Quality Analysis of Tribal Casting Products by TOPSIS for Different Gating System

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Abstract. Indian Tribal Products has high demand in the International market but the quality of the Tribal Products are not been analyzed by scientific technique, as no R&D is involved with the sector. A Lost-Wax Investment cast metal craft traditions were adopted for the project which has been in practice from the ancient age. An experiment was designed and done to understand the effect of gating design which controls the quality of the casting. The quality of castings was analyzed based on Eccentricity, Uniformity of Thickness, Surface Quality and Surface Roughness. The preferable gating system was chosen using TOPSIS.

1. Introduction
Indian sub-continent has a very sophisticated Non-Ferrous Investment Casting tradition from Cooperage [1] named “Dhokra” or “Dokra” which is cultured by the Tribal population of West Bengal, Orissa, Jharkhand and Chattishgarh. Bikna Shilpa Danga at Bankura District (23°15.3’N 87°5.9’E) and Dariapur, Gusarka at Burdwan District (23°29’1”N 87°44’6”E) [2] are the most popular site in West Bengal.

The Lost Wax casting process is used in Dhokra Casting. They produce Complex-shaped items and most of the products are Hollow and Thin-walled (up to 0.4 mm thin). Thin-walled hollow products are very difficult to cast as liquid metal experienced high friction force due to its high viscosity[3], and also resistance is created due to capillary action caused by narrow mold cavity[4]. Hot Clay Mold has been used from an early age to overcome this problem [5].

Gating system controls the quality of a cast product [6] by controls the kinetics of liquid metal flow [7, 8]. Different Gating System was experimented adopted from the Tribal Casting Technique. The Eccentricity, Uniformity of Thickness, Surface Quality and Surface Roughness of all samples was analyzed and better gating system was determined using a very popular MCDM (Multi-criteria decision making) method- TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) [8].

2. Experimental Methodology
Wax Patterns of Vermillion Case and Cap of the same design and same dimension were made. The procedure of production is described pictorially (Fig.-1). Four Gating System was chosen for the experiment (Fig.-2) (i) Central Axial Top Gating System (TYPE-I), (ii) Peripheral Axial Top Gating System (TYPE-II), (iii) Peripheral Radial Top Gating System (TYPE-III), (iv) Peripheral Radial Bottom Gating System –(TYPE-IV). Few samples of each product were cast for each of the gating
systems. Cast Product Quality was analyzed based on (i) Uniformity of Thickness, (ii) Eccentricity, (iii) Surface Quality and (iv) Roughness.

Figure 1. Production Steps of Cosmetics Case and its Cap: (a, b)- Clay core, (c, d)- Wax Pattern, (e) Clay Coating with Gating, (f) Fired mold- pouring of liquid metal also done, (g) Samples with Gating System (Details in Fig.-2), (h) Final product.

Figure 2. Gating System of Vermillion Case and Cap
3. Calculation Procedure of TOPSIS to determine the Rank of the Product
TOPSIS [9] (Technique for Order Preference by Similarity to Ideal Solution) is one of the popular and scientific numerical methods of the multi-criteria decision making (MCDM) which is helpful to measure the quality of products with non-commensurable parameters. Solution Method of a problem, using TOPSIS [10] is discussed below.

**Step-1:** Consider m alternatives A₁, A₂, ……., Aₘ. Each alternative Aᵢ respects n criteria C₁, C₂, ……., Cₙ which are expressed with positive numbers Cᵢⱼ. The criteria C₁, C₂, …… Cₙ are benefit (monotonically increasing preference), and criteria are non-benefit (monotonically decreasing preference). Weights wⱼ of the criteria Cⱼ are given so that \( \sum_{j=1}^{n} w_j = 1 \).

The Most optimal alternative, criteria and its weights are placed in the table- 1.

**Step-2:** The pay off matrix must be balanced, as the numbers cᵢⱼ of different criteria having different measuring units. The given weights wⱼ of the criteria must be taken into account. First, the measuring numbers cᵢⱼ of the criteria cⱼ are replaced with the normalized or relative numbers (rᵢⱼ) are followed by:

\[
 r_{ij} = \frac{c_{ij}}{\sqrt{\sum_{r=1}^{m} x_{ij}^2}}
\]

The Normalized Payoff Matrix has been shown in Table- 1

| Criteria | C₁ | C₂ | …… | Cₙ |
|----------|----|----|-----|-----|
| Weights  | w₁ | w₂ | …… | wₙ |
| Alternatives | A₁ | c₁₁ | c₁₂ | …… | c₁ₙ |
| A₂ | c₂₁ | c₂₂ | …… | c₂ₙ |
| …… | …… | …… | …… | …… |
| Aₘ | cₘ₁ | cₘ₂ | …… | cₘₙ |

Table-1: Payoff Matrix and Normalized Payoff Matrix [11]

| Criteria | C₁ | C₂ | …… | Cₙ |
|----------|----|----|-----|-----|
| Alternatives | A₁ | a₁₁ | a₁₂ | …… | aₙ₁ |
| …… | …… | …… | …… | …… |
| Cₘ | aₘ₁ | aₘ₂ | …… | aₘₙ |

**Step-3:** The relative numbers (rᵢⱼ) belonging to the open interval <0, 1>. Then, according to the share wᵢcᵢⱼ of the criteria cⱼ, the normalized numbers (rᵢⱼ) are replaced with the weighted normalized numbers given by:

\[
a_{ij} = w_j r_{ij} = w_j \frac{c_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{1}
\]

Determine ideal (fᵢ*) value (maximum) and negative ideal (fᵢ**) value (Minimum) for each criterion j. The Weighted Normalized Payoff Matrix, ideal (fᵢ*), negative ideal (fᵢ**) values are tabulated in Table-2.

| Criteria | C₁ | C₂ | …… | Cₙ |
|----------|----|----|-----|-----|
| Alternatives | A₁ | a₁₁ | a₁₂ | …… | aₙ₁ |
| …… | …… | …… | …… | …… |
| Cₘ | aₘ₁ | aₘ₂ | …… | aₘₙ |
Step-4: Parameters are required for the computation of separation measure are $f_j^{*}$, $f_j^{**}$ value for each criterion $j$. Calculate separation measure $D_a^+$, $D_a^-$, in J-dimension Euclidean distance for each alternative.

(i) The separation measure of each alternative ‘a’ from the positive and negative ideal solution is the distance of each criterion from its ideal value, and summing these for all criteria for given alternative ‘a’, i.e.,

$$D_a^+ = \sqrt{\sum_{j=1}^{J} (f_j(a) - f_j^*)^2}$$

$$D_a^- = \sqrt{\sum_{j=1}^{J} (f_j(a) - f_j^{**})^2}$$

(ii) Computation of relative closeness of each alternative ‘a’ with reference to negative ideal measure $D_a^-$ is:

$$C_a = \frac{D_a^-}{D_a^+ + D_a^-}$$

Rank of the alternative based on the $C_a$ value. The lower the $C_a$ value, the better the alternative.

4. Results and Discussions

The quality of Vermillion Case and Cap was tabulated in Table-3. The measurement was done by the following parameters:

- Uniformity of Thickness: Root Mean Square (RMS) technique was followed.
- Eccentricity: Inner diameter, Outer diameter of the case for both the lip and base was measured averaged for calculation. For the Cap, the only base diameter was measured.
- Surface Quality: Percentage of the good quality surface was measured.
- Surface Roughness: (Ra): Surface roughness [Arithmetic mean of departures (Ra)] of the Samples was measured with the sampling length ($L_s$) of 0.8 mm.

The criteria taken to determine the rank of the products is as discussed above and also

(i) All the criteria chosen such a way, that lowest values are the best for each one,
(ii) Equal Weight (0.25) was chosen to determine the rank of the castings.

Based on the calculation of TOPSIS technique, the products have been ranked, with preferable and rejected gating system with explanation in Table-4. Preferable Gating System for different geometrical shape was given. The Rejected Gating System was mentioned with the reason and defects. Another important observation was found that “Bottom Gating” always be avoided for thin-walled investment casting production.

Table-3: Quality Analysis of Vermillion Case & Cap with Individual Ranking (R)

| Gating Type | Thickness Uniformity (RMS) | R | Eccentricity | R | Surface Quality (%) | R | Surface Roughness (Ra) | R |
|-------------|----------------------------|---|--------------|---|---------------------|---|-----------------------|---|
| Case        |                            |   |              |   |                     |   |                       |   |
| Type-I      | 0.381                      | 7 | 0.1255       | 5 | 0                   | 1 | 1.16                  | 2 |
| Type-II     | 0.378                      | 6 | 0.1085       | 3 | 1                   | 2 | 1.96                  | 6 |
| Type-III    | 0.248                      | 2 | 0.07         | 2 | 2                   | 3 | 2.84                  | 7 |
| Type-IV     | 0.276                      | 3 | 0.2315       | 8 | 25                  | 6 | 1.46                  | 3 |
| Cap         |                            |   |              |   |                     |   |                       |   |
| Type-I      | 0.198                      | 1 | 0.1413       | 6 | 0                   | 1 | 1.12                  | 1 |
| Type-II     | 0.304                      | 4 | 0.02995      | 1 | 3                   | 4 | 1.48                  | 4 |
| Type-III    | 0.336                      | 5 | 0.1205       | 4 | 15                  | 5 | 1.76                  | 5 |
| Type-IV     | 0.579                      | 8 | 0.16         | 7 | 45                  | 7 | 2.11                  | 8 |
Table 4: Preferable and Rejected Gating System with Ranking

| Product  | Gating Type | Product Ranking | Preferable Gating System | Rejection (%) Gating System with Defects |
|----------|-------------|----------------|--------------------------|------------------------------------------|
|          |             | Individual     | Overall                  |                                          |
| Cosmetics Case | I  | 1             | 4                        | 1. Type-I                                |
|           | II | 2             | 3                        | 2. Type-II                               |
|           | III| 3             | 5                        | 3. Type-III                              |
|           | IV | 4             | 7                        | Type-IV: (100% Rejected, Defects: Misrun) |
| Cosmetics Cap | I  | 2             | 2                        | 1. Type-II                               |
|           | II | 1             | 1                        | 2. Type-I                                |
|           | III| 3             | 6                        | Type-IV: (100% Rejected; Defects: Misrun) |
|           | IV | 4             | 8                        | Type-III: (40% Rejected; Defects: Misrun) |

5. Conclusions
The experiment proved that the quality of Indian Tribal Cast Products is better enough for mass production also. The experiment showed the following conclusion.
- The overall Surface Roughness irrespective of Gating System was better for Cosmetics Cap which is Hemispherical Geometrical Shape. The reason was the flow liquid metal was smoother than other geometrical shapes.
- The maximum unfilled section was found at opposite to the gate for the bottom gating system. Also, the dimension variation was large for the bottom gating system.
- Gating system should be chosen according to the shape, size and thickness of the product. Gating type and position should be chosen such a way that the liquid metal flow should be smoother and also the position of the gate was important for good quality economic casting production.

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