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Distortion Analysis of Thin-Walled Investment Castings

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Abstract

Dokra casting is famous for its Artistic value to the world but it is also sophisticated engineering. The technique is almost 4500 years old. It is practiced by the tribal artisans of India. It is a clay moulded wax-based thin-walled investment casting technique where liquid metal was poured into the red hot mould. Dimensional accuracy is always preferable for consumers of any product. Distortion is one of the barriers to achieving the accurate dimension for this type of casting especially for the bending parts. The cause and nature of the distortion for this type of casting must be analyzed to design a product with nominal tolerance and dimensional accuracy.

Keywords: Dokra casting, Thin-walled investment casting, Distortion, Dimensional accuracy, SEM

1. Introduction

Dokra is an Art and technique (better to say engineering) which is almost 4500 years old [1]. It is practiced by the artisans belong to some tribal community who lived in eastern part of India. Dokra is a clay moulded wax-based investment casting technique [2-6]. A good amount of foreign currency is earned by exporting the Dokra products every year. It helps in growth of rural economy also.

The dimensional tolerance [7-9] is generally not given interest for this type of artistic product. But the international community preferred the products to have good dimensional accuracy. Also, a few items like door handle, lamp shade and many utensils are made by Dokra casting, which need more care regarding dimensional accuracy. Distortion is one of the barriers to achieve the accurate dimension [10-16]. It is a common problem for the bandings, curves, or angles of any casting. The nature of the distortion for this type of casting must be analyzed to design a product with nominal tolerance and dimensional accuracy.

The distortions were found in the cast samples of the casting techniques. The project was designed to understand the nature of the distortion in thin walled investment castings in hot mold. The artisans suffer a lot to design any precise items like lamp shades, table lamp, any container with its lid, any push fit items etc.

The items produced in this technique are so complicated. To understand the problem, two-dimensional semi-circular sections for different thicknesses produced were produced. The mechanical and metallurgical properties of all the samples were analyzed to identify the distortion property and its reason.

2. Understanding the problem

A field visit was organized to understand the problem; also detailed research work of previous researchers was investigated. The item observed in the field visit is the key to design the experimentation to understand the distortion analysis of the thin walled investment castings in hot mold. Also, the production technique is vital to investigate the distortions.

2.1. History of Dokra Casting

Dokra is a primitive technique which was found back in the Indus Valley Civilization about 4500 years ago. Many cast idols, utensils has found from the Archaeological sites of Harappa and Mohenjo-Daro civilization. Advanced technical knowledge about the casting technique has gained from those items [17]. Dokra artists are a group of wanderers who are practicing this metallic craft technique from ancient time. These nomadic groups have settled presently in different states of India like, the tribal areas of Andhra Pradesh, Orissa, Chhattisgarh, Jharkhand, and West Bengal. The dimensional, mechanical and metallurgical analysis of this item has been studied by various researchers [18-22].

2.2. Field visit

A field visit has been conducted at Bikna, Bankura in West Bengal, India. The artisans of that village generally produced fascinating brass items, like Idols, Models, Utensils, ornaments etc using Dokra technique. Initially, the Dokra artisans of Bankura settled in the suburbs on the outskirts of the district. Later, they moved to another village for their convenience, and a large part of them shifted to Bikana village in the same district.

2.2.1. Production stages

The production stages are elaborated by a flow chart (fig. 1.) and also shown in fig. 2. for a dear model. The dimensions of various parts were shown in the fig. for the wax pattern and cast sample to show the change in dimension.

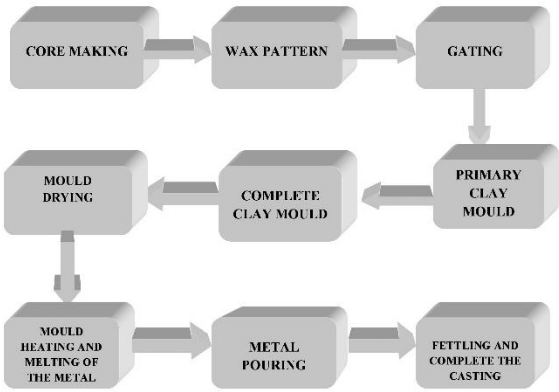


Fig. 1. Flowchart of the Dokra Casting process

2.2.2. Observation

Distortion for various parts of the different models was identified during the Dimensional analysis of the cast products compared to the wax patterns. In figure-2 the dimensions are shown to describe the problems. Distortion at the leg position was identified.

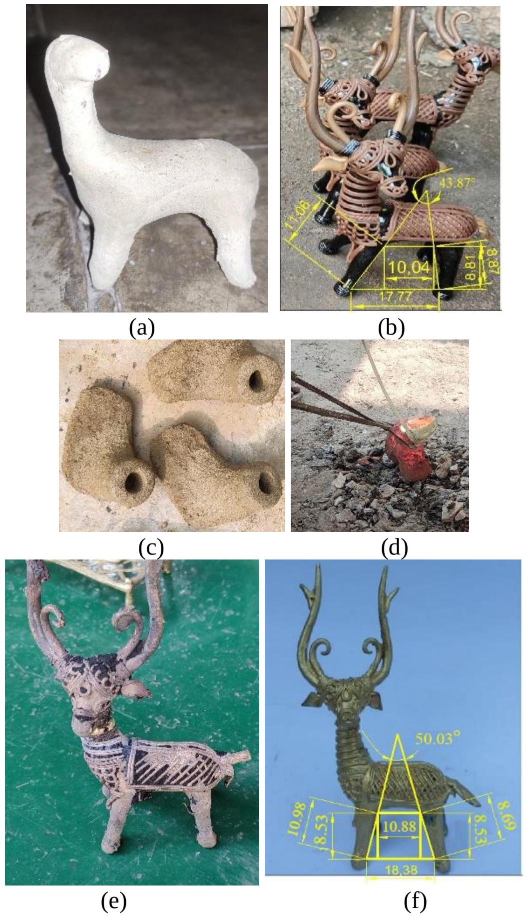


Fig. 2. Different steps of Dokra casting (a) Core (b) wax pattern over clay core (c) Clay mould with gating system (d) Pouring of liquid metal (e) Unfinished casting (f) Final product

3. Experimentation

To identify the distortion problem at first layout of the experimentation was designed.

3.1. Experimental method

The samples were designed as a ring-like plate with one end cut (closely looked like the English alphabet "C") for different thicknesses. The dimension of the die has been varied with three different levels 0.5mm, 1.5mm and 2.5mm. One gating system mould with a top gate has been selected for preparing the castings. Prepared samples were to be examined by measuring the dimensions, chemical composition, micro-hardness testing, micro-structural studies and XRD.

3.2. Production procedure

In order to make the sample, first the design of the die has been done through solid wax design software and the die has been made through 3D printing. After making the die with the help of 3-D printing, a model of one getting system of three different thicknesses was made and casting was done. The casting was done with brass metal. The different steps of casting are shown in the fig. no-3 below. The reason for designing the sample without making it u-shaped is that if it was u-shaped, the distortion would only occur in the u-shaped place, but as a result of making circular design, it seems that the distortion will be created across all over the samples.

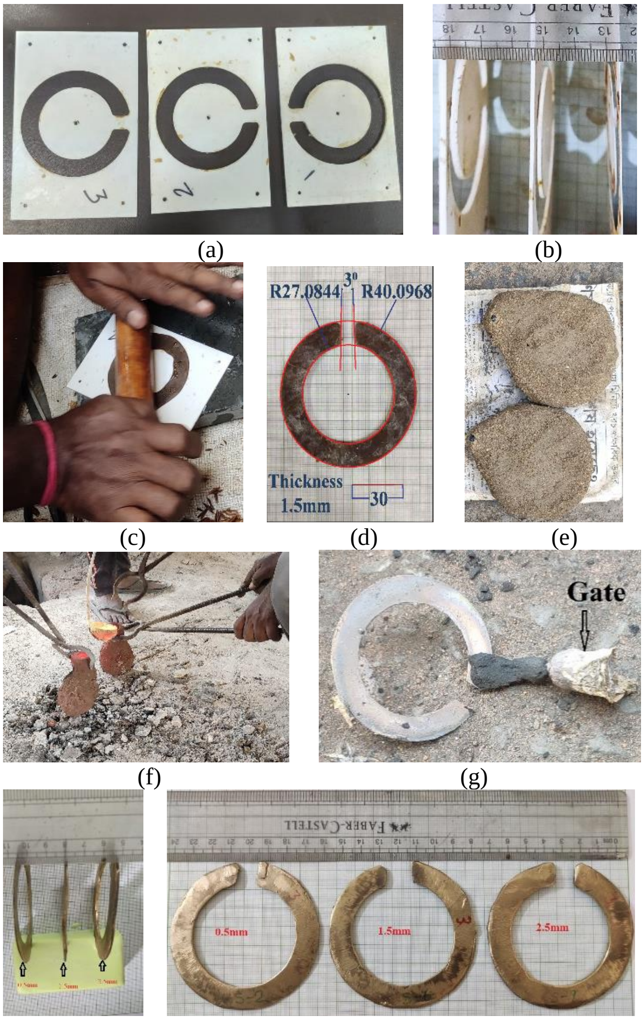


Fig. 3. Different steps of sample preparation (a) Die (b) Side view of die (c) Wax pattern making (d) Complete wax pattern (e) clay moulds (f) Liquid Metal pouring, (g) Unfinished product with gate (h) Final product (side view) (i) Final product (top view)

3.3. Calculation technique

The shrinkage of inner and outer diameter of the cast samples were compared with the die and the wax pattern. Also, the distortion of the cast samples was measured.

The two free edges of the dies were parallel and angle between the axis and the edges are 180°. After casting, the edges made an angle with the axis; the angles were measured according to the schematic diagram (fig. 4.). Instead of 0°, 180° was chosen because percentage of increment and decrement can be calculated with respect to 0° [0 cannot be allowed at denominator]. The measurements were done by the following expressions.

Shrinkage (%) of Cast samples diameters compared to die diameter

$$\text{Shrinkage}(\%) = \frac{D_d - D_c}{D_d} \times 100\% \quad (1)$$

D_d = Inner or outer Diameter of Die

D_c = Inner or outer Diameter of Casting

Shrinkage (%) of Cast samples diameter compared to wax pattern

$$\text{Shrinkage}(\%) = \frac{D_w - D_c}{D_w} \times 100\% \quad (2)$$

D_w= Inner or outer Diameter of Wax

D_c= Inner or outer Diameter of Casting

Distortion (%) of Cast samples Angel compared to Die Angel

$$\text{Distortion}(\%) = \frac{\theta_d - \theta_c}{\theta_d} \times 100\% \quad (3)$$

θ_d = Die Angel

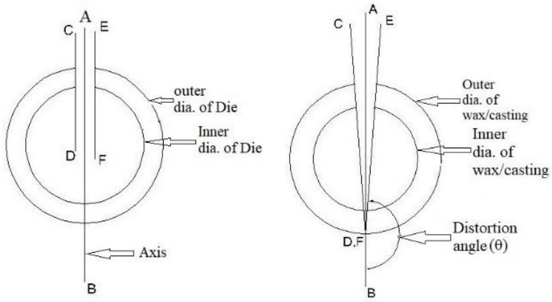
θ_c = Cast Sample Angel

Distortion (%) of Cast samples Angel compared to Wax Angel

$$\text{Distortion}(\%) = \frac{\theta_w - \theta_c}{\theta_w} \times 100\% \quad (4)$$

θ_d = Wax Angel

θ_c = Cast Sample Angel



(a) (b)

Fig. 4. (a) Schematic Diagram of the Die: edges are parallel (180°) to the axis, (b) Schematic diagram of the wax pattern or cast sample: distorted edges make an obtuse angle with the axis

3.4. Cast sample analysis

Microstructure studies and Micro hardness [23] testing was done for all casting samples. Microstructure was studied in optical microscope (make-OLYMPUS, model no. - BX53M) and SEM (Scanning electron microscope) (make-ZEISS) Vickers micro hardness of casting samples was measured according to ASTM standard E384–16. Load of 10gf was applied at four different places on each sample with dwell time of 12 seconds and the average of these was selected as the final micro-hardness value.

4. Result and discussion

Based on the above experimentation the distortion analysis has been done along with discussion.

4.1 Dimensional analysis of actual casting

Dimensional distribution and shrinkage percentage of the cast samples is observed and documented.

4.1.1. Distribution of cast samples dimension

Comparative observation of dimensional distribution of die, wax pattern and cast product is shown in fig. 5.

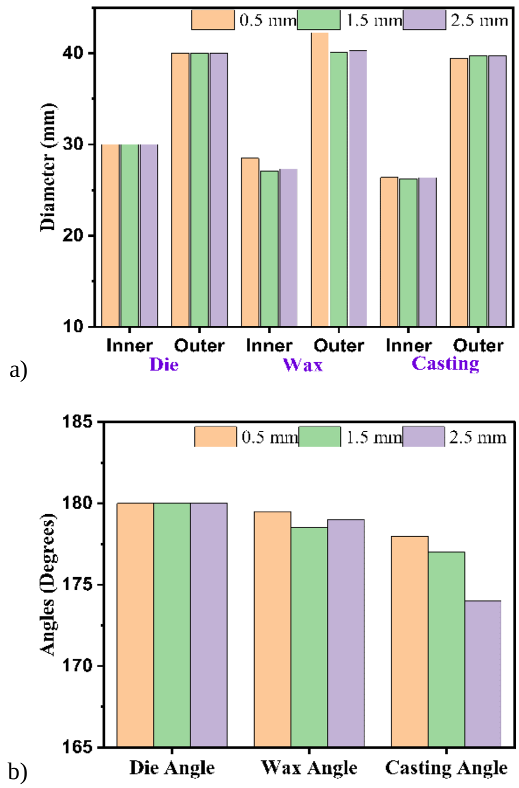


Fig. 5. Dimensional distribution of (a) inner and outer diameter (mm) and (b) angle (degrees) of the die, wax patterns and cast samples

4.1.2. Shrinkage (%) of cast samples dimension

Shrinkage percentage of cast samples dimensions with respect to corresponding die and wax pattern was analyzed in fig. 6.

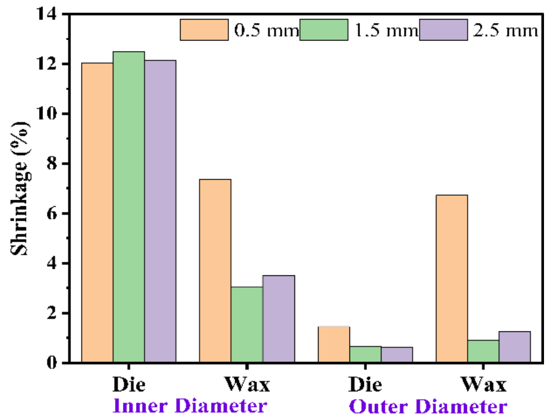


Fig. 6. Shrinkage (%) of cast samples dimensions with respect to corresponding die and wax pattern

4.1.3. Distortion (%) of cast samples dimension

Distortion percentage of cast samples dimensions with respect to corresponding die and wax pattern was analyzed in fig. 7.

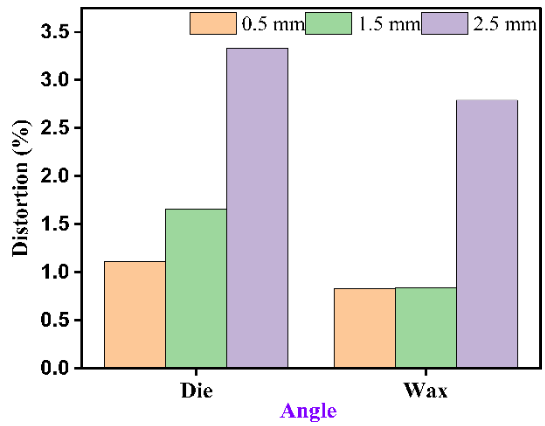


Fig. 7. Distortion (%) of cast samples dimensions with respect to corresponding die and wax pattern

4.2 Characterization

Characterization of the cast samples were analyzed to understand the distortion behavior.

4.2.1 Chemical analysis

Chemical analysis has been done with the help of Spectrophotometer and the chemical composition of the casting material has been found that is shown in the following chart.

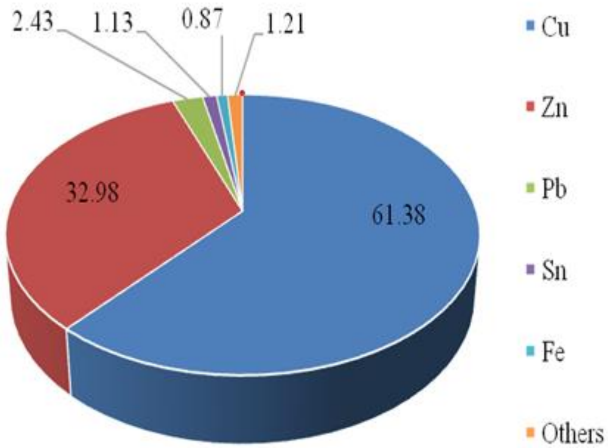


Fig. 8. Chemical composition of brass sample (%)

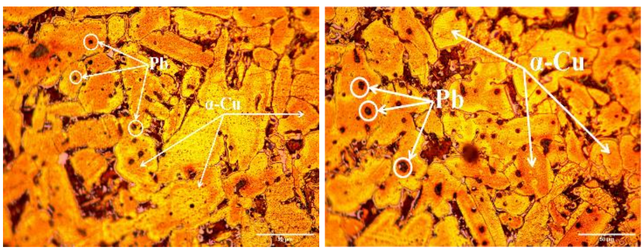
4.2.2 Micro structure studies

Grain size was measured by Olympus software during the Microstructure analysis of the cast samples. The phases and chemical compositions for different regions of cast samples were determined by EDAX (Energy dispersive X-Ray). The phases were shown in SEM microstructure (fig. 9. - g, h).

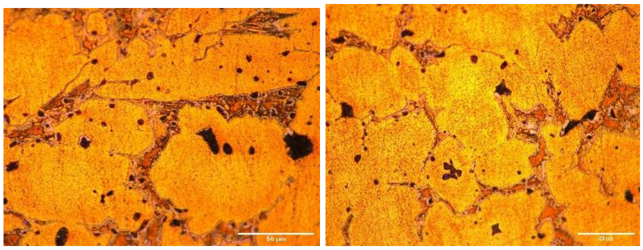
In the inner diameter region the grain size has been found to be gradually increasing with the increase of thickness. Similarly in case of outer diameter region the same behaviour of grain area and grain size no. can be observed i.e. gradually increases and decreases respectively with the increase of thickness.

Table 1.
Grain size of the cast samples

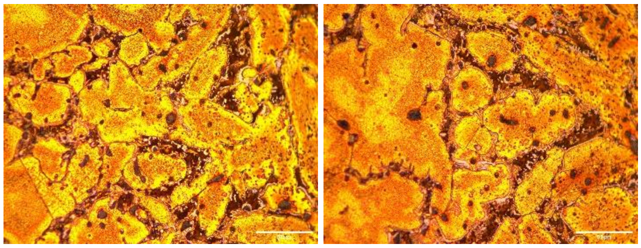
Sample no.	Inner Diameter		Outer Diameter	
	Grain Size no.	Grain Area (mm^2)	Grain Size no.	Grain Area (mm^2)
0.5	7.16	902.53	7.96	517.97
1.5	5.31	3260.99	6.32	1613.81
2.5	4.83	4542.25	5.23	3436.77



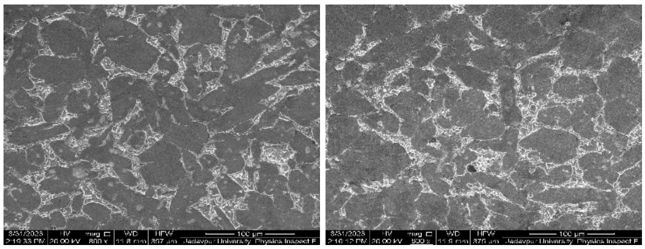
(a) 0.5mm Inner diameter (b) 0.5mm Outer diameter



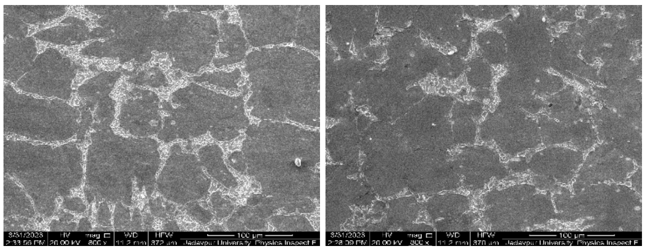
(c) 1.5mm Inner diameter (d) 1.5mm Outer diameter



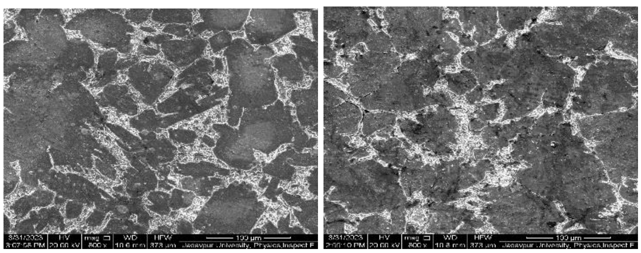
(e) 2.5mm Inner diameter (f) 2.5mm Outer diameter



(g) 0.5mm Inner diameter (h) 0.5mm Outer diameter



(i) 1.5mm Inner diameter (j) 1.5mm Outer diameter



(k) 2.5mm Inner diameter (l) 2.5mm Outer diameter

Fig. 9. (a-f) Optical (500X) microstructure and (g-l) SEM (800X) microstructure of inner and outer part of the cast samples for different thickness. α-Cu phase and distributed insoluble Pb is shown. Etchant: ferric chloride

4.2.3 Micro-Hardness

In the bar diagram, it can be observed that the micro hardness values for diameter region is higher compared to outer diameter region in case of all three cast samples. The maximum hardness was found for sample of 1.5mm inner diameter.

Less grain boundaries were found out in inner diameter of every sample as can be seen in table-1 because of larger grain area and this interpret that hardness of casing is high. But this result for outer diameter was completely opposite because of more grain boundaries [24].

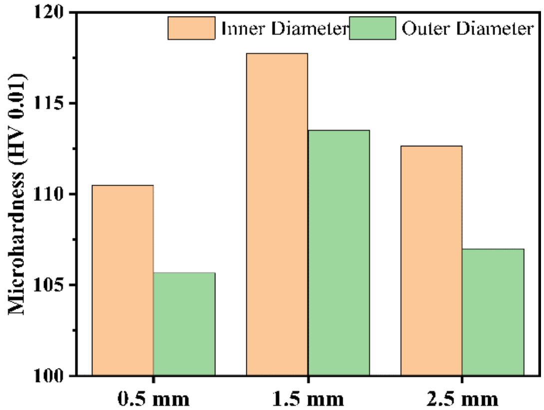


Fig. 10. Micro hardness of casting samples at different thickness

4.2.4 XRD

The casting structure obtained by X-ray diffraction study reveals some phases which are shown in the fig. 11. The copper phase was identified at angels of 36.23°, 42.25°, 72.15° and zinc phase was found at angels of 42.25°, 43.05°, and 49.25°. All these phases were identified from previous research articles. [25-27] since almost all the peaks are sharp in nature and also have negligible width that results in crystalline nature of the casting.

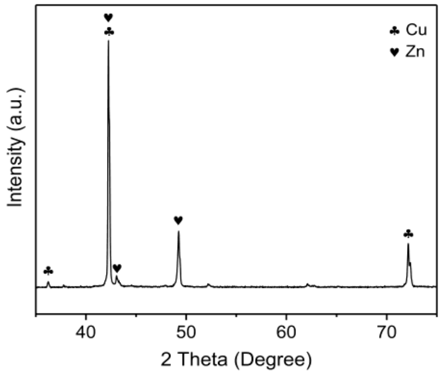
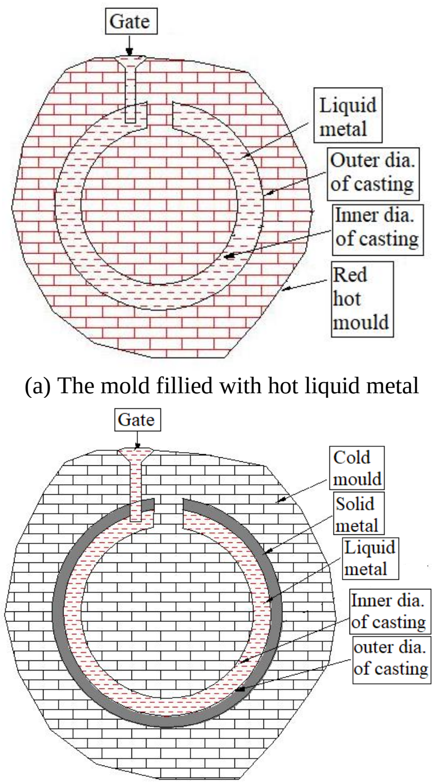


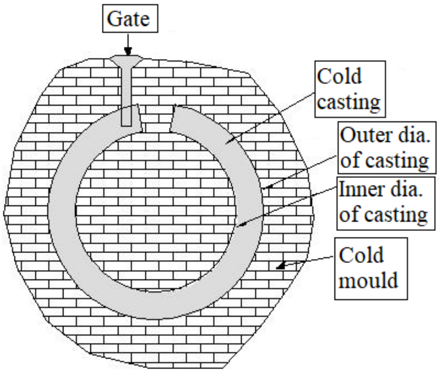
Fig. 11. XRD patterns of cast alloy of Brass

4.3 Discussion

1. Solidification rate is higher at outside of the mould due to view factor (Heat radiation is higher at outside of the curve). Due to this phenomenon outside of the curve solidify first and start shrinking (fig. 12.). As the liquid has no tensile strength and inside metal of the curve is still liquidus, so, inner side of the curve elongated and the complete product get distorted.
2. The grain sizes are larger at inner side (due to slow cooling) and smaller at outer side (fast cooling). So, the grain analysis of the microstructure study vindicated the theory. The casting was done in red hot clay mould, so, grain sizes should be larger in size due to slow cooling with respect to sand casting or any other gravity die casting.
3. Inner diameters of all samples were smaller compared to the corresponding wax pattern which is not common in foundry. But, here Keolinite clay was used for making core and mould. Keolinite clay contracts [28,29] about 1%-2% in the range between 500°C to 1100°C. Here maximum mould temperature was observed 1100°C so; core temperature must be lower than that and it get shrunk as well as the inner diameter also shrunk.
4. Outer diameter of the 2.5mm thick sample is largest among all the samples. Liquid metal flow from the riser is easy through the thicker section which helps to overcome the Liquid–liquid and liquid-solid contraction during solidification. Due to the same reason, outer diameter of the 0.5 mm thick plate is smallest.
5. The chemical analysis shows that the material used for casting is 60-40 Cu-Zn Brass. The micro-hardness of the inside region is more than outer region for all sample.



(b) Partially solidified metal inside the mold, (Metal outside the mold surface solidified first)



(c) After complete solidification

Fig. 12. Solidification pattern of liquid metal inside the red hot clay mould

5. Conclusions

Flow through thin walled mold is quite complicated [30]. Liquid metal flow is one of the important parameter that controls the quality of a casting. Quality control of a product is important either for industrial items or artifact. Dimensional accuracy is a common requirement of the buyers. In Dokra casting R&D is not available for this type of analysis.

1. The distortion is a common foundry problem. The problem was identified during the field visit. For artifact the problem can be ignored but for making any utensils or any other precision job this should be taken care off.
2. The unlike dimension was observed for Inner Diameter shrinkage. Inner diameters of all cast samples were smaller than corresponding die as well as wax pattern. But for outer dimension all casting samples are smaller than that of the die and wax pattern which is common in foundry practice.
3. Distortion is maximum for 2.5 mm thick sample and minimum at 0.5 mm thick sample. The reason is, the tensile stress during solidification due to shrinkage is larger for the thicker one and this tensile stress is the cause of distortion.
4. The chemical analysis and microstructure studies are the supportive evidence against the explanations.
5. The experiment helps to make the accurate design for any precise products which prosperous this industry in future.

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