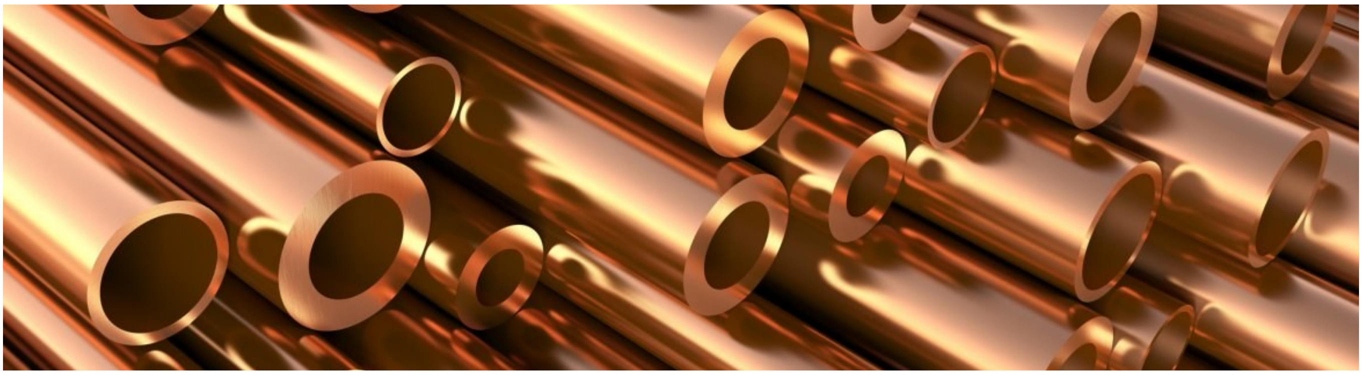
GATING SYSTEM IN THIN WALLED COPPER ALLOY CASTING



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ABSTRACT

Large numbers of tiny brass and bronze foundry units thrive traditionally in Indian sub-continent covering Bangladesh and India. Reputed to be producers of a variety of thin walled copper alloy product their production process deserves close technical examination for available sophisticated engineering technology. The intricate shape and thin section with convoluted extensions and aberrations of the cast product throws a great challenge for mechanical engineers to utilize the process for quality production. In particular gating of castings for efficient and convenient liquid metal flow into the narrow space of mold becomes the main impediment in production process. With this fluid mechanics in view a research work has been undertaken to examine the foundry sector. Field work reported in this report concluded that many of these units adopted either investment clay molds or common clay molds. Brief characterization of collected castings indicated a wide variety in chemical composition with little regard to metal chemistry. Some gating calculations on these cast items suggested the future quality improvement that could improve surface quality as well as core mechanical properties.

Keyword: Gating System, Investment casting, Cu-alloy characterization

I. INTRODUCTION

To investigate gating system in thin walled copper alloy casting in Indian sub-continent covering Bangladesh and India, some casting centers have been visited. Most of the casting centers use investment casting process as well as clay mold process. For experimentation few castings have been collected and their Gating and Risering System have been calculated. Characterization of the cast copper alloys are also been reported in this paper. A brief description of the process with materials used has been provided in the field report.

2. FIELD VISIT

The artisan community centers of brass and bronze casters are located in the following sites, (Fig. 1). Dariapur[1], District Burdwan of West Bengal. Artisans of Dariapur practice investment casting process. Investment casting process use the clay aggregates for molding on Wax models.

2.1 Investment Casting (Clay Molded) Process:

The process details have been represented graphically (Fig. 2-11).

Core Making: A Mold aggregate constitutes mixtures of fine clay (Fig.2) with coarse sand, calf dung and jute cuttings along with sufficient moisture for dough making.

Core Drying: The surface is polished and the core is dried under the sun (Fig. 3). The surface of the clay core is smoothened before waxing.

Waxing: Bee-Wax is applied over the dried core, along with suitable runners (Fig. 4) and gates, made of the same Bee-wax. For core-less or solid castings the process starts from this stage with making of the Bee-wax pattern.

Shell Molding: A 0.5 – 1.0 mm thick investment shell, made (Fig.5) of dough consisting of Bentonite, Alumina sand (325 mesh), charged rice-husk and jute cutting is pasted over the wax pattern and slowly dried.

Back-up Shell Molding: Covering the investment shell, (Fig. 6) another back-up layer of the clay-sand-rice husk aggregate (used earlier in the core) of generous thickness is applied with the making of a funnel at the gate, to pour the metal @ the mold.

Fig.1 Location of the site of investment casting artisan community, at Dariapur, Burdwan marked by

Mold Firing: The complete mold is directly transferred to a pit-furnace (Fig. 7) and gradually heated in furnace over 1500 ^{0}K for de waxing and casting.

Metal Melting: Brass or bronze is charged in a preheated graphite crucible (Fig. 8) and melted in a furnace to the required temperature and is prepared to proper liquid condition to pour in to the mold.

Metal Pouring: The hot liquid metal is directly poured through the gate (Fig. 9) in the vacant, dried, hot clay mold kept at 1500^{0}K after removing the red hot mold from the furnace.

Fettling: The casting (Fig. 10) within the mold is being cooled in air.

Finishing: Final casting is being completed by the (Fig. 11) artisan.

Fig. 2 Core Making

Fig.3 Core Drying

Fig.4 Waxing

Fig. 5 Shell Molding

Fig. 6 Backup Shell Molding

Fig.7 Mold Firing

Fig. 8 Metal Melting

Fig.9 Metal Pouring

Fig 10 Fettling

Fig.11Finishing

III. GATING DESIGN

Gating system plan starts with design technique2 of "shortest filling time".

The design begins with assumption of Sprue diameter, on given assumption of Sprue height and Cup height. The liquid metal velocity at Sprue gate has been evaluated. Mass flow rate then provides the expected filling time. Considering short filling times obtained there by design has been finalized. Aspiration correction of Sprue is introduced to avoid gas entrapment. Streamline metal flow gets checked by means of Reynolds Number and iteration technique could be helpful to recalculate the optimum design. Modulus of casting has been computed for adequate riser with further check on efficiency of the design.

3.1. For Item No.1[Model of Tribal Woman]

Details of casting as received are given, (Fig.12)
Volume of the casting, × 106, m3 = 14.714;
Heat dissipating area of the casting, × 103, m2 = 8.173

Assumptions: Top gating

Sprue diameter, × 103, m = 4 ; Sprue height, × 103, m = 60

Cup height, × 103, m = 20 Discharge coefficient, = 0.8

For Brass: Viscosity, mPa.s = 4 and Liquid Density, kg/m3 = 8400(say)

On the basis of above,

Sprue area, × 106, m2 = 12.56

Velocity at Sprue, vs, m/sec = $C\sqrt{(2g\ h\_sp)}$ = 0.87; Liquid metal flow rate, Asvs, × 106, m3/sec = 10.93

Time of filling, tf =Vc/AsVs, sec, ≈ 1[small time accepted]

Check by Reynolds's No., R = (Vs×ρ×ds)/μ = 7308. Since tf is small and R < 10,000.

So, Design satisfactory (Fig 12).

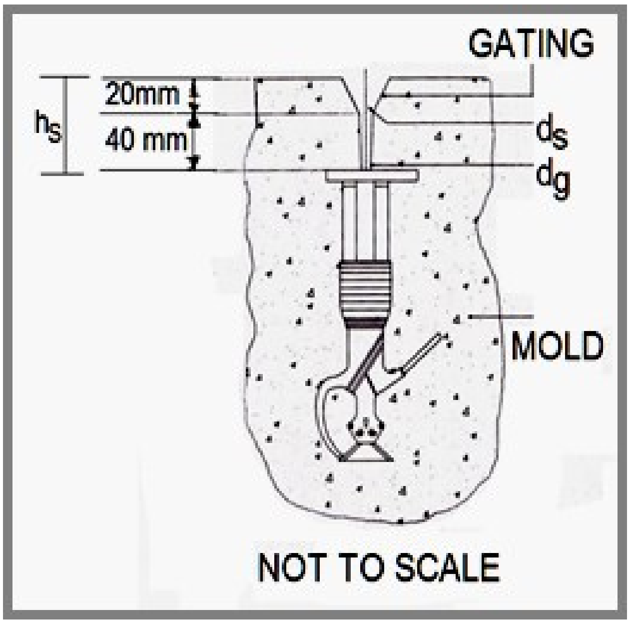

Fig.12 Item No 1 [Model of A Tribe Woman]

Sprue Design:

Aspiration correction, As/Acu = √(h_cup)/ √(h_sp) hence d_sp/d_cup
= ∜h_cup/h_sp
Thus cup diameter, d_cup, × 103, m ≈ 6

Riser Design:

Modulus of the casting, Mc=Volume/Area.
Here Mc, × 103, m = 1.80

Let, Mr = Modulus of riser = 1.2 Mc.
Thus Mr, × 103, m = 2.16

Assume cylindrical riser, dr = hr

Mr = (Volume of the riser)/(Heat Dissipating Area)= (πdd_r r×dr×dr)/(4×π×dr×dr) = dr/4
Hence dr, × 103, m ≈8
Design summary (× 103, m) has been given Table 1

Table 1 Design summary for item No 1[Model]

Sprue Diameter	Sprue Height	Cup Height	Cup Diameter	Riser Diameter
4	60	20	6	8

Details of Gating Design for the item no 2 & 3 in form of standard flat (95) x (20) x (7) and (225) x (20) x (7) have been designed (Fig 13 & 14) following the method already described earlier. The design summary has been tabulated in the Table 2 & 3. Castings (Fig 15) of model and the flats have been poured using the design in hot clay molds for experimentation.

Design summary (× 10^3, m)

Table 2 Design summary for item No 2

Sprue Diameter	Sprue Height	Cup Height	Cup Diameter	Riser Diameter
7	40	60	8	16

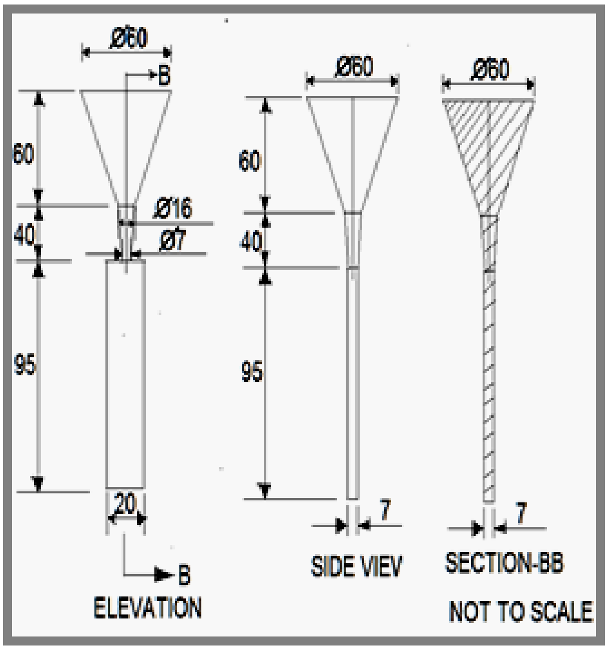

Fig.13 Item no 2 - Short Flat

Design summary (× 103, m)

Table 3 Design summary for item No 3

Sprue Diameter	Sprue Height	Cup Height	Cup Diameter	Riser Diameter
7	50	60	8	16

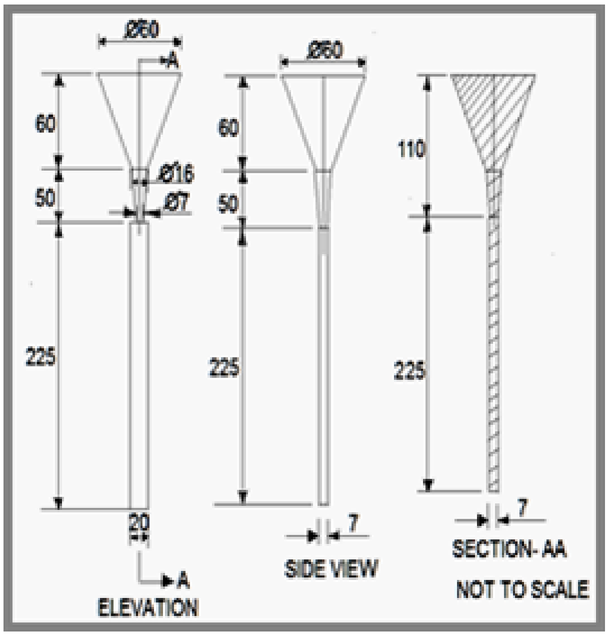

Fig.14 Item no 3 - Long Flat

IV. RESULT OF THE CASTING

Surface finish of all the castings produced (Fig 15) by artisans and the laboratory displayed smooth surface with few surface defects like small fins, rat tails and projected metal dots. No scabs or drops were available. Overall the surface quality can be termed reasonably satisfactory as can be seen (Fig 15).

Fig.15 Model casting of Tribe Women

4.1 Quality Gating Summarized:

Based on field work and fluid mechanics, gating should be formulated on the following Principles:
Top Gating – Small casting production provide satisfactory filling.
Sections - Otherwise mentioned all sections are round or conics.
Vertical Gating – Pattern Position in Standalone or Bottom Side-up.
Gate Location - Through Flat base of Vertical reverse patterns: [Upside Down of pattern in the mold Recommended]
In-gate Position - Back side of Patterns
Location of Sprue - Conical geometry @ the Top of the mold
Sprue Cup requirement- Preferably assisted with Filters.
Sprue Quality- Aspiration Safe Design.
Sprue Well – No longer necessary & metal directly fed into mold
Sprue Design – Fluid Mechanics Assisted.
Runners – Long curvilinear design followed in complex castings
Metal Flow – Streamline corrected to Reynolds no.20000-25000 In case of Cu-alloys .
Riser Design – Sprue Cup used as substitute riser.
Economy of Casting Production: 70-80%

V. CHARACTERIZATION OF CASTINGS

Characterization of the brass castings starts with determination of chemical compositions of cast metals

5.1 Compositions of Cast Metals

The results of chemical analyses of the cast metals investigated have been given in Table 4. The study of alloys demonstrated the alloys as brass[2]. Both contain Cu and Zn as the major elements with minor elements of Pb, Sn, Ni, Fe, Al and As plus P in the second. Only lead is insoluble[3] in this alloy. As and P can be the result of deoxidizing attempt used. Sn acts as the natural element of Naval Brass. Others possibly enter as Tramp elements. The second alloy looks much cleaner but the first alloy represents use of scrap. Both castings belong to 60/40 variety or α-β Brass, traditionally called Muntz Metal by mechanical engineers and favorite to casters for high strength.

Table 4 Chemical Composition of item No 1, 2 & 3

Elements (Weight %)	Indian Tribe	Small Rod	Long Rod
Copper (Cu)	58.8%	63.6%	63.4%
Zinc (Zn)	35.2%	35.9%	36%
Lead (Pb)	3.5%	-	-
Tin (Sn)	1.0	0.4%	0.5%
Arsenic (As)	0.07%	-	-
Iron (Fe)	0.8%	0.1	0.1
Nickel (Ni)	0.4%	-	-
Aluminum(Al)	0.3%	-	-
Phosphorus(P)	0.01	0.01	0.01
Zn Equivalent	37.8	36.4	36.7
Brass Grade	60/40[Naval]	64/36	64/36

5.2 Microstructures of Casting

Test specimens of cast samples were ground by a belt grinder and then emery paper was used with a sequence of 120, 180, 1/0, and 2/0 before cloth polishing. After polishing brass specimens were etched[4] with $FeCl_3$.

The microstructures of artisan casting (Fig.16) depict predominantly the coarse single phase structure (white) of **α**-Cu dendrites with surrounding **β**-Cu phase (black) (Zn-rich solid solution in Cu) in the grain boundary.

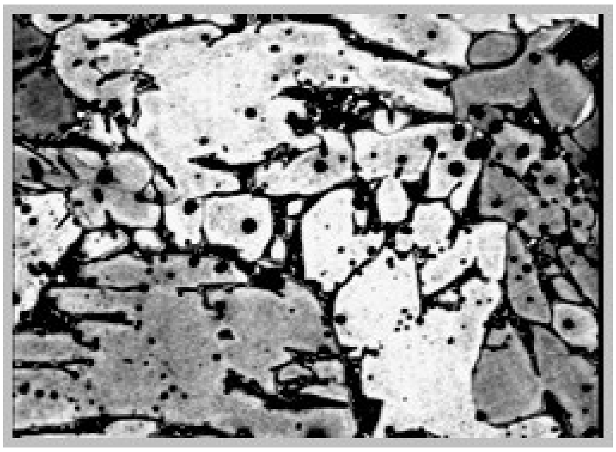

Fig 16 [200x, Etched $FeCl_3$ in HCl] Microstructure of Item No1 shows thick stem with coarse branch of primary dendrite in form of Cu α-phase of Cu-Zn alloy. Globules of lead also get well spread over structure for possible removal of contraction in castings.

Solid solution **α**-Cu phase constitutes Zn and other elements of Sn, Fe, and Al. Long solidification time occurred when the liquid alloy of the casting cooled within red hot investment mold. Large amount of constitutional super cooling with too long time for grain growth made those **α**-Cu dendrites so large. Black round precipitates of insoluble lead spread widely distributed, under the background of **α** and **β** phases. For compensating the volume contraction of liquid brass during freezing the addition of lead might be intentional in alloy design.

The microstructures of laboratory produced castings marked item nos. 2 (Fig 17) & 3 (Fig.18) from 64/36 Cu-Zn alloy demonstrate cored structure of α- Cu phase dendrites. The dendrites of castings produced in the hot mold as usual are very coarse (Fig 17) with inter dendritic regions holding β - Cu phase (Fig 18). Being close to α - β brass the amount of β phase has appreciable amount.

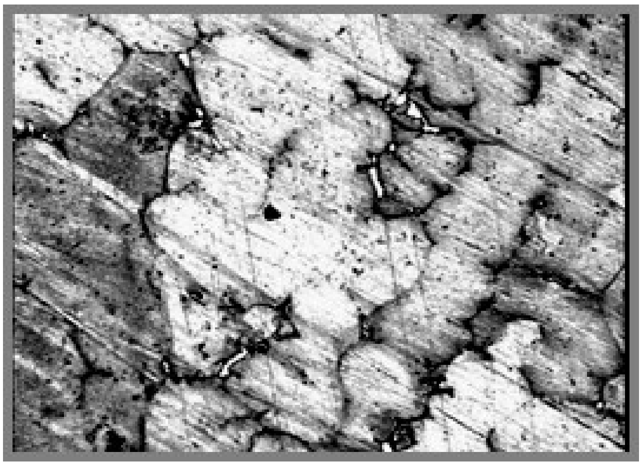

Fig.17 Microstructure of Item No.2 [200x] Long branches of primary α- Cu phase dendrites of Cu-Zn system cover the structure as matrix. The intermediate regions hold remnants of β - Cu phase solidified later.

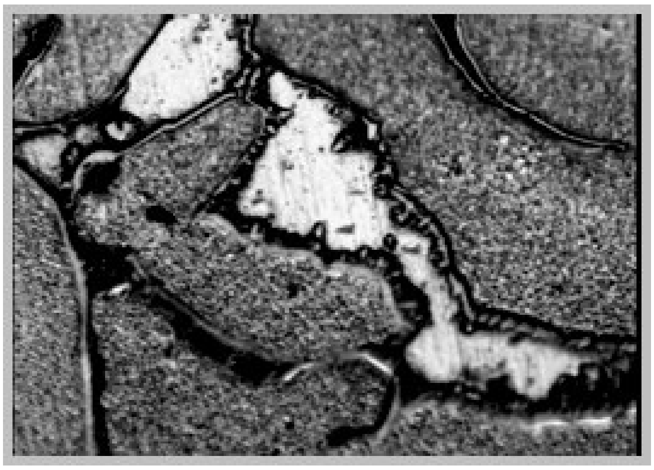

Fig.18 Microstructure of Item No 3 [500x] α- Cu phase (gray) and inter granular β - Cu phase (white area) of Cu-Zn solid solutions can be seen.

VI. CONCLUSION

From the short research work under taken few conclusions can be summarized

i) Dariapur artisans seen to be very much expert in investment clay molded process. The wide verity of cast products and utilitarian article production demand complex gating system and people their possess expertise in many gating systems but the dimensions of gating are arbitrary and do not justify natural fluid flow principles.

ii) On the basis of the field reports gating system and the riser design have been formulated using fluid mechanics. The gated design has been utilized to cast few castings in the laboratory with in hot molds. A summary on Gating Design has been formulated.

iii) Brass being the common alloy used by the Dariapur artisans has been taken into experimentation. Brass castings at Dariapur are produced from scrap material and suffer from high amount of lead and many tramp elements. Castings from the laboratory have been produced from 64/36 Graded Brass free from those impurities Microstructures of all castings corroborate the observations. α-β brass would be very commonly used in case of investment castings. The metal generally should contain little lead that remains insoluble to compensate the solidification shrinkage .

Nomenclature

d_s :Sprue Diameter, m
A_s : Sprue Area, m^2
h_s :Sprue Height ,m
h_{cu} :Cup Height, m
C :Discharge coefficient, -
μ :Viscosity of Brass, mPa.s
ρ : Density of Bronze, kg/m^3
v_s : Sprue velocity, m/sec
t_f :Time of filling, sec
R :Reynolds's No's, (-)
A_{cu} :Cup Area, m^2
d_{cu} :Cup Diameter
Mc : Modulus of the Casting, m
M_r : Modulus of the Riser ,m
d_r : Riser Diameter, m
h_r : Height of the Riser, m

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