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Shrinkage Analysis of Wax Patterns For Aerospace Components in Investment Casting Process

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ABSTRACT: *Investment casting has been the most widely used process for several centuries for producing components of excellent surface finish, dimensional accuracy and complex shapes. In the present study, work has been done to select a correct wax type with minimum shrinkage for further investment casting process of aerospace components. Wax Patterns were made with different types of waxes namely Pattern Wax, Sprue wax and machine wax. In each case, linear shrinkage was determined. The experimental setup for building the silicone rubber mould is explained, by which different wax are used and aerospace parts are made. The selection of wax is shown by using graphical representation and inspection results of linear shrinkage of no of wax patterns. Accuracy of dimension is the main aim achieved in this paper by shrinkage analysis to get an accurate final product.*

Keywords: *Shrinkage, Silicone rubber mould, Selection of wax, Pattern wax, Investment casting*

I. INTRODUCTION

In investment casting technique, a pattern, usually made of wax, is utilized in forming the inside cavity of a refractory mould. The pattern is formed by pouring the molten wax into rubber mould of the desired shape and there by cooling it until solidification. In the ceramic shell method, the pattern or a cluster of such patterns is formed. Then the patterns are invested with ceramic slurry which is then solidified forming a mould around the wax pattern [1].The wax pattern is then removed from the mould by melting or burning. The resulting refractory shell is further hardened by heating and then filled with molten metal to produce the finished part. The working efficiency of investment casting depends largely upon the quality of the disposable pattern since its surface and dimensional characteristics are transferred to the ceramic shell and so to the final casting. Wax is the most widely used pattern material. The accuracy of the wax patterns used in the investment casting process has a direct effect on the accuracy achievable in the final cast part. It is essential to understand the proper parameters of wax. Shrinkage allowance is the main factor occurring in the dimensions of wax patterns. This shrinkage allowance differs as per wax. There are three types of wax used for patterns; they are machine wax, Sprue wax and pattern wax. The proper shrinkage study should be done on the wax patterns to select the suitable wax for getting the accurate dimensions and finishing of the end product.

II. MOULD BUILDING

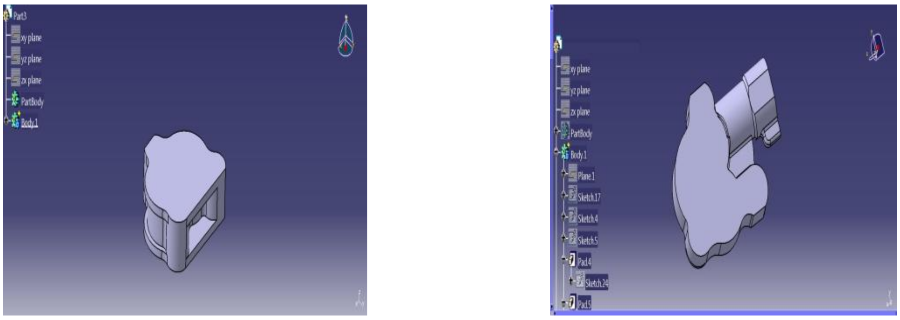
The starting point for these complex geometry castings is a master pattern, by which silicone rubber moulds are made. The pattern is a prototype piece of the aerospace component which is made by using FDM method. Ideally these master patterns would be modified from the original components as per the shrinkage allowance, and the intricate geometries. External geometries are important in investment casting.

2.1. Experimental setup

A pattern is placed in a fibre (plastic) chamber (mould chamber) which is sealed by the fluid plastic using the melting gun. Mould chamber is used to make mould. Prototype (Master pattern) has been attached to the wooden sticks and can be put inside the mould chamber. Initially parting line is been drawn on master pattern.

2.2. Material

After being ready with mould chamber the process, silicone rubber is poured over it. Silicone material has been poured up to the bottom level of wooden stick. The material used for mould is Silicone Rubber [TSE3455T (A)] and it's Hardener in the ratio 9:1. TSE3455T is a two-component, addition cure liquid silicone rubber designed for mould making. TSE3455T cures at room temperature to a translucent high strength elastic rubber with the addition of curing agents. It has excellent moulding durability to epoxy resin and polyurethane.



(a) (b)

Fig.1. Remodelling of the components (a) Aerospace component 1
(b) Aerospace component 2 for making the master patterns

Fig.2. Master Pattern with parting line for both the components

Fig.3. Wooden Stick and Mould chamber

2.3. Rubber curing process

The process then follows the vacuum chamber, where 6 bar pressure is maintained with the help of a sealed container and a vacuum pump. As the 6 bar vacuum is created the material of started rising up to the top of mould chamber. The process of raising and lowering the material inside the mould chamber is been repeated 5 times to mixed the composition perfectly and reduce the air bubbles to get the high strength mould. Vacuum pump has maximum capacity of 2.0 mbar and it has power of 0.75kw, rpm of 2780/3420. After completing the procedure 6 bar vacuum has been released and the mould chamber is kept for 72 hrs. As rubber cures, the mould is cut with a sharp knife to create the opening joint as per the parting line and the pattern is removed. These moulds are used to create wax patterns of aerospace parts. In this type of mould, the wax pattern can only be hand poured [, as the rubber mould has no support and any pressure would distort the cavity.

Fig.4. Vacuum Chamber and Vacuum pump

1] Component 1

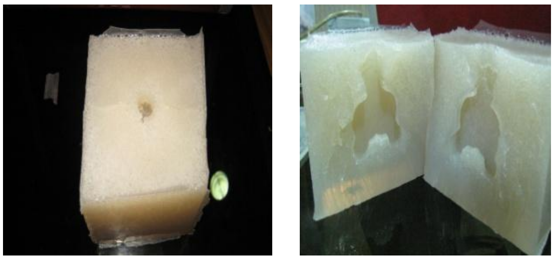


Fig.5. Mould (cope and drag) of component 1

2] Component 2

Fig. 6. Mould (cope and drag) of component 2

It is concluded from the process that raising and lowering of material in vacuum chamber removes the air bubbles and stresses from the mould. Maximum the material is raised in vacuum chamber, gives the high strength mould. Complex geometries and surface finish of component is produces perfectly.

III. WAX PATTERNS

Wax is the most widely used pattern material for investment casting process .However, accuracy of investment casting depends on many factors like: pattern shrinkage, metal shrinkage, pattern distortion, size, shape expansion of ceramic shell during dewaxing and sintering. Many industries and few researchers have established these values through their experience. There are three types of wax are used in Wax pattern: (a) Pattern Wax, (b) Machine Wax, (c) Sprue Wax.

Table 1 Time intervals during the production of each wax patterns

Process Parameters	Range
Melting temperature	55ºC – 64ºC
Pouring temperature	50ºC – 60ºC Approx. (130ºF)
Mould temperature	30 ºC – 35 ºC
Dwell time	80secs
Holding time	2 min – 3 min

Wax is preferred to pour continuously with semi-liquid or paste form of wax at constant flow at a temperature of 50º C to 60ºC to reduce air bubbles. High temperature of wax produces more bubbles and shrinkage. Holding time is 95 sec to 120 sec depending on the geometry of both components. For selecting the right wax type, Shrinkage study has carried out by making 22 wax patterns. Each wax pattern takes 3-4 hours to complete.
Sufficient cooling time is also important for strength of wax pattern. Generally for wax patterns cooling time is more if you pour at high temperature. As per my study if pouring temperature is in and around 50-60ºC, then cooling time is minimum. The viscosity of a casting wax compound is critical to successful pattern production, wherein fine sections need to be produced. In such cases, often a low viscosity wax is required to enable the wax to enter into the smaller spaces in the mould. Viscosity is usually directly related to pouring temperature.

In this case, Machine wax and Sprue wax takes more time than pattern wax to get solidify.

Table 2 Types of wax used with pouring and cooling time

Sr. No.	Types of wax used	Pouring Temperature (°C)	Cooling time (in min)
1	Machine wax	50-60	88
2	Sprue Wax	50-60	83
3	Pattern Wax	50-60	65

IV. EXPERIMENTAL ANALYSIS

The shrinkage decreased as the flow of the wax pattern increased. When wax patterns are formed for casting purposes, it is important to select the type of wax with the most desirable shrinkage allowance.
The geometry of the following patterns considered for this study is shown in figures below: (1) component 1 (2) component 2. Linear shrinkage is calculated by measuring the difference between mould dimensions and pattern dimensions produced for the following wax patterns

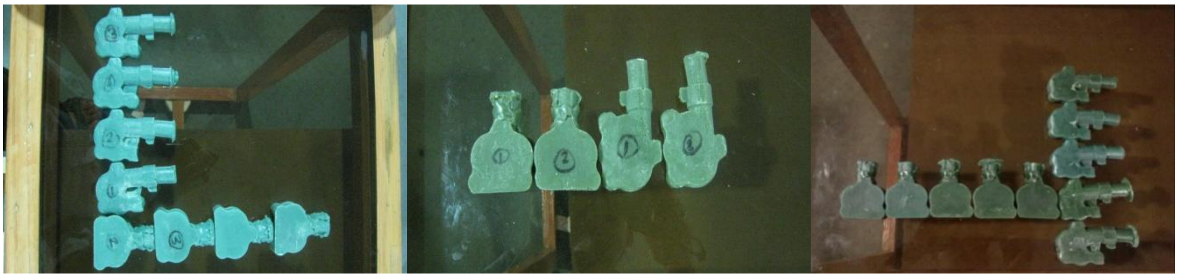


Fig.7. Pattern wax, Sprue wax and Machine wax samples

Each component is tested for machine wax, Sprue wax and pattern wax for shrinkage allowance. Accordingly total 22 wax samples are made and tested.

4.1 Inspection report

The linear shrinkage is carried out for the samples. All dimensions are measured by digital vernier calliper. Each wax sample dimensions are compared with the original master pattern dimension.

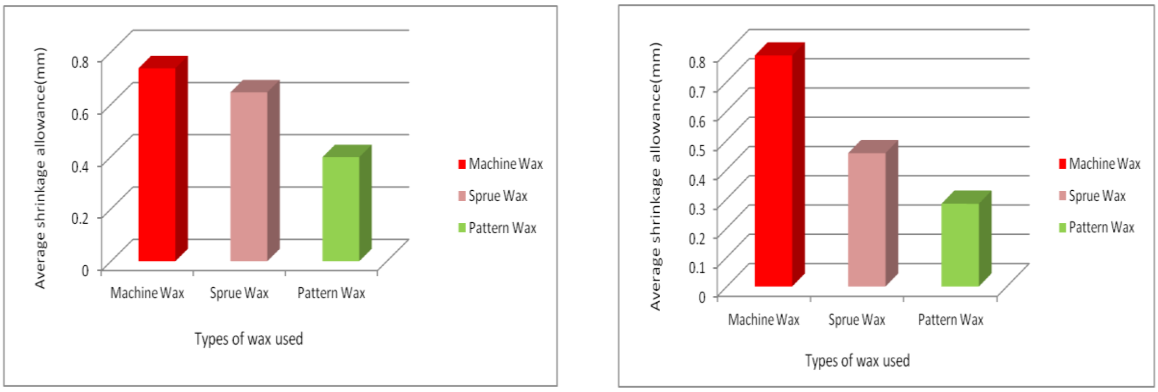
Table 3 Shrinkage values measured for component 1

Sr no	Types of Wax used	Shrinkage in Samples (mm)					Ave. Shrink (mm)
		1	2	3	4	5	
1	Pattern wax	0.396	0.413	0.436	0.346	-	0.398
2	Sprue Wax	0.66	0.633	-	-	-	0.646
3	Machine Wax	0.763	0.773	0.706	0.713	0.736	0.738

Table 4 Shrinkage values measured for component 2

Sr. No	Types of Wax used	Shrinkage in Samples (mm)					Ave. Shrink. (mm)
		1	2	3	4	5	
1	Pattern wax	0.216	0.226	0.366	0.283	-	0.283
2	Sprue Wax	0.496	0.416	-	-	-	0.456
3	Machine Wax	0.833	0.806	0.783	0.733	0.796	0.790

For pattern wax, sprue wax and machine wax 4 samples are tasted to carry out shrinkage study. Average shrinkage value has been calculated



(a) (b)

Fig.8. (a) Comparison of shrinkage occurred in Machine wax, Sprue wax and Pattern wax for component 1, (b) Comparison of shrinkage occurred in machine wax, Sprue wax and pattern wax for component 2

Graph shows the positive results for pattern wax having very less shrinkage compared to machine wax and sprue wax for both the components. It is found that even the surface finish and the shrink time is less in pattern wax. This shrinkage study gives actual idea about the linear shrinkage occurred. All this wax patterns are carried out in between 50ºC- 64ºC of pouring temperature. So it is observed that, as pouring is done at temperature of 64ºC, it gives better results but further increase in pouring temperature increases the linear shrinkage, surface roughness. It is observed that Mould at room temperature (30ºC) gives the better results.

V. RESULTS

According to inspection report of shrinkage study the results are: For component 1: pattern wax has average linear shrinkage is **0.398mm**, Sprue wax has average linear shrinkage of 0.646mm while Machine wax has more shrinkage than any other wax, 0.738mm.According to shrinkage study of all wax types, pattern wax is selected for further processing as it has minimum shrinkage allowance. For component 2:-Pattern Wax has average linear shrinkage is **0.283 mm**, Sprue wax has average linear shrinkage is 0.456 mm while Machine wax has more shrinkage than any other wax, 0.79 mm. According to the shrinkage study pattern wax is selected for further processing, as it has minimum amount of shrinkage.

VI. CONCLUSION

According to the shrinkage study pattern wax is selected for further processing, as it has minimum amount of shrinkage. This shrinkage allowance is mainly depends on the geometry and pouring temperature of component. More the geometry more shrinkage allowance, especially in machine wax. All wax patterns are studied for linear shrinkage study. It is concluded from the shrinkage study that, high pouring temperature gives more shrinkage. So wax patterns are carried out between 50º-60º C pouring temperatures. It also varies as per its geometry; component 1 has more linear shrinkage than the other one due to its geometry. By using this shrinkage analysis proper modification in dimensions of master pattern would be made to go for further processing of shell making and casting to get dimensional accuracy.

VII. Acknowledgement

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