The Effect of Gating System on Quality of Traditional Rural Metal Castings of India

Soumyajit Roy, Akshay Kr Pramanick, and Prasanta Kr Datta

Abstract Wax-based investment casting is a popular technique to produce complex-shaped products that require very little machining for use. Experiments were conducted for understanding the effect of the gating system on dimensional accuracy as well as the metal quality of cast products having different thickness in case of restricted and unrestricted sections. The production technique is followed by traditional rural artisans of India. The casting method uses bee's wax as pattern material and local clay as the mold material. 60/40 brass is generally melted, and the liquid metal is poured in hot clay molds. For gradation of cast samples, technique for order of preference by similarity to ideal solution (TOPSIS) was used for evaluation.

Keywords Wax-based investment casting · Gating system · Hot clay mold · Indian traditional rural casting method · 60/40 brass · TOPSIS

1 Introduction

Investment casting or near-net-shape casting process is used to produce complex-shaped or thin-walled cast products with close-dimensional tolerances [1]. Little machining is required for these types of components. This process is known as "Dhokra" casting, a rural casting technique, famous for hollow casting production, and can be found in West Bengal, Orissa, Chhattisgarh, and Jharkhand of India. In this process, pattern materials contain a synthetic alloy of bees wax and sal-dammer resin, and mold materials use locally available lateritic clay with fine silica sand.

Kinetics of liquid metal [2] inside a mold controls the quality of casting, and so, this becomes of primary importance for thin casting sections (like "hollow Dhokra" castings). The gating system and the position of the gate also control the flow. This demands additional care to select the proper gating parameters for better quality as the liquid metal flow gets resisted by high frictional drag (of large flat mold surface) as well as the capillary action due to too narrow mold cavity. Although, when liquid

S. Roy (✉) · A. Kr Pramanick · P. Kr Datta
Metallurgical and Material Engineering Department, Jadavpur University, Kolkata, India

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metal slips in red hot clay mold some of this resistance can be overcome by the high fluidity due to the minimum drop of liquid temperature. The experiments follow the traditional casting technique, and it was so designed to understand the effect of gating system on dimensional accuracy, surface quality, and metallurgical properties on casting thickness. Both open (unrestricted) and restricted pattern dimensions were considered during experimentation.

The investigated data on the cast products of the given properties was then analyzed by a very popular multi-criteria decision-making (MCDM) method—technique for order of preference by similarity to ideal solution (TOPSIS).

2 Background

Indian subcontinent has a very sophisticated non-ferrous investment casting tradition from ancient age (especially Cooperage) [3]. Two important centers were visited to understand the problems of the technology.

i. Dariapur, Guskara, Burdwan District, West Bengal (23°29′1″ N 87°44′6″ E), India.
ii. BiknaShilpaDanga, Bankura District, West Bengal (23°15.3″ N 87°5.9″ E), India.

Most of the utensils and icons produced by them are hollow castings, with 0.5–3.0 mm thick sections. The sections of the castings can be categorized by restricted and open (non-restricted) sections.

The materials used [4] for the wax pattern and clay mold are given in Table 1 with detailed analysis. The steps of the casting technique are summarized below:

(i) Wax pattern (for solid casting)/wax pattern using wax sheets and threads over core (for hollow casting) was made, (ii) several layers of clay over wax pattern were pasted, (iii) drying was done, (iv) gating system (Sprue and cup) was added to exposed wax pattern, (v) the mold was heated inside a coal-fired furnace to red hot condition, (vi) the liquid metal (separately melted) was poured in red hot mold, (vii)

Table 1 Base exchange capacity (sodium equivalent) and grain fineness number of the clay

Material used	Component
Wax pattern	Bees wax—60% and sal-dammar resin 40%
Core clay	Fine kaolinite + sand [Sodium equivalent (miliequivalent/100 g clay) = 3.73] [GFN = 100.68]
Primary coating (Clay mold)	Very fine kaolinite [Sodium equivalent = 0.365] [GFN = 124.97]
Secondary coating (Clay mold)	Kaolinite + rice husk + cow dung + jute cuttings + sand [Sodium equivalent = 1.71] [GFN = 60.7]

Fig. 1 Few defects of “Dokra” casting samples

fettling after cooling was done, and (viii) finishing was conducted. Surfaces near the gate and thicker sections were found poorer to thinner section (Fig. 1).

To improve the quality of investment castings, many researchers tried [5–9] different techniques. The method adopted by Horáček [10] was taken into consideration for assessment of parameters regarding pattern design.

3 Experimental Methodology

Three factors were given importance: (i) Gating system, (ii) casting thickness, and (iii) the presence of core. Quality was optimized by measuring dimensional variation and surface quality.

3.1 Design of Experiment

Three types of gating systems were designed for the experiment—(i) Top gating, (ii) side gating, and (iii) bottom gating. Two types of thickness (w) were chosen for patterns—(i) Thick (w > 3 mm) and (ii) thin (w < 2 mm). The presence of cores is another important factor during pattern dimensions—(i) restricted (cored castings) and (ii) unrestricted/open (solid castings).

The sample numbers according to these factors were given in Table 2. The schematic diagrams of the samples were shown in Fig. 2, which are followed by the proposed model of Horáček [10].

Table 2 Details of the samples

Thin plate (Thickness < 2 mm)			Thick Plate (Thickness > 3 mm)		
S. no.	Type of pattern	Gating system	S. no.	Type of pattern	Gating system
1	Solid	Side	7	Solid	Side
2	Solid	Top	8	Solid	Top
3	Solid	Bottom	9	Solid	Bottom
4	Cored	Side	10	Cored	Side
5	Cored	Top	11	Cored	Top
6	Cored	Bottom	12	Cored	Bottom

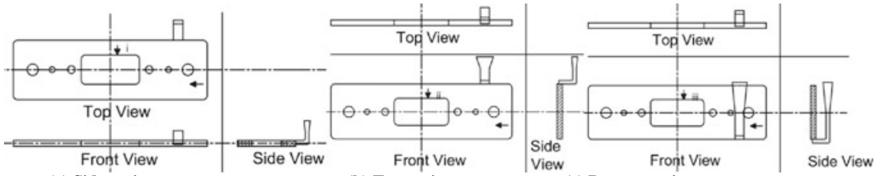

Fig. 2 Schematic diagram of pattern design

3.2 Experimental Procedure

A laser cut acrylic thermoplastics dies were designed to produce the wax patterns (Fig. 2). The steps of "Dhokra casting" techniques are shown in Fig. 3. An alloy of Cu–Zn, (60/40) brass was used for casting.

4 Results and Discussions

The cast samples were shown in (Fig. 4) indicating the salvaged and damaged areas.

4.1 Mechanical Analysis of Cast Samples

The dimensional variation and surface roughness were measured, following ISO standards ISO 1:2016 [11] and ISO 5436-2:2012 [12], respectively.

- Uniformity of the metal thickness: Root mean square (RMS) technique was used to measure the average thickness variation of all samples (Table 3).

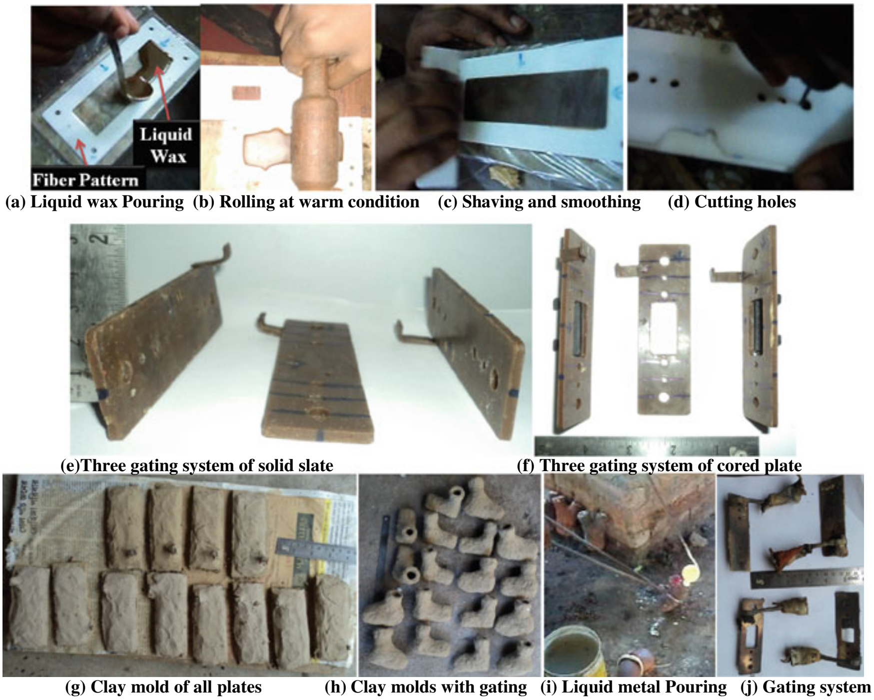

Fig. 3 Procedure of plate making

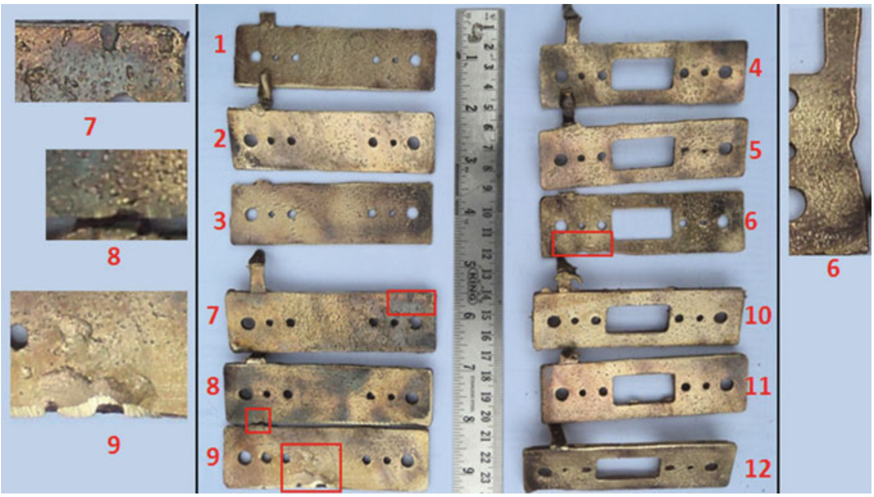

Fig. 4 Surface with enlarged view of casting defects of cast plates with sample no

Table 3 Percentage of mean variation (R.M.S) of the dimensions of the plates

Pattern type	Thin plate ($w < 2$ mm)						Thick plate ($w > 3$ mm)					
	Solid			Cored			Solid			Cored		
Gating type	Top	Side	Bottom	Top	Side	Bottom	Top	Side	Bottom	Top	Side	Bottom
Sample number	1	2	3	4	5	6	7	8	9	10	11	12
Thickness	15.62	18.51	12.7	23.8	14.7	12.74	16.2	11.34	28.2	13.38	9.27	8.23
Longitudinal	0.54	0.4	1.08	1.025	0.925	1.33	1.12	1.895	1.255	1.065	0.965	5.135

- Uniformity of longitudinal dimension (length and breadth): The average of length and breadth, were calculated by the RMS method with computing the discrepancies of the longitudinal dimensions (Table 3).
- Surface quality: The percentage of the salvaged and damaged surface areas were measured by mapping system (Table 4).
- Surface roughness: (Ra): Surface roughness [The arithmetic mean of departures (Ra)] [13] of the samples measured with the sampling length (LC) of 0.8 mm (Fig. 5).

4.2 Characterization

The corrected chemical compositions (wt.%) for zinc equivalent [14] have been assessed and given in Table. 5, along with bulk hardness of the cast samples. The SEM microstructures (Fig. 6) of the cast samples expose the dendrites (which are the signatures of casting process) as well as grain boundaries. The dendrites of the cast metal consist of copper rich α-Cu phase (gray colored) as the major phase ("First-to-freeze" Lean in solute [here Zn]).

4.3 Gradation by TOPSIS

The criteria for gradation were (i) surface quality (less damaged surface is better), (ii) surface roughness (less Ra value is better), (iii) longitudinal dimensional variation (less variation is better), and (iv) metal thickness variation (less variation is better). These criteria are non-commensurable, so, to rank the products, according to acceptance practice, a very popular MCDM method TOPSIS [15–18] was used. To determine the rank of the products, the criteria were chosen in such a way: (i) The lowest values were the best quality; (ii) Equal weight (0.25) was given to determine the rank. The individual and overall ranking of the products were given in Table 6.

4.4 Discussions

The observations of the experiment were detailed below

i. The variation of metal thickness is more in the thin plate than in the thick plate.
ii. The inner mold-wall near the gate expanded and damaged the mold surface for bottom gating system. This happened, due to the slow liquid metal flow (more heat flow to the mold surface) in this case. It causes the surface near the gate poor with high surface roughness and more salvaged and damaged area could be found in sample no's—6, 9, and 12, which were cast using for bottom gating system.

Table 4 Sectional quality and surface roughness of the plates

	Gating type	S. no	Thin plate ($w < 2$ mm)			S. no	Thick plate ($w > 3$ mm)		
			Surface quality (%)		Roughness (Ra)		Surface quality (%)		Roughness (Ra)
			Salvaged	Damaged			Salvaged	Damaged	
Unrestricted (solid)	Side	1	0	0	1.415	7	0	0	0.0112
	Top	2	0	0	1.29	8	0.07	0	0.01895
	Bottom	3	1.55	0	2.275	9	2.57	0	0.01255
Restricted (cored)	Side	4	0	0	4.265	10	2.55	0	0.01065
	Top	5	0	0	4.92	11	0.01	0	0.00965
	Bottom	6	2.81	2.24	3.185	12	2.92	2.24	0.05135

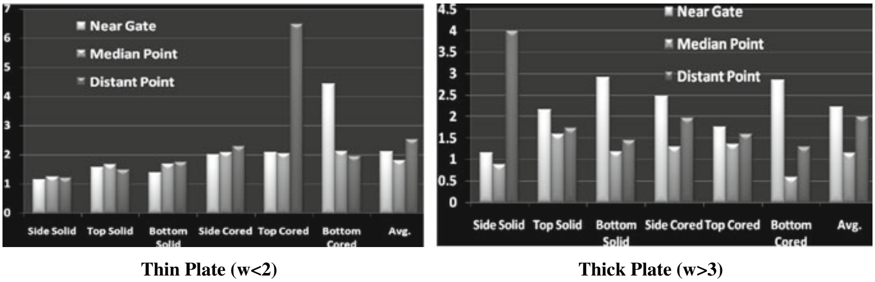

Fig. 5 Surface roughness (Ra) with respect to distance from gate

Table 5 Chemical composition and bulk hardness

Chemical composition (wt%)					Bulk hardness (HV 5/10)	
Cu	Zn	Sn	Pb	Fe	Thin plate	88.0
62.5	30.39	1.39	4.18	1.04	Thick plate	84.6

Zn Equivalent: 36.18, **Cu–Zn Ratio**: 63.82: 36.18

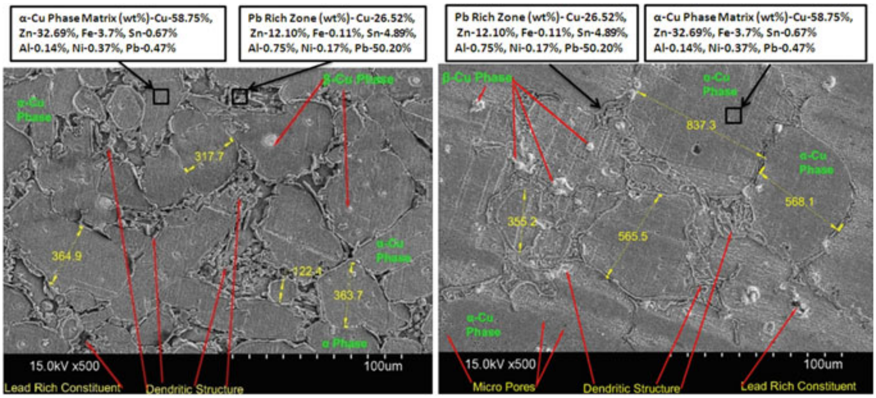

Fig. 6 Microstructure (SEM) of thin plate (top) and thick plate (bottom) (500×) with EDX analysis (Etchant: $FeCl_3$ in HCl). The structure shows coarse α-Cu phase as matrix with inter dendritic region and also with minor amount of β-Cu phase (white patches). Insoluble Pb is present at few points. Dimension of grains shows that thin casting contains smaller grains compare to thinner one (All dimensions are in μm)

iii. The smooth liquid metal flow was obstructed due to presence of cores, especially for thin casting. As a result, the surface roughness of (Ra) thin plates was better for unrestricted (solid) castings compared to restricted (cored) ones. But for thick castings, the core has a negligible effect. Because in this case the liquid-to-solid metal shrinkage property only controls the surface quality.

Table 6 Ranking of the casting samples based on quality using the TOPSIS method

Ranking	Thin plate (thickness < 2 mm)						Thick plate (thickness > 3 mm)					
	Unrestricted			Restricted			Unrestricted			Restricted		
	Top	Side	Bottom	Top	Side	Bottom	Top	Side	Bottom	Top	Side	Bottom
Sample no	1	2	3	4	5	6	7	8	9	10	11	12
Individual	1	2	5	3	4	6	1	2	4	3	5	6
Overall	1	2	5	6	7	11	3	4	9	8	10	12

iv. The surfaces distant from the gate had more shrinkage defect [19]. Poor rising may be the cause of unacceptable surface for sample no's 5 and 7.

v. In microstructures, coarse (large) grains were present in thick plates, whereas (small) fine grains are present in the thin plates. Quite a large number of dendrites are present in thin plates as faster cooling happened, which gives rise to large number of nucleation sites without consequent available time for growth. Smaller the thickness, lower is the solidification time, as per 'Chvorinov Rule,' the solidification time is directly influenced by of the ruling section, following, [20]

$$w = k\sqrt{t - c} \tag{1}$$

where w = solidification thickness, t = solidification time, and k, c are constant. Therefore, the experimentation had shown that the grain size of a cast sample depends on the casting thickness.

iv. Side gating and top gating systems produced castings having better acceptable surface compared to bottom gating system. So, bottom gating system is not followed for thin casting production.

5 Conclusion

On the basis of the investigation, the following conclusions can be drawn.

i. In the field visit, the major defects of the castings, identified in thin sections, were misrun and rat tails. In thick sections, the main defects found were crushes, metal penetration, scab, and pits.

ii. Design of gating system is important for good quality casting and economic production. The experiment proves that gates should not be positioned at the corner of any sample; rather this should be positioned in such a way that every corner should be filled quickly [21] from the principle of gating design: "Shortest filling time."

iii. Restricted cast components (castings having core) and thin sections require more care and accuracy for better quality and economic production. The castings having thick sections require proper riser design to avoid shrinkage defects.

iv. The grains structure and size are controlled by the ruling thickness of a component. So, the heat treatment and machining of a component can be reduced by proper design of a component and production method selection.

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