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Optimization of Investment Casting Process Parameters Deployed in Diamond Jewellery Firm by using Design of Experiment Tools

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***Abstract*:- Owing to the ever-growing need to develop high performance to satisfy the needs of the customer, many companies are adopting various methods which results in better quality of products with minimum cost. Since the jewellery manufacturing industry deals with use of precious metals, it has become important to maximize the productivity and efficiency. Even a small improvement in the productivity can culminate into a better commercial output.**

This study aimed at optimizing the process parameters in the Metal Casting process, which was used in jewellery firm. The input parameters chosen were runner diameter, casting temperature and quenching time with at three different levels each. An experiment was designed based on Taguchi's Orthogonal array experimental design (DOE). As a result, a series of nine experiments were performed. Rejection due to Gas Porosity and Surface Porosity was selected as output response. The experimental investigation concluded that the optimal output is not only dependent on the three parameters chosen but also is influenced due to some unseen parameters like pouring temperature. But better results would be achieved when the three input parameters are set in the following manner: temperature being set at 970◦ c and quenching for around 15 min. and the runner diameter was set at 2mm. The analysis of Taguchi DOE indicates that casting temperature is the more influential parameter.

Keywords – Design of Experiments, Taguchi, Minitab, optimization, ANOVA

I. INTRODUCTION

In order to optimize the manufacturing of Diamond jewellery, one need to has a thorough knowledge about the processes involved in it. Following is overview of the whole manufacturing process:

1. Design
2. Formation of Prototype
3.Mould Preparation
4.Wax model
5.Pre-casting process
6.Investment Casting
7.Post-casting process

II. LITERATURE REVIEW

Jiju Antony et. al. [1] studied the Taguchi method for improvement in the process performance, yield and productivity. They carried out a simple experiment to teach the basics of the technique and illustrate simple analytical and graphical tools which promote rapid understanding of the results of the experiment. Barua et. al. [2] used the Taguchi's method to optimise the mechanical properties of the Vacuum (V) casting process. In this study, they found the effects of the selected process parameters on the mechanical properties of alloy casting and subsequent optimal settings of the parameters, which were accomplished using Taguchi's parameter design approach.

Syrcos [3] analyzed various significant process parameters of the die casting method of aluminium alloy. He made an attempt to obtain optimal settings of the die casting parameters in order to yield the optimum casting density of the aluminium alloy castings. Rahmati et al. [4] determined the accuracy of wax patterns produced by hard and soft tooling. Some H-shaped wax patterns were produced using both the hard (polyurethane mould) and soft (RTV silicone rubber mould) tools. It is found that wax patterns produced from silicone rubber mould not only have better surface finish but are also able to produce wax patterns with complex shapes. However, from accuracy point of view, polyurethane moulds performance is much better than silicone moulds as they can produce a more accurate and less distorted wax patterns. It is found that the injection parameters like temperature, pressure and holding time do affect the accuracy of the wax pattern produced.

Sarojrani Pattnaik et. al. [5] studied the effect of the selected injection process parameters on the dimensional stability of the wax patterns made by the investment casting process using silicon rubber mould and suggested the optimum injection process parameters to reduce the shrinkage of wax patterns. The wax injection processing parameters considered for experimentation were injection

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temperature, injection pressure and injection time. They used Taguchi's L9 orthogonal array was for designing the experiments. The signal-to-noise and the analysis of variance were used to find the optimum levels and to indicate the impact of the process parameters on shrinkage of wax patterns. The confirmation tests were conducted and the results were found to be within the confidence interval. The analysis of experimental results showed that the injection temperature and injection pressure greatly influenced the dimensional stability of wax patterns.

Rajendra Khavekar *et.al.[6] compared t*wo well-known Design of Experiments (DoE) methodologies, such as Taguchi Methods (TM) and Shainin Systems (SS) and analyzed them through their implementation in a plastic injection molding unit. They performed experiments at a perfume bottle cap manufacturing company (made by acrylic material) using TM and SS to find out the root cause of defects and to optimize the process parameters for minimum rejection. They concluded that Shainin system is less complicated and is easy to implement, whereas Taguchi methods is statistically more reliable for optimization of process parameters.

Rupinder Singh et. al. [7] investigated the effect of shape factor, slurry layers and pouring temperature in precision investment casting. They studied Three controllable factors of the precision investment casting process (namely: shape factor, slurry layers, mold thickness and pouring temperature) at three levels each by Taguchi's parametric approach and single-response optimization was conducted to identify the main factors controlling surface hardness, dimensional accuracy (Δd) and surface roughness (Ra). Castings were produced using aluminum (Al), mild steel (M.S.) and stainless steel (S.S) at recommended parameters through ceramic shell precision investment casting process. After conducting confirmation experiments at an optimal condition, they concluded that the surface hardness, Δd and Ra of the precision investment casting were improved significantly.

III. PROBLEM DEFINITION

Soon after Industrial revolution, mass production was at full swing, leading to improved quality of products with a higher quantity. In recent times, the consumption of resources has increased tremendously, due to which there is a need to increase the productivity of manufacturing units. Hence for an effective use of a machining process, it becomes necessary to find the optimal process parameters for improved quality as well as increase in productivity. As the use of Investment Casting in varied sectors is high, it is necessary to find the optimal process parameters, in order to increase the productivity of the manufacturing process. The current knowledge and process parameters for Investment Casting process, seems to be inadequate to for its optimal utilization.

Investment Casting is widely used casting operation for casting of jewellery using precious metals and produce well defined shapes of high quality surface. It can be used for casting Symmetrical as well as on asymmetrical work piece jewellery. Studies related to use of Taguchi DOE for Investment Casting process in the jewellery industry is limited. Hence this study focused on finding the optimum level of casting process parameters. This experiment was conducted using Taguchi's L9 orthogonal array. The process parameters which were controlled are casting temperature, runner diameter and quenching time. The output parameters were to minimize the porosity and hence it would help decrease the rework and the rejection.

Optimizing a single parameter may have some positive effect, but may adversely affect other aspects. Hence multiple objective parameters are optimized simultaneously. This can be done using Taguchi technique, which can determine the optimal combination of input parameters to yield optimal solution for multi-objective parameters.

IV. TAGUCHI DESIGN EXPERIMENT

- *Introduction of Taguchi*

The Taguchi philosophy provides two tenets:
1.Reduction in variation (improved quality) of a product or process represents a lower loss to society, and
2.The proper development strategy can intentionally reduce variation. Again, most managers and engineers are not aware of the economics of improved quality and the techniques to achieve higher quality at lower costs.

- *Taguchi loss function*

The Taguchi loss function recognizes the customer's desire to have products that are more consistent, part to part, and a producer's desire to make a low-cost product. The loss to society is composed of the costs incurred in the production process as well as the costs encountered during use by the customer (repair, lost business, etc.).

Depending upon the effect of the desired output, Taguchi Loss Function is divided into different parts:-
Nominal-the-best (NTB): The nominal value is best because it is the one that satisfies the customer's need. The characteristic value away on either side of the target is undesirable, such as air pressure in vehicle tires or location of gauges on the instrument panel**[8].**
Smaller-the-better (STB): A smaller value is better and higher values are undesirable, such as vehicle emissions or fuel consumption (dollar per distance)**[**8].
Larger-the-better (LTB): A larger value is better and smaller values are undesirable, such as gas mileage (distance per gallon). The loss function can be applied to product characteristics for the above three situations [8].

- *Taguchi's Orthogonal Array(OA)*

Taguchi's orthogonal arrays are highly fractional orthogonal designs. These designs can be used to estimate main effects using only a few experimental run.

Orthogonality: The idea of balance ensures giving equal chance to each level of each variable. Similarly, we want to give equal attention to combinations of two variables. Assume that we have two variables, A (values: a1, ..., an) and B (values b1, ..., bm).[1]. Then the set of experiments is orthogonal if each pair-wise combination of values, (ai, bj) occurs in the same number of trials. To determine the

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effect each variable has on the output, the signal-to-noise ratio, or the SN number, needs to be calculated for each experiment conducted.
Minitab software was used to design the orthogonal array using Taguchi Method. As the experiment had 3 input parameters at 4 levels, the best design was to use L16.

- *Signal to noise ratio (SN ratio)*

One must consider all the factors that may affect the process. Taguchi method separates factors in two main groups. They are as follows:-

- Control factors
- Noise factors

Control factors are those which are set by the manufacturer and cannot be directly changed by the customer. Noise factors are those which the manufacturer has no direct control over and can vary with the customer's environment. The three types of noise factors are [7]

- Outer noise: They are environmental factors such as ambient temperature, humidity, pressure and people.
- Inner noise: They are function and time related such as deterioration, wear, fade of color, shrinkage and drying out.
- Product noise: They vary in part to part of the product.

Control factors that may contribute to reduced variation are identified by looking at the amount of variation present as a response. Signal to noise ratio helps to find the effect of variation by different factors on the response. Taguchi has created a transformation of the repetition of data to another value which is a measure of the variation present. The transformation is the signal-to-noise(S/N) ratio. The signal to noise ratio consolidates several repetitions into one value which reflects the amount of variation present.

There are several S/N ratios available depending on type of characteristics:

- Lower is better(LB)
- Nominal is better(NB)
- Higher is better(HB)

The S/N ratio is treated as a response of the experiment, which is a measure of the variation within a trial when noise factors are present. A standard ANOVA can be done on the S/N ratio which will identify factors significant to increasing the average value of S/N and subsequently reducing variation.

V. PARAMETERS IN THE CASTING PROCESS

We then found parameters of the process that had an effect on the output i.e. the porosity on the manufactured products [5]. Following are the parameters that have an effect on the porosity of the product:

- Casting temperature
- Quenching time
- Runner diameter
- Slurry composition
- Pouring time
- Product design
- Tree design
- Alloy composition

These parameters were then classified in to the Control parameters and Noise parameters based on their controllability after conducting a brainstorming session with the concerned person of the factory.

Noise Parameters
Since noise parameters are the parameters whose variation cannot be controlled during production or product use, the following parameters were classified as noise parameters: [3]
Slurry composition: Since slurry composition is always fixed and doesn't change irrespective of any changes in the product, it doesn't have any effect on it's porosity. Hence, it is an internal noise factor.

- Pouring time: Pouring time of every alloy is fixed according to its composition. Since it is not controlled by the manufacturer and is a fixed property of the process, it falls as internal noise factor.
- Product design: Since the design of the product varies according to the demands of the customer and the manufacturer has no say in it, product design is categorised as an external noise factor.
- Tree Design: Tree Design depends upon the craftsmanship of the worker; it varies according to the skills of the labour. Hence it is dependent on manufacturing variations and falls under product noise factors.
- Alloy Composition: The composition of the alloy depends upon the capacity of the customers to spend on their requirement. Based on the capacity and the choice of the customer, the composition of gold in karats is fixed. Hence it is an external noise factor.

Control Parameters

- Casting Temperature**:** The variation of the casting temperature has a direct impact on the output of the product and since it is controlled by the manufacturer, it is a control parameter.
- Runner Diameter: Runner diameter influences the flow and deposition of the gold into the mould cavity. Since the diameter of the runner can be fixed while making the wax model and there are no variations possible in it after it is decided, it is classified as a control factor.
- Quenching Time: The rate of cooling of the gold is very influential in the surface properties of the product. Hence, it is a control parameter.

VI. PROCEDURE FOR ANALYSIS

After selecting the control parameters, their working range was found out through the data provided by the

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manufacturer. Then the levels and value of each level of the parameter was assigned. This was done so that it can be worked upon inthe minitab software. Three levels were selected for each parameter, which is shown in the Table 1. and Table 2 shows the OA.

Table 1: Control parameters and their readings

Levels	Temperature (T)	Quenching Time (QT)	Runner Diameter (RD)
1	950 ˚C	5mins	2 mm
2	960 ˚C	10mins	3 mm
3	970 ˚C	15mins	4 mm

Table 2: Orthogonal Array

temperature	quenching time	runner dia	repairs
950	5	2	3
950	10	4	1
950	15	3	2
960	5	4	2
960	10	3	3
960	15	2	4
970	5	3	4
970	10	2	4
970	15	4	5

VII. CALCULATIONS

There are various calculations involved in this experiments which help us get the desired results. Selected smaller the better S/N ratio since we want to minimise the porosity.
The signal-to-noise (S/N) ratio is calculated for each factor level combination. The formula for the smaller-is-better S/N ratio using base 10 log is given as:

$$S/N = -10*\log(\Sigma(Y^2)/n)$$

Where,

Y = responses for the given factor level combination n = number of responses in the factor level combination.

VIII. DETERMINATION OF OPTIMUM PARAMETERS

Finally, the following graphs were obtained from the Minitab software of the signal to noise ratio where ‘smaller the better’ results were desired since the output desired was of rework. Figure 1 and Figure 2 show the main effect plot for SN ratios and data means.

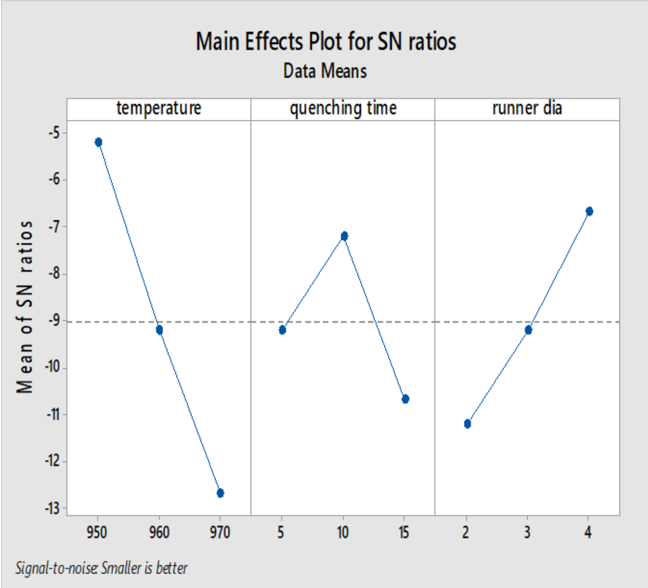

Figure 1 Mean Effects plot for SN ratio

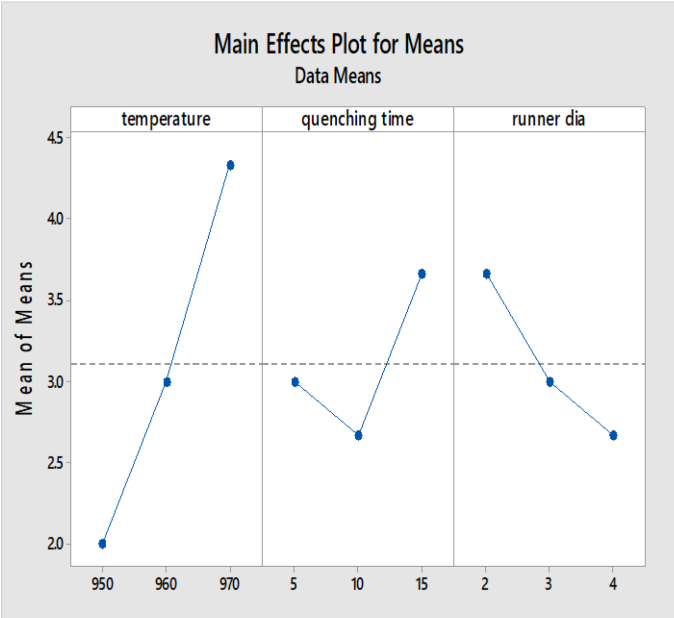

Figure 2 Mean Effects plot for data means

The Table 3 and Table 4 were obtained from Minitab software. These are response table for Means table…. and Response table for signal to noise ratio table… The most significant factor affecting multiple performance characteristics is determined by comparing these values. This comparison will present the level of significance of the controllable factors over the multiple performance characteristics. Larger the value of delta more is the significance of the parameter on the performance characteristics. From table… and table… we can see that:
1) Temperature is the most significant parameter
2) Runner diameter being the second one
3) Quenching time being third significant parameter.

Table 3: Response Table for Means

Level	temperature	quenching time	runner dia
1	-5.188	-9.201	-11.208
2	-9.201	-7.195	-9.201
3	-12.687	-10.680	-6.667
Delta	7.500	3.486	4.542
Rank	1	3	2

Table 4: Response Table for Signal to Noise Ratios

Level	temperature	quenching time	runner dia
1	2.000	3.000	3.667
2	3.000	2.667	3.000
3	4.333	3.666	2.667
Delta	2.333	0.999	1.000
Rank	1	3	2

Analysis of variance (**ANOVA**) is a collection of statistical models and their associated estimation procedures used to analyze the differences among group means in a sample. In this case, (Table 5) the p-value is greater than the significance level, you do not have enough evidence to reject the null hypothesis that the population means are all equal. Verify that your test has enough power to detect a difference that is practically significant.

Table 5: Analysis of Variance for Means

Sour	DF	Seq SS	Adj SS	Adj MS	F	P
T	2	8.222	8.22	4.111	5.29	0.159
QT	2	1.556	1.55	0.777	1.00	0.500
RD	2	1.556	1.55	0.777	1.00	0.500
Resida Error	2	1.556	1.55	0.777		
Total	8	12.88				

Since we are working with a Taguchi model whose output is repair/rework, we select smaller-the-better model as we want the output to be least possible. From Mean effects plot for signal to noise ratio we can say that level having the least value in each parameter is the optimum value of that parameter. We can state that for our first parameter i.e. Temperature, 970°C (level 3) is the most optimum parameter. Second one i.e. Quenching time, 15 minutes (level 3) is the most optimum and for third parameter i.e. Runner diameter, 2mm (level 1) is the most optimum parameter.

Table 6: Optimum Values of the Parameters

Temperature	Quenching time	Runner diameter
950	5	2
960	10	4
970	15	3

IX.CONCLUSION

The following conclusions can be drawn from the experiment performed, and the analysis done:

1. In this study, Design of Experiments approach coupled with Taguchi method for optimization of machining parameters is proposed to give high quality and reliable results with fewer experimentation.
2. Through Taguchi design of experiments, temperature of casting was found to be the most influencing input parameter followed by runner diameter and quenching time respectively in obtaining the required optimum surface characteristics and minimum rework.
3. From the results obtained by Minitab, we get that the optimum parameters for desired results are 970°C casting temperature, 15 minutes quenching time and 2mm runner diameter which suggests that higher casting temperature, more quenching time and lower runner diameter gives better results.
4. This approach can be recommended for surface quality improvement and efficient machining of gold alloy jewellery components used in Jewellery manufacturing industry.

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