dev. mm	Lower Dev. mm	Mean Variation mm	Mean Dia mm	Std. Dev. mm	Upper Dev. mm	Lower Dev. mm	Mean Variation mm
Base	45.24	0.45	0.75	0.82	0.595	48.46	0.53	1.15	0.62	0.55
Height	15.67	0.45	2.66	1.23	x	23.33	1.04	1.54	1.57	x



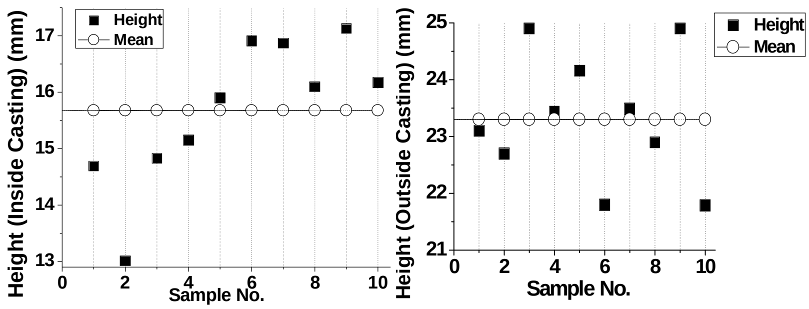


Fig.3.7: Distribution of Height and mean height of Clay core, Wax Pattern, Inside and outside measurement of Cosmetics Cap

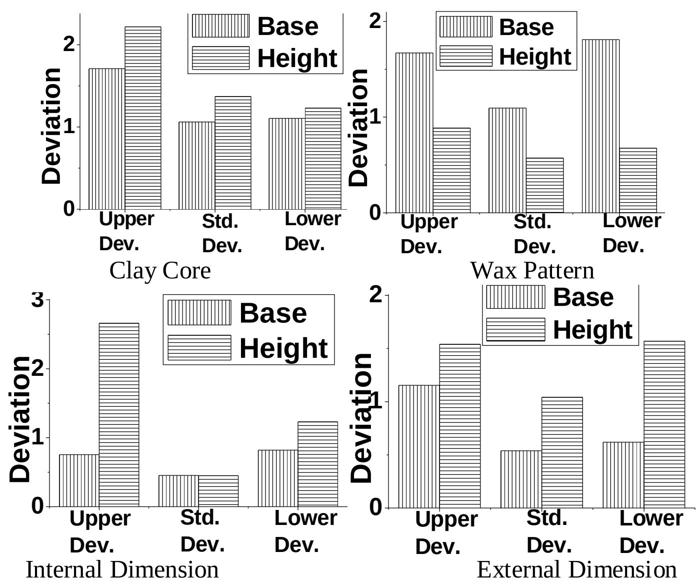
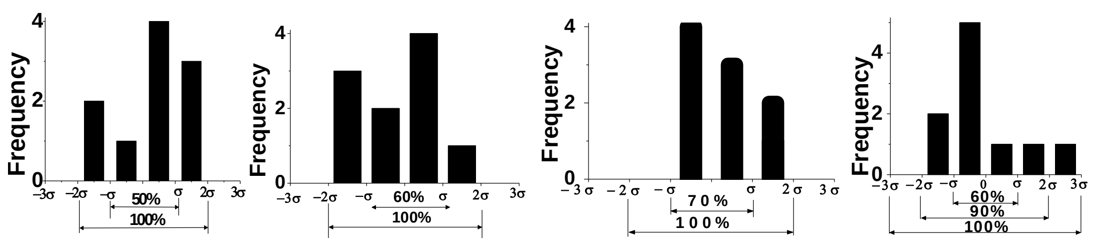


Fig.3.8: Upper, Lower and Standard deviation of (a) clay core, (b) wax pattern, (c) Internal and (d) External dimensions of container cap.

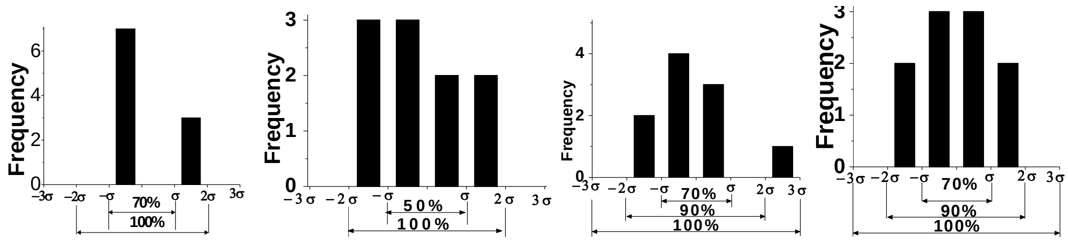
Table-3.7: Frequency Distribution of Mean Diameter of Lip and Base, Height of Clay core, Wax Pattern, inside and outside dimensions of small powder case cap:

Position	Clay Core			Wax Pattern			Inside of Casting			Outside of Casting		
	2σ (%)	4σ (%)	6σ (%)	2σ (%)	4σ (%)	6σ (%)	2σ (%)	4σ (%)	6σ (%)	2σ (%)	4σ (%)	6σ (%)
Base	50	100	100	60	100	100	70	100	100	60	90	100
Height	70	100	100	40	100	100	70	90	100	80	100	100



Core Wax Pattern Inside diameter Outside diameter

Fig.-3.9:(a) Frequency Distribution of Core, Wax pattern, Internal and External Lip Diameter



Core Height   Wax Pattern   Inside Height   Outside Height

Fig. 3.9 (b) Frequency Distribution of Core, Wax pattern, Internal and External Height

Fig. -3.9: Frequency distribution of the diameters and heights of clay core, wax pattern, internal and external dimension of cast container caps

3.1.3. Discussion:

i. Shrinkage percentage for restricted dimensions (base, lip) varied from 0.7% to 4%, and for unrestricted dimensions (height) varied from 0.4% to 8.5%. For restricted dimension shrinkage percentage variation was less.

ii.100% Frequency Distributions for all the samples are found within the 6 sigma region.

iii. Deviation of Base diameter is smaller than the deviation of lip diameter and height. The analysis indicates that the open sections have more deviation.

3.2. **Shrinkage Analysis of the Castings**

The factors affecting the shrinkage are shown by the diagram (fig.-3.10). Drying of clay core is cause for shrinkage of internal of dimension, expansion of cay core over the wax pattern is caused for shrinkage of internal of dimension. Clay core shrinkage with respect to die after drying is tabulated in table-3.8 for both the cosmetics cap and cosmetics case.

3.2.1. Calculation Procedure

Following calculations were done for analysis the dimensional variations of the casting.

Clay Core Shrinkage:

Clay Core Shrinkage (%)
$$= \frac{\text{Die dia - Clay Core Dia}}{\text{Die dia}} \times 100$$

Shrinkage of Internal and External Dimension of Final Cast Product

$$\text{Avg. diameter} = \frac{\text{Major Diameter} + \text{Minor Diameter}}{2}$$

$$\text{Mean. diameter} = \frac{\sum_{i=1}^{N} \text{Avg. Diameter}}{N}$$

$$\text{External Dimension Shrinkage (\%)} = \frac{\text{Wax Pattern dia - External Dia}}{\text{Wax Pattern dia}} \times 100$$

$$\text{Internal Dimension Shrinkage (\%)} = \frac{\text{Clay core dia - Internal Dia}}{\text{Clay Core dia}} \times 100$$

Metal Thickness Shrinkage:

Wax Thickness = (Mean Wax Pattern Radius – Mean Clay Core Radius)

$$\text{Wax Thickness Shrinkage} = \frac{\text{wax thick ness - metal thickness}}{\text{wax thickn ess}} \times 100\%$$

According to calculation '+ve' value is for SHRINKAGE and '-ve' value is for EXPANSION.

3.2.2. Sample-1: Cosmetic Case

Shrinkage analysis of Diameter and height of the Cosmetic case was tabulated in table-3.9 and the shrinkage of metal thickness is tabulated in table-3.10. A schematic diagram is shown fig.3.11.

3.2.3. Sample-2: Cosmetic Cap

Shrinkage analysis of Diameter and height of the small Cosmetic Cap case was tabulated in table-3.11 and the shrinkage of metal thickness is tabulated in table-3.12. A schematic diagram is shown fig.3.12.

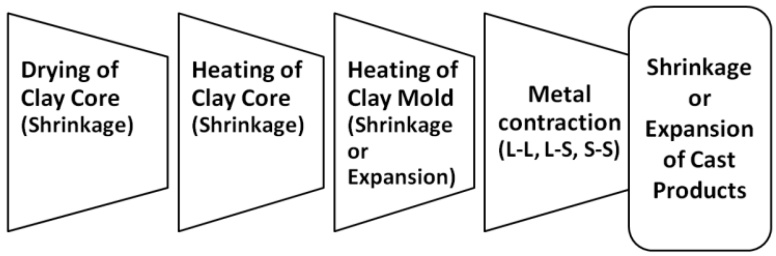


Fig.-3.10: Shrinkage/ Expansion of Mold and Metal at different stages of Production

Table-3.8: Clay Core Shrinkage

	Cosmetic Case (container)			Cosmetic cap	
Shrinkage	**Lip Dia.**	**Base Dia.**	**Height**	**Base Dia.**	**Height**
Mean (mm)	3.832	0.79	0.348	4.53	0.65
%	7.66	2.3	1.72	8.9	3.93

Table-3.9: Calculation of Mean Shrinkage of Diameter and Height

	Inner diameter		outer diameter	
Position	**Mean (mm)**	**(%)**	**Mean (mm)**	**(%)**
Lip	1.74	3.76%	0.49	1.0%
Base	1.28	3.83%	0.26	0.72%
Height	1.7	8.56%	1.61	7.7%

Table-3.10: Calculation of Mean Shrinkage of Metal width ('+ve' is for shrinkage and '-ve' is for expansion)

	Mean wax Thickness	Avg. Metal Width	σ of Metal width	% Shrinkage/ Expansion of metal width
Lip	1.2	1.66	0.13	-38.33
Base	1.37	1.93	0.14	-40.7
Height	0.8	1.52	0.19	-90

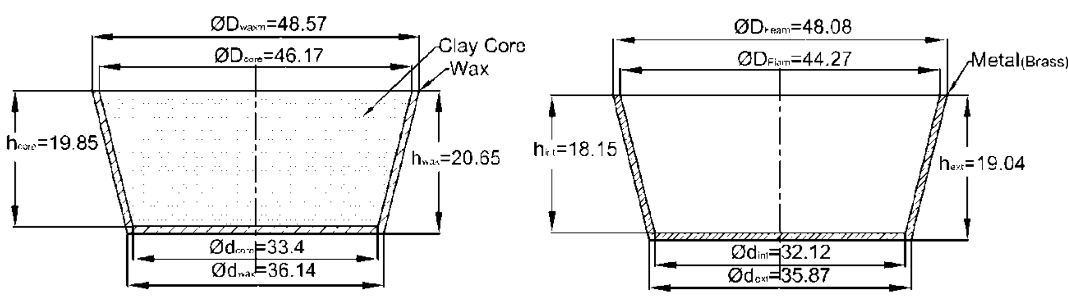


Fig. 3.11: Schematic diagram of Cosmetic Case with Dimension in different stage of production. Clay Core and Wax pattern (Top), Cast Sample (Bottom)

Table-3.11: Calculation of Mean Shrinkage of Diameter and Height

Position	Internal dimension		External Dimension	
	Mean (mm)	**(%)**	**Mean (mm)**	**(%)**
Base	1.08	2.32%	0.36	0.74%
Height	0.005	0.47%	0.55	2.35%

Table-3.12: Calculation of Mean Shrinkage of Metal width
('+ve' is for shrinkage and '-ve' is for expansion)

	Mean wax Thickness	Avg. Metal Width	σ of Metal width	% Shrinkage/ Expansion of metal width
Base	1.25	1.638	0.16	-31.04%
Height	8.13	7.66	1.01	5.78% (Thick section)

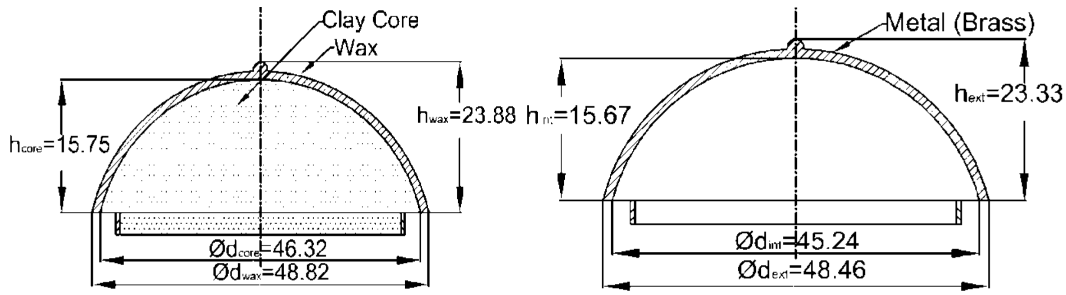


Fig. 3.12: Schematic diagram of small powder case cap in different stage of production.

3.2.4. Design Summery

i. Shrinkage percentage for restricted dimensions (base, leap) varied from 0.7% to 4%, and for unrestricted dimensions (height) varied from 0.4% to 8.5%.

ii. The most important observation was the thin metal width (thickness) EXPANDED with respect to wax pattern instead of shrinkage.

IV. CONCLUSION:

i. Shrinkage percentage for restricted dimensions (base, lip) varied from 0.7% to 4%, and for unrestricted dimensions (height) varied from 0.4% to 8.5%. For restricted dimension shrinkage percentage variation was less.

ii.100% Frequency Distributions for all the samples are found within the 6 sigma region.

iii. Deviation of Base diameter is smaller than the deviation of lip diameter and height. The analysis indicates that the open sections have more deviation.

iv. For the thin sections less than or equal to 3 mm, metal thickness EXPANDED with respect to the thickness of wax pattern.

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