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AN ENGINEERING APPROACH TO THE MANUFACTURING PRACTICE OF THE TRADITIONAL INVESTMENT CASTING PROCESS OF INDIAN SUB-CONTINENT

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ABSTRACT
The traditional investment casting process of the Indian sub-continent is practised for millennium in Eastern India and Bangladesh for manufacturing domestic brass and bronze items. Commonly known as Dokra process, this method remained highly competitive both in cost and technology. Appreciating this positive aspect, a mechanical engineer's direction has been introduced so that this process can be streamlined to produce non-ferrous machine components of consistent quality and persistent dimensional stability. The process design starts with the analysis of the casting using standard CAD software followed by development of the gating design and the riser design which uses Modulus method. More than a dozen castings of complex shapes and forms obtained from some producing centers are taken for investigation and comparison. And a few examples are presented showing very encouraging result as the method is simple and user friendly for the producers.

Keywords: Dokra Casting, Investment Casting, CAD

1. INTRODUCTION
Clay Molded Investment Casting (CMIC) process originated in Chalcolithic age of human society in early 3rd millennium B.C [1]. This process is an ancient tradition of Asia, Africa and Pan-Pacific regions and still followed in many regions of India, Bangladesh, Papua-New Guinea and Benin of west Africa [2, 3]. Even so, scanty technical data are available in the literature [3,4]. Modern designers do not get opportunity for recommending the castings even though those are cheap and can easily be manufactured. The present investigation deals with establishing an engineering approach to the manufacturing aspect of this age-old practice [5] so that it can be further applied to industrial production process employing invest casting methods for engineering items.

2. TECHNIQUES OF DOKRA CASTING
An extensive study was conducted on the method of CMIC in different villages of Eastern India [3] and the technique of manufacturing is as follows:

2.1 Core Making.
Stage 1: A Clay-core is made up of appropriate form, using a mixture of core-clay, rice-husk and coarse sand (40-60 AFS No.) in the ratio of 4 : 1 : 1, with sufficient moisture so as to develop enough flowability suitable for making the form.
Stage 2: Polishing & Drying.- The top surface is polished and the core is dried under the sun, preferably initially under a shade, for 2-3 days. The surface of the clay core is smoothened before waxing.
Stage 3: Waxing or Wax Pattern Making - Waxing is done over the dried core, along with suitable runners and gates, made of the same wax. For core-less or solid castings, the process starts from this stage with making of the wax pattern (Fig 1).

Fig 1. The Dried Clay Core (Left) and the Finished Wax Pattern (Right)

2.2 Investment Shell Molding

Stage 4: Shell Molding (Facing) - A 3-5 mm thick investment shell of fine clay and cow-dung mixture is pasted over the wax pattern and is slowly dried. The clay used here is of type 2 clay described earlier.

Stage 5: Shell Molding (Back-up) - Covering the investment shell, another back-up layer of the clay-sand-rice husk aggregate (used earlier in the core) of generous thickness (minimum 6 mm) is applied, with the making of a funnel at the gate, to hold the metal. Then, the whole of this mold is sun dried.

2.3 Metal Charging, Firing & Dewaxing

Stage 6: When the metal is separately melted for casting, then the investment mold is directly transferred to a pit-furnace and gradually heated in coal-fire for dewazing and casting. But, in case, when the metal is melted within the integrated mold, the metal pieces are placed in the funnel of the mold. The funnel is then covered by a green clay-cap. An opening at is kept at the top of the funnel. Brass or bronze scrap generally is charged into the mold, eight to ten times the weight of the wax. More metal is melted than is necessary to have a continuous flow of liquid metal and avoid shrinkage due to volume contraction. The total mold is heated in a steam coal-fire at around 1100^0C for first de-waxing and then melting the solid metal into liquid.

Fig 2. Traditional Dokra Production in Progress

2.4 Melting and Pouring Technique

System 1: By tilting the investment mold the hot liquid metal is directly poured through the gate in the vacant dried clay mold.

System 2: Metal is melted in a graphite crucible (Fig 2) on a coal-fired pit-furnace and then the hot metal is poured uninterrupted by in the pre-heated dewaxed investment clay mold, like any other casting process.

Stage 7: Fettling. When the casting cools, usual fettling, brushing and repairing by soldering (if any) are done. For shinning the metal, the surface is polished with shop-nut solution or tamarind solution or dung-liquor, using wire-brass.

Stage 8 : Finished Casting. After finishing, the casting (Fig 3) becomes ready for shipment.

Fig 3. A Traditional Dokra casting (made of brass)

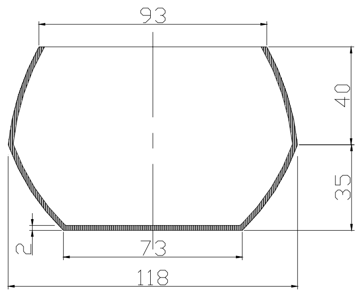
3. EXPERIMENTATION

Dokra cast samples were collected from rural production centers and all the required dimensions were measured with necessary pattern allowances for the purpose CAD methoding and subsequent laboratory.

3.1 Method of Investment Casting

The study starts with the method of investment casting (Fig 4) from the engineering drawing (Fig.5) obtained in the foundry.

Fig 4. Sample Investment Casting for the study



Total Heat Dissipating Area = $617.04\text{x}10^{-3}$m

Total Volume of the material = $61.084\text{ x}10^{-6}$m

Total Weight of the material = 0.513 kg

Fig 5. Front Sectional View of the Bowl

A CAD model has been developed using the drawing, From the CAD model, all the relevant dimensions necessary for founding have been estimated using software, whose flow sheet has been provided in Fig 6. All the method dimensions, namely of gates, runners, risers along with placement have been shown in Fig 7. as the design diagram using foundry principles[6].

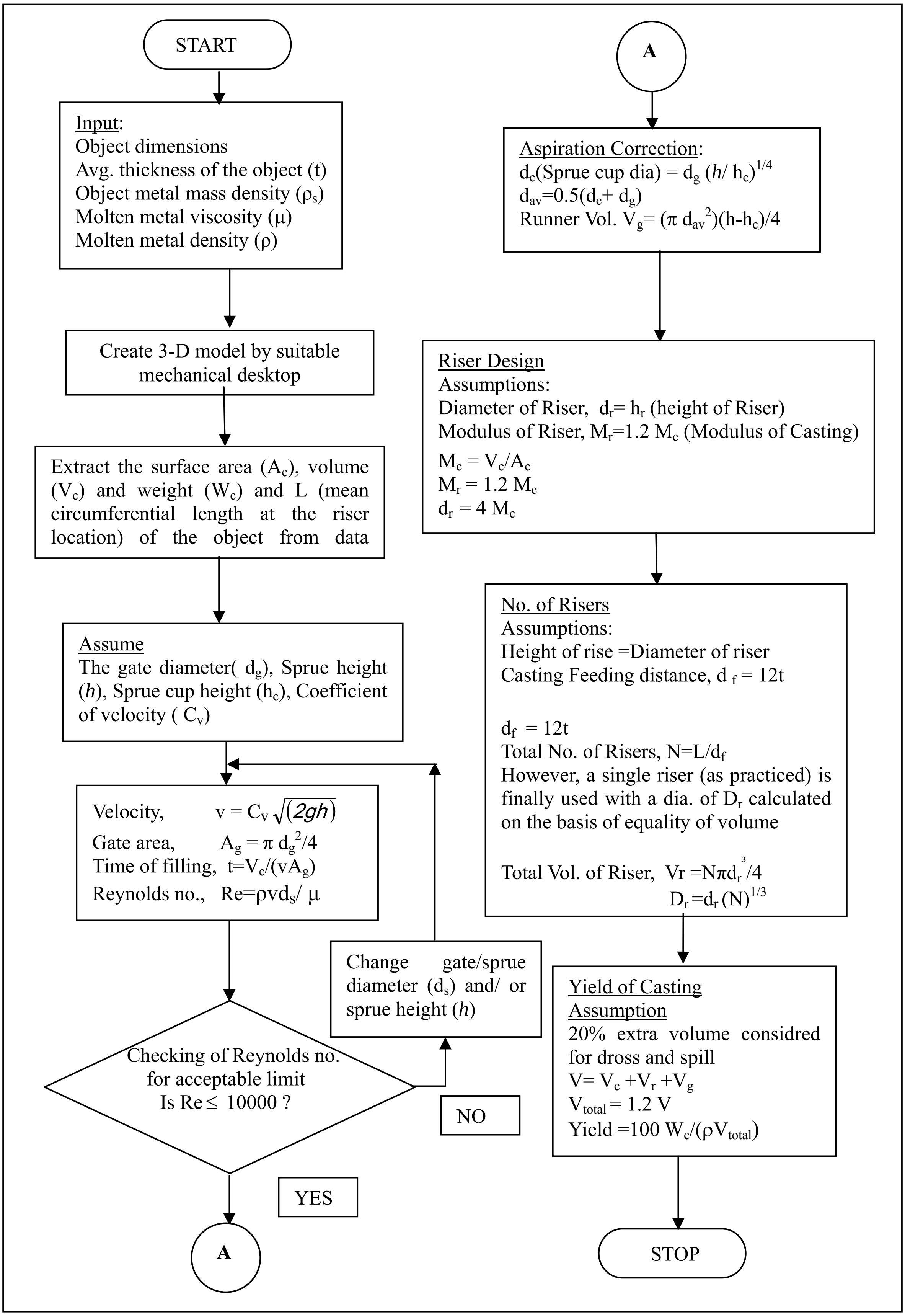


Fig 6. Flowchart for Methoding Design of Dokra Casting

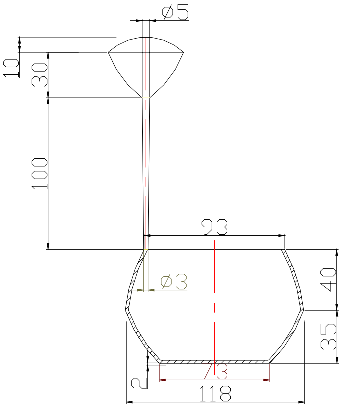


Fig 7. The Bowl pattern with riser dimensions and location using CAD model

3.2 Casting and Comparison

Using the design data, some castings of copper alloys have been made in the laboratory, whose details are given in Fig 7. Design data for some castings, made at different casting workshop of rural India, were collected during the field visits,. The field data were compared with the data generated through CAD program, for understanding the relevance of the methoding of the investment casting as applied. Results show very close matching indicating the success of the exercise.

4. CHARACTERIZATION OF MATERIAL

All the castings were subjected to usual metallurgical tests like metallography, hardness testing and X-ray diffraction analysis.

4.1 Metallography

Metallographic results of castings as obtained in the laboratory (Fig.8) as well as from field visit (Fig.9) show

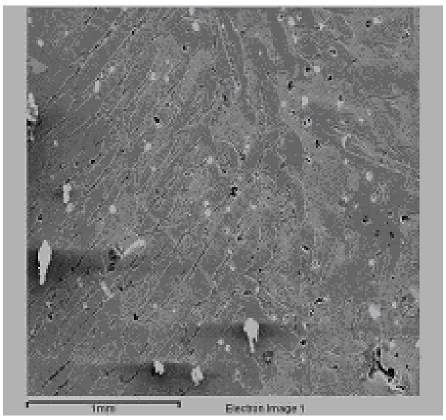


Fig 8. The SEM microstructure shows predominantly α-phase in the brass casting produced in the laboratory

heavily cored structure of coarse dendrites. Most alloys are single phase with residuals in the inter dendritic region. The cooling rates as obtained from large secondary dendritic arm spacing (DAS) has been found to be very slow, usual for common investment casting [6]. DAS has been measured from metallographic observations and the cooling rates [7] have been determined by the expression as follows,

$$\lambda = 101 x R^{-0.42}$$

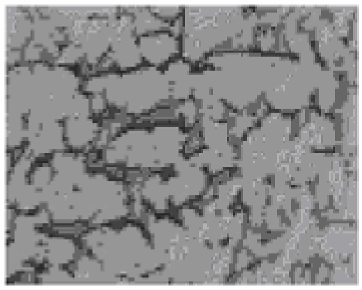


Fig 9. The microstructure (180x)shows α-Cu phase as the matrix with inter-dendritic liquid (Kotpad centre)

where λ= DAS in μm and R = Cooling rate in K/sec. As λ varies from 50 – 15 μm and R has been obtained varying from 20-70 K/sec indicating slow heat dissipation rates of investment molds.

4.2 Hardness

Both micro and macro hardness testing have been carried out on the cast samples. Hardness results indicate somewhat higher hardness than generally had been reported in literature for sand cast samples. The phenomenon is common to most Dokra casting centers because most of the tiny foundries commonly use market scraps rather than standard brass and bronze ingots or assorted clean scraps of known castable compositions. Hardness obtained from laboratory samples are very close to the data [8] obtained in handbooks for sand cast samples.

Table 1: Vickers Micro-hardness(Load 50gf)

No.	**Dia (d_1,μm)**	**Dia (d_2,μm)**	**!st phase (H_v,Kg.mm^{-2}**
1	20.8	21.1	210.8
2	21.0	21.5	205.7
3	23.9	20.4	199.2
No	Dia (d_1,μm)	Dia (d_2,μm)	2nd phase (H_v,Kg.mm^{-2})
1	17.3	18.6	286.7
2	17.8	18.5	282.6
3	19.5	16.5	287.2

Table 2: Vickers Macro-Hardness(Load 5kgf)

Dia (d_1,mm	**Dia (d_2,mm)**	**Avg. Dia (d,mm)**	**Hardness (Kg.mm^{-2})**
0.211	0.199	0.205	221
0.204	0.198	0.201	208
0.191	0.187	0.187	260

As an example, hardness results (Table 1 and 2) of Bikna centre are comparatively very high when compared with general group of Cu-Zn alloys (50-70) or (150-230)[12] and the alloy, probably, contains elements like Al, Fe, Sn, etc.

4.3 XRD Result

XRD results for most of the samples indicate the predominance of the solid solution of Zn, Sn or Ni in copper as α-phase [9]. The second phase, in general, is β-solid solution and possibilities of some minor phases cannot be discarded. Tables 3 and 4 show results from typical x-ray diffraction analyses of the castings under investigation.

Table 3: Brief XRD result (Sample Sadaibherini)

K-α	(Θ/Ω=2:1)	d	I_{rel}
1	11.960	7.393	54
2	42.388	2.130	1000
3	49.287	1.847	382
4	72.406	1.304	480
5	87.645	1.1125	194
6	92.629.	1.0652	87

Table 4: Brief XRD result (Sample Jadavpur)

K-α	(Θ/Ω=2:1)	d	I_{rel}
1	42.437	2.1283	1000
2	49.368	1.8445	379
3	72.406	1.3020	91
4	79.227	1.2081	16
5	87.657	1.1123	73
6	96.523.	1.0323	18

For these samples, XRD results confirm the presence of many unidentified foreign phases, other than the major phase of α-Cu (d=2.13A°).

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4.4 EDAX Results

The compositions of phases (Fig 10) were analyzed by SEM-EDAX, confirming the overall presence of Cu-rich α-phase in the matrix in form of solid solution and solute rich β- phase in the inter-dendritic regions [10]. The presence of more than one element in perceptible amount vindicates use of unknown market scraps of doubtful compositions, sold as brass or bronze to rural artisans

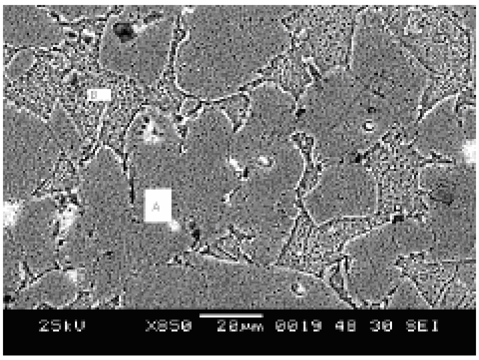

Fig 10. Dendrites (marked 'A') and the inter-dendriric liquid (marked 'B') have been analysed by EDAX of a sample from Kondagaon, Bastar, India

Table 5: Composition of dendrite marked 'A'

Element	Weight%	Atomic%
Cu	83.95	83.24
Zn	24.92	24.15
Ni	8.54	9.21
Fe	2.30	2.61

Table 6: Composition of inter-dendritic liquid marked 'B'

Element	Weight%	Atomic%
Zn	23.92	23.66
Cu	64.39	65.52
Sn	3.69	2.21
Ni	8.01	8.82

5. CONCLUSIONS

An attempt has been made to introduce the principles of methoding into the traditional clay molded investment casting practice (Dokra Casting) using the modern 3-D modeling approach of CAD. If the production castings utilize this gating and risering practice there is a scope of lowering the rejection rate as well as the increasing the yield of the castings. Most of the microstructures developed from actual castings indicate the use of non-standard material. Therefore the use of standard material with the modern technical input can contribute to quality castings at lower production cost.

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