# An Effective Way of Reducing the Wax Pattern Shrinkage to Improve the Dimensional Accuracy of the Investment Castings

**Sarojrani Pattnaik and Mihir Kumar Sutar**

**Abstract** In investment casting (IC) process, the properties of the disposable patterns are eventually transferred to the cast parts. In the present research work, disposable patterns made up of waxes are used to construct the moulds for casting. The wax patterns are easy to prepare and possess very good surface texture. But, they contract upon cooling, which causes dimensional variations in castings. An attempt has been made in this study to decrease the linear shrinkage of the wax pattern without affecting its surface texture by arresting its shrinkage characteristics by adding few materials such as filler and a resin, compatible to IC waxes. The materials chosen for the conduct of experiments are paraffin wax (40%), microcrystalline wax (10%), polyethylene wax (10%), starch powder (10%) and teraphenolic resin (30%). Further, the injection process parameters, namely, die temperature (DT), wax injection temperature (WIT) and holding time (HT) of the IC process are varied at three different levels and experiments are conducted as per Taguchi's L9 orthogonal array (OA) to determine the optimum input parametric levels. The results revealed that there was a considerable reduction (4.5%) in wax pattern linear shrinkage (PLS) by the aforementioned materials.

**Keywords** Investment casting · Wax · Resin · Process parameters

## 1 Introduction

The IC process, also known as precision casting technique is a widely known method around the world to produce dimensionally accurate metal parts bearing very good surface finish. The process utilises a sacrificial wax pattern for getting a hollow mould for casting and its characteristics are ultimately transferred to the cast parts [1–4]. The major employment of the IC process is in the manufacture of turbine blades and vanes

S. Pattnaik (✉) · M. K. Sutar
Mechanical Engineering Department, Veer Surendra Sai University of Technology, Burla, Odisha, India
e-mail: sarojrani07@gmail.com



K. Dutta et al. (eds.), *Processing and Characterization of Materials*, Springer Proceedings in Materials 26, https://doi.org/10.1007/978-981-99-5509-1_12

cast in superalloys, which are used in aircraft industries [5–7]. The stages involved in the process are as follows: injection moulding of a disposable pattern, ceramic coating, dewaxing, drying and metal casting, followed by minor finishing operations [8]. The wax pattern should possess desirable properties such as low ash content, good surface finish, dimensional stability, environmental friendliness, unreactivity to the refractory mould, sufficient hardness to prevent breakage, etc. [9].

The operational effectiveness of the IC process can be enhanced by improving one or more aforementioned features of the wax patterns. The diverse IC waxes are of vegetable, animal, petroleum, mineral and synthetic types. The exploration by Solomon [10] disclosed that the patterns made from only waxes are deficient in strength and are dimensionally unstable due to solidification shrinkage during and after pattern injection from the mould/die. Horton [11] proposed that the wax pattern characteristics can be increased by the substitution of various substances called additives and fillers, since they have ring-structured carbon atoms, whereas the majority of the IC waxes are of straight-chained carbon atoms, and consequently, a strong link is formed amid them. Rezavand and Behravesh [12] established that the wax pattern characteristics are affected by wax blend composition and different wax injection process parameters such as the injection temperature, the injection pressure, the holding time, the die temperature, etc. However, selecting and varying all the process parameters simultaneously would complicate the entire process. Thus, a few essential process parameters should be chosen based on available literature on wax pattern making process for experimentation. Once process parameters are decided, subsequently, the best possible values of input process parameters should be determined to obtain the best results from it.

The present competitive situation requires a greater consideration of the dimensional accuracy and surface texture of the cast products. Since, the IC process commences with the construction of wax patterns, the feature of the constructed wax patterns directly affects the overall quality of the castings. In the present research work, an attempt has been made to decrease the linear shrinkage of the wax pattern without affecting its surface texture by arresting its shrinkage characteristics owing to the addition of few materials such as filler and a resin compatible to IC waxes.

## 2 Experimentation

Each chosen constituent influences the properties of the wax patterns in some way or the other. The materials chosen for constructing the wax patterns by injection moulding process were paraffin wax, microcrystalline wax, polyethylene wax, starch powder and teraphenolic resin. The percentage of filler i.e. starch powder in the mixture was fixed to 10%, whereas the percentage of other ingredients was varied as shown in Table 1. The wax blend was forced into a properly lubricated pre-heated metallic die using a wax injection machine. The PLS and SR were measured using a digital vernier callipers and surface profilometer. Initially, the experimentation was done at fixed input injection process parameters viz. DT = 40 °C, WIT = 70 °C and

**Table 1** Different wax blend composition

| Blend no. | Waxes (% wt.) | Resin (% wt.) | | Filler (% wt.) | |
|---|---|---|---|---|---|
| | Paraffin | Microcrystalline | Polyethylene | Teraphenolic | Starch powder |
| 1. | 40 | 15 | 15 | 20 | 10 |
| 2. | 40 | 10 | 10 | 30 | 10 |
| 3. | 50 | 10 | 10 | 20 | 10 |
| 4. | 50 | 10 | 5 | 25 | 10 |
| 5. | 60 | 10 | 10 | 10 | 10 |

**Table 2** Process parameters at diverse levels

| Process parameters | Unit | Range | Level 1 | Level 2 | Level 3 |
|---|---|---|---|---|---|
| DT | °C | 45–55 | 40 | 45 | 50 |
| WIT | °C | 70–80 | 70 | 75 | 80 |
| HT | Hour | 1–2 | 1.0 | 1.5 | 2.0 |

HT = 1 h to determine the optimum wax composition among the chosen blends. It was found that blend 2 demonstrated minimal PLS and SR. Thus, it was considered as the best wax blend amongst all and used for further experimentation in order to determine the optimal input wax injection process parameters.

The wax pattern characteristics are controlled by wax composition as well as wax injection process parameters such as die temperature, wax injection temperature, holding time, etc. In the first part of experimentation, only best wax composition has been determined. Thus, further, experiments are needed to determine the optimum input wax injection process parameters. The process parameters, namely, die temperature, wax injection temperature and holding time of the IC process were varied at three different levels and experiments were conducted as per Taguchi's L9 orthogonal array to determine the optimum parametric levels. The span of chosen input process parameters is shown in Table 2. The response of the process is pattern linear shrinkage. Figure 1 exhibits the wax patterns made as per L9 experimental runs.

## 3 Results and Discussions

The experimental results are depicted in Table 3. The wax patterns should possess least shrinkage. Thus, Taguchi's lower-the-better criteria has been chosen for computing the analysis of means (ANOM) to determine the optimal input parameter setting for the chosen response [13]. The ANOM for the response, PLS, is presented in Table 4 and the graph is depicted in Fig. 2. Delta is the difference between the highest and the lowest value of PLS obtained under each process parameter. Ranking is done on the basis of decreasing order of delta. From Table 4, it is obvious that the

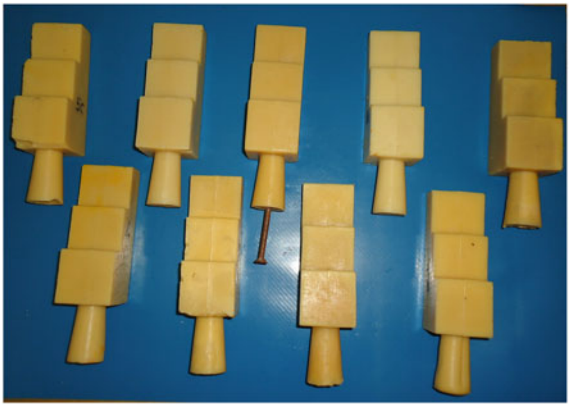

**Fig. 1** Wax patterns made by injection process

optimal input process parameters for obtaining least PLS are found to be DT at level 1 i.e. 40 °C, WIT at level 1 i.e. 70 °C and HT at level 3 i.e. 2 h. Wax injection temperature is found to be the most important injection process parameter impacting the pattern shrinkage. The second most influential process parameter is die temperature, as it is ranked no. 2. It is seen that the optimum die temperature and wax injection temperature is at the lowest level of chosen parameters. If these temperatures are higher, then there are chances of wax leakage in-between the joints of the die-halves. Also, more time is available for the pattern for shrinkage, as cooling rate decreases. The dimensional constancy of the disposable wax pattern is affected by wax blend constituents, injection temperature, die temperature, die holding time, surrounding temperature, etc.

The lower the die and wax injection temperatures, the more the wax is in mushy state. Thus, it solidifies soon with very little chance of thermal contraction. However, the wax should not be too much in a semi-solid state that it could not able to flow to the nook and corners of the die smoothly. It would adversely affect the shape as

**Table 3** Experimental results of wax patterns

| Sl. no | Input parameters | | | Response |
|---|---|---|---|---|
| | DT (°C) | WIT (°C) | HT (Hour) | PLS (%) |
| 1 | 40 | 70 | 1.0 | 2.65 |
| 2 | 45 | 70 | 1.5 | 2.74 |
| 3 | 50 | 70 | 2.0 | 2.79 |
| 4 | 40 | 75 | 1.5 | 2.71 |
| 5 | 45 | 75 | 2.0 | 2.83 |
| 6 | 50 | 75 | 1.0 | 3.08 |
| 7 | 40 | 80 | 2.0 | 2.94 |
| 8 | 45 | 80 | 1.0 | 3.11 |
| 9 | 50 | 80 | 1.5 | 3.42 |

**Table 4** ANOM table of PLS

| Level 1 | DT (°C) | WIT (°C) | HT (Hour) |
|---|---|---|---|
| 1 | **2.767** | **2.727** | 2.947 |
| 2 | 2.893 | 2.873 | 2.957 |
| 3 | 3.097 | 3.157 | **2.853** |
| Delta | 0.330 | 0.430 | 0.103 |
| Rank | 2 | 1 | 3 |

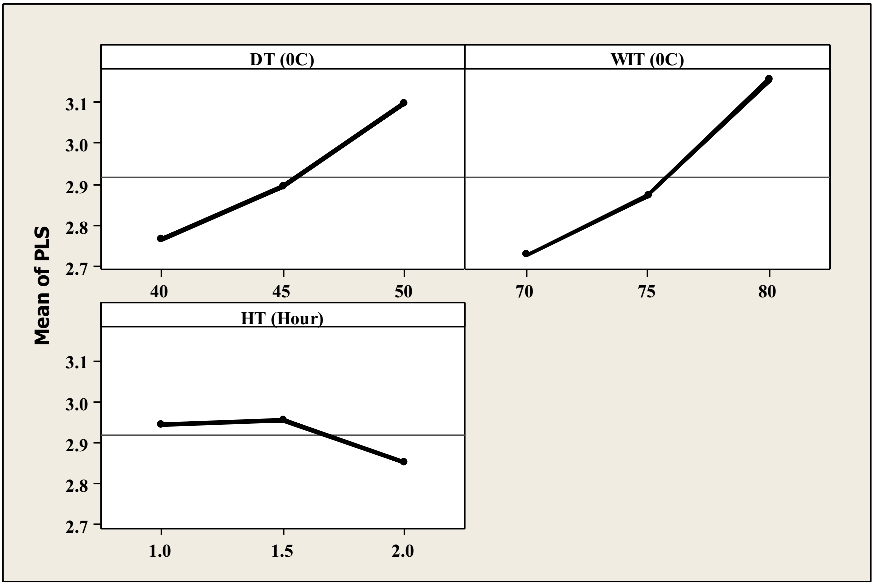


**Fig. 2** ANOM graph of PLS

well as the surface texture of the wax pattern. It is beneficial for the wax pattern to be at a higher holding time so that it is cooled properly inside the die and undergoes shrinkage to the fullest. It is clear from Table 4 that WIT is the most significant process parameter affecting the pattern shrinkage properties in the IC process, as it is ranked no. 1. It is followed by DT and the least significant process parameter is HT.

## 4 Confirmatory Experiments

The optimal input parametric setting i.e. WIT of 70 °C, DT of 40 °C and HT of 2 h is not found in the experimental run done as per L9 array in Table 3. Thus, there was a need to perform additional experiments at this obtained parametric setting.

**Table 5** Predicted and actual value of PLS of the wax patterns

| Optimal condition | PLS of wax patterns (%) |
|---|---|
| $WIT_1DT_1HT_3$ | 2.53 |

Three supplementary tests were done at the aforementioned parametric setting and the mean of the results are presented in Table 5. The least value of PLS seen in Table 3 is 2.65%. However, the PLS at the optimal condition is found to be 2.53%, which shows that there is a decrease of PLS further by 4.5% from the least value of Table 3, when the experiments are done at the obtained optimal setting. Thus, it can be said that the Taguchi predicted optimal setting is able to reduce the wax pattern shrinkage, thereby reducing the dimensional variations in castings.

The waxes chosen for this study are very cheaply and easily available throughout the world. Resins are added to provide strength to the IC waxes and thus, teraphenolic resin has been blended with the chosen waxes in the present study. The wax pattern shrinkage is unavoidable, but can be controlled or reduced to a maximum level. Literature reveals that fillers are added to restrict the wax pattern shrinkage and in this regard, starch powder has been mixed with selected waxes and resin. Ultimately, a combination of the chosen ingredients in the present study proved that it can be used as commercial pattern IC wax material worldwide, as it exhibited good pattern properties and this combination of ingredients has never been used before for investment casting. It is expected that this novel combination of wax mixture may be used by the investment casters for producing the shell moulds.

## 5 Conclusions

The conclusions drawn from the present study are as follows:

- Blend 2 containing 40% paraffin wax, 10% microcrystalline wax, 10% polyethylene, 30% teraphenolic and 10% starch powder is the best wax blend for pattern making producing least shrinkage.
- The Taguchi predicted optimal parametric setting was found to be WIT of 70 °C, DT of 40 °C and HT of 2 h.
- When the experiment was done at the obtained optimal setting, the wax pattern's linear shrinkage was further reduced by 4.5%.

## References

1. Pattnaik SR, Karunakar DB, Jha PK (2012) Developments in investment casting process-a review. J Mater Process Technol 212:2332–2348
2. Wang D, Sun J, Dong A (2019) Prediction of core deflection in wax injection for investment casting by using SVM and BPNN. Int J Adv Manuf Technol 101:2165–2173

3. Wei Q, Wang R, Xu Q (2018) Effects of process parameters on dimensional precision and tensile strength of wax patterns for investment casting by selective laser sintering. China Foundry 15:299–306
4. Pattnaik SR, Karunakar DB, Jha PK (2013) Multi-characteristic optimization of wax patterns in the investment casting process using grey–fuzzy logic. Int J Adv Manuf Technol 67:1577–1587
5. Li Y, Liu X, Lu K (2019) Preparation of fiber-reinforced shell by airflow placement fiber technology for investment casting. Int J Met Cast 13:979–986
6. Lu K, Duan Z, Liu X, Li Y (2019) Effects of fibre length and mixing routes on fibre reinforced shell for investment casting. Ceram Int 45(6):6925–6930
7. Pattnaik SR, Karunakar DB, Jha PK (2014) Utility-fuzzy-Taguchi based hybrid approach in investment casting process. Int J Interact Des Manuf 8:77–89
8. Pattnaik SR, Karunakar DB, Jha PK (2012) Optimization of multiple responses in the lost wax process using Taguchi method and grey relational analysis. Proc Inst Mech Eng Part L 227(2):156–167
9. Pattnaik SR (2017) An investigation on enhancing ceramic shell properties using naturally available additives. Int J Adv Manuf Technol 91:3061–3078
10. Kuo CC, Tasi YR, Chen MY (2021) Development of a cost-effective technique for batch production of precision wax patterns using 3D optical inspection and rapid tooling technologies. Int J Adv Manuf Technol 117:3211–3227
11. Wang D, Dong A, Zhu G (2019) Rapid casting of complex impeller based on 3D printing wax pattern and simulation optimization. Int J Adv Manuf Technol 100:2629–2635
12. Singh D, Singh R, Boparai KS (2018) Development and surface improvement of FDM pattern based investment casting of biomedical implants: a state of art review. J Manuf Process 31:80–95
13. Pattnaik S (2018) Investigation on controlling the process parameters for improving the quality of investment cast parts. J Braz Soc Mech Sci Eng 40:318