Optimization of Investment Casting Parameters To Improve The Mechanical Properties By Taguchi Method

by

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Declaration

This is to certify that the project work entitled "*Optimization of Investment Casting Parameters to Improve the Mechanical Properties by Taguchi Method*" has been carried out by *Nil Ratan Mondal* in the Department of *Industrial Engineering and Management*, Khulna University of Engineering & Technology, Khulna, Bangladesh. The above project work or any part of this work has not been submitted anywhere for the award of any degree or diploma.

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Approval

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Abstract

In this present study investment casting process parameter is optimized by using Taguchi approach to improve the mechanical properties of mild steel. A set of experiments were conducted as per Taguchi's L9 orthogonal array to determine the most influential control factors, which will provide better and consistent for optimization to the casting's process parameters regardless of the noise factors present. For test the performance characteristics, orthogonal range, signal to noise ratio and variance analysis were used. Data values are obtained under the constraint of different process parameters like preheat temperature, pouring temperature, preheat time to investigate their effects on the surface hardness, tensile strength of the final results. The variations in the trend of the mechanical properties were observed and it was deduced out that high mold preheat temperature, higher pouring temperature, maximum preheat time significantly reduce the mechanical properties of castings produced by Taguchi method.

Keywords: Optimization, Investment Casting, Casting Parameters, Taguchi Method, ANOVA Analysis

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CHAPTER 1

INTRODUCTION

1.1 General

Investment casting has been a commonly used method for hundreds of years (also known as ' lost wax casting) [1]. It is one of the primeval casting processes, in which into an expendable ceramic mould molten metal is poured. It is also acknowledged as the oldest method of art casting. Technological advances have also made it the most advanced and versatile of all metal casting types [2].

By using a wax pattern, the mould is shaped in the shape of the part we need. The wax pattern is dipped into ceramic slurry which hardens into the ceramic mould [3].When the mould has been formed the wax pattern is melted out. For this reason investment is known as “lost wax casting”. It is commonly used to render sophisticated types of parts and rigid tolerances [4]. Wax pattern, ceramic slurry, metal die, ferrous or non-ferrous metal, cutting and sand blasting machine are the components and machines used in investment casting .

There is no doubt that casting as a manufacturing process demands so many parameters such as charge melting temperature, temperature of the mold, velocity , pouring temperature and so others. Casting criteria affect the consistency of the casting [5]. Several researchers performed promising studies on the various effects of casting activity parameters on the mechanical properties of cast metals and their alloys [5-9].

Jones et al. claimed that if the refractory coating slurry is not permitted to drain evenly, the pattern may have an irregular thickness that may influence its strength [6]. Jones and Yuan found that a weakened ceramic shell structure could reduce the quality of a casting [7]. A ceramic shell mould's strength depends on the mould content, the method of shell forming, and the temperature of firing.

Yuan et al. reported a paper explaining the ceramic shell affected by fiber and the modified polymer framework [8]. Polymer modified system has more green strength than fiber modified ceramic shell. The modified polymer system has a higher resistance in the green dry stage.

Li et al. presented a paper which explain that mechanical properties and micro porosity of the cast items are influenced by ceramic preheat temperature, pouring temperature, melt hydrogen content [9].They concluded that the amount of micro porosity in the investment casting process is determined by hydrogen content and shell preheat temperature. By increasing with the hydrogen content and shell preheat temperature, the porosity is also increased. High mechanical properties are generally created by low pouring temperature.

Baumeisth et al. described a paper which describes the effect of casting parameters on microstructures and the mechanical properties of extremely small micro-casting pieces [10]. He concluded that by increasing with the mould temperature, the edges of the specimen also become sharper. One of Japan's recent scholar Engr. In 1950, Dr. Genichi Taguchi.

Taguchi method is a statistical approach to improve the quality of the manufactured components. It provides effective and standardized way to balance the efficiency and price configuration [11] .This approach is appropriate when design parameters are subjective .Most important optimization processes is the Taguchi method [12].Taguchi parameter design can improve performance characteristics by setting design parameters and scale down system performance sensitivity to origin of variability [13-14].

It is therefore inferred from this perspective that the consistency of investment casting is greatly affected by its specific process parameters. Therefore, an attempt was made in this study to determine the optimum settings of investment casting process parameters such as temperature pouring, preheat temperature and preheat period to achieve optimum mechanical properties using Taguchi's experimental design method. .

Taguchi method is a streamlined type of experimental design (DOE), where the experiments are systematically planned and evaluated to enhance the performance characteristics.ANOVA was used for analyzing the results of designed experiments. Finally, it was found that Taguchi optimization processes help to aquire the optimal settings process parameters.

1.2 Research Objectives

The objectives of this study are given below-

1. To determine the optimal settings of investment casting process parameters such as pouring temp, preheat temp and preheat time by Taguchi method.
2. To measure the effectiveness of the proposed techniques through feasibility test.

1.3 Organization of this research

This article is organized into five chapters for the completion its objectives and the organization is

Chapter 1- Introduction: Concept of 'Investment Casting', research objectives and organization of this work had been aggregated in this chapter.

Chapter 2- Literature Review: In this chapter, the concept of 'Investment Casting' of a metal forming process is generated by literatures/articles reviewing. This chapter also shows the summary of previous research works.

Chapter 3- Research Methodology: In this chapter, a research methodology is adopted for the completion of its objectives. The adopted methodology shows the sequences to complete its objectives that will make the readers easy to understand the adopted methods.

Chapter 4- Results and Discussion: In this chapter, all the results had been discussed and Compared to others research results.

Chapter 5-Conclusions and Recommendations: Significance of this research, recommendations, limitations, and scope of further research had been integrated in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Literature Review

Pouring molten metal into the intended hollow cavities and then leaving it to solidify is a method of development that can be dated back thousands of years. Usually, the conventional product is gritty with a condensed interface. The lost wax method was implemented with greater complexity of designs to manage casting of complex shapes.
Li Y.M. et al. (2001) studied the consequence of system variables on micro porosity and mechanical properties in investment cast aluminum alloy and it was concluded that low shell and low temperatures generally yielded high mechanical properties [15]. Gebelin et al. (2003) explained that the wax pattern durability used directly impacts the accuracy of the final cast component. They also concluded that the investment caster usually uses precision-machined full-metal dies to produce wax patterns when large numbers of high-precision components are needed [16].Tascyogylu et al. (2004) found that waxes are complex mixtures of many materials, including natural or synthetic wax, solid fillers and water. They carried out tests such as penetration, absolute gravity, viscosity to determine the wax mixture's consistency [17]. Singh et al. (2006) suggested that variables such as wax injection temperature, hold time, die temperature and injection time have a major impact on cast part quality. As the injection temperature raised, they observed that the percentage deviation of the pattern dimension enhanced [18].Nikhil Yadav et al. (2011) attempted to create a wax mixture of paraffin wax, china wax, carnauba wax and montane wax by varying proportions that could provide a better surface finish [19].

Starting in the early 1920s, Sir R. A. Fisher developed the method of designing experiments (DOE) in ancient agricultural sciences to determine the optimal treatments or test conditions to produce the best crop [20]. Work on injection moulding conditions can be divided into absolute factorial design and factorial fractional design using traditional DOE approaches [21].

A full fractional model can describe all possible combinations for a given set of factors. However, it is very costly and time-consuming [22]. For this purpose, a limited number of experiments are chosen from all the possibilities that Generate the most knowledge to the to a practical level the number of experiments. Though fractional factor design is well known, it is too difficult and there are no general guidelines for applying it or analyzing the results obtained through the experiments [23].

In the late 1940s, Dr. Genichi Taguchi developed a new experimental technique, the Taguchi system, using an updated and streamlined version of DOE. [24, 25]. For the past 20 years, the use of the Taguchi method has gained further interest in the literature and the Taguchi method has now been commonly used in various fields, such as the manufacturing sector [26], mechanical component design [27], and process optimization [28, 29].

Taguchi's standalone method takes the elements of the Taguchi from the experimental design stage to the final optimization process. The Taguchi method's parameter architecture is used orthogonal array (OA), signal-to-noise ratios, mean effects, and analysis of variance (ANOVA). OA offers a range of well-balanced experiments and Taguchi, which are the logarithmic functions of the desired output, serve as objective optimization functions [30]. The main effects and ANOVA are carried out after performing the statistical analysis of ratio. According to reference [31] the Taguchi method is used to optimize seven processing parameters, including melting temperature, molding temperature, injection speed, injection pressure, short-shot duration, gas injection pressure and delay of gas injection, to increase the surface roughness of the gas injection molding. Reference [32] Conducted tests using an orthogonal L9 array to refine the manufacturing parameters of ABS mouldings made from two separate moulding materials like steel and aluminum. According to reference [33] also exploited the L9 experimental design to study the effect of processing parameters on the weld-line of the right door of copy machine which was modelled with three gates. Four processing parameters were optimized to remove the weld line on the plastic part, including melt temperature, injection speed, and injection pressure. Based on the experimental data at optimum level combination, the weld line defect was significantly reduced by optimization and the melt temperature was found to be the most critical parameter influencing the weld line's visibility.. In another research, by using the Taguchi optimization process, the weld line strength of an injection molded component was further improved [34].

CHAPTER-3

METHODOLOGY

3.1 Material Selection

In this present investigation mild steel has been taken to make the castings. It is a steel alloy with a weight content of at least 11.5% chromium and a weight content of at most 0.05–0.30% carbon. Stainless steels are most remarkable for their corrosion resistance, which raises with increasing chromium content.

Table 3. 1 The Chemical Composition of Stainless Steel

Amount	C %	Si %	Mn %	S %	P %	Cr %	Ni %	Mo %
Min	0.10	0.15	0.40	-	-	-	-	-
Max	0.18	0.35	0.70	0.04	0.04	-	-	-

3.2 Selection of Process Parameters

The following system variables have been identified in this analysis to imagine their consequence on the structural accuracy and surface roughness of the cast parts

- Preheat Temperature
- Pre Heat Time
- Pouring Temperature

3.2.1 Preheat Temperature

Usually, the mould is preheated before pouring the liquid metal into investment casting to minimize the thermal shock due to rapid cooling. Just before pouring, to remove any wax traces the mould is pre-heated to 1000-1200 ° C temperature.

According to the different properties of differ alloys this range of preheat temperature varies in this section for stainless steel investment casting it varies in the range 1000-1200^{o}C. Escalating preheat eliminates the heat that can be soaked up by a mould.

3.2.2 Preheat Time

The duration of preheating the mould to eliminate any wax trace. A two stage burnout methods was selected. This burnout schedule was for 30 minutes from room temperature to 250^{0}C and then the temperature was increased to 900 0C. Once the maximum temperature was reached, the mould was heat soaked for half an hour. Maintain the desired temperature for at least 2 hours. Heat for longer periods of time for large patterns, and occasionally burn a second time for extremely large patterns.

3.2.3 Pouring Temperature

In investment casting the temperature while pouring the molten metal into the mould. The temperature of metal pouring varies significantly depending on the particular alloy used. Ceramic moulds can be upgraded to over 1,500 F (8160C) to maximize their capacity.

According to the different properties of differ alloys this range of preheat temperature varies in this section for stainless steel investment casting it varies in the range 1000-1200°C. Increasing preheat reduces the amount of heat a mould can absorb, the thermal gradient across the mould, and the amount by which it will expand when heated.

The above process variables were picked to imagine their influence on surface finish and mechanical properties of the cast components generated. The ranges were selected for the study are shown in the table. Further these ranges that were divided into the three levels according to the Taguchi method are as shown in the Table 3.2

Table 3. 2 Process Variables

Factors	**Range**	**Levels**		
		L1	**L2**	**L3**
Preheat temperature (A)	900°C –1000°C	900	950	1000
Preheat time (hrs)	2-3 hrs	2	2.5	3
Pouring temperature (°C)	1500-1600	1500	1550	1600

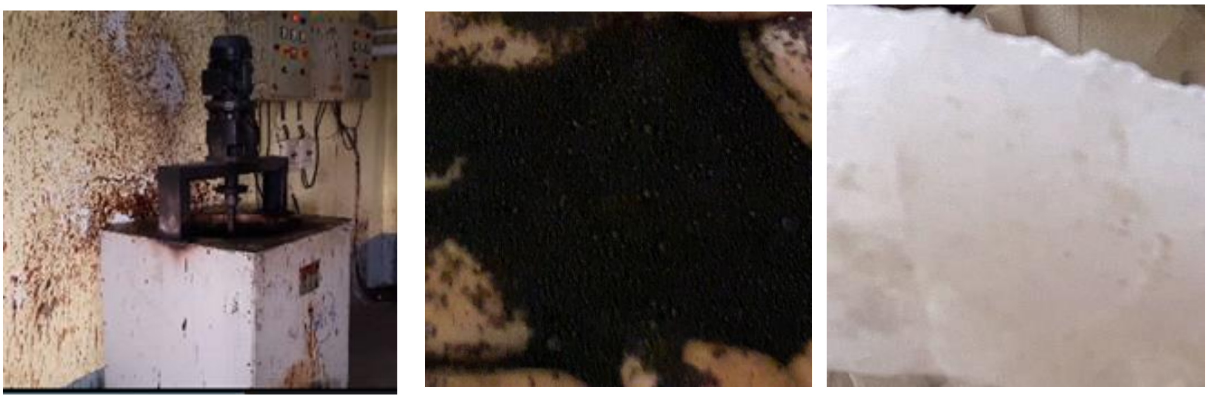
3.3 Casting Procedure

3.3.1 Design of Pattern

To develop pattern, the initial design of the test bar was chosen. For mild steel casting, the gating method was also identified. This method consisted of the same construction materials as the mould cavity.

3.3.2 Preparation of Wax

In investment casting waxes are frequently used as a pattern material. Since the ultimate quality of castings in this process mainly depends on wax patterns, It is therefore necessary to understand how to achieve the best quality of wax – blend. For the purpose, we blended the different types of wax such as paraffin, manton wax, microsoft soft and hard, paraffin wax with low density polymer. Figure 3.1(a) shows the preparation of wax and figure 3.1(b), 3.1 (c)) 3.2 (d), 3.2 (e), 3.2(f) different types of waxes and LDP.



(a) (b) (c)

Figure 3. 1 (a) Preparation of Wax (b) Manton Wax (c) Paraffin Wax

(d) (e) (f)

Figure 3. 2 (d) Low Density Polymer (e) Microsoft Soft Wax (f) Microsoft Hard Wax

3.3.3 Making of Wax Pattern

An aluminum die in the shape test bar was filled with molten wax which is illustrated by figure 3.3. Then it was allowed to cooling in the water for solidification as shown by figure 3.4. Then these patterns were taken for cleaning and repairing-figure 3.5.

Figure 3. 3 Creating wax Pattern

Figure 3. 4 Wax Patterns for Cooling

Figure 3. 5 Wax Patterns are kept for Cleaning and Repairing

3.3.4 Assemble of Wax Patterns

In this situation, patterns were added to a wax sprue in this situation to build a pattern cluster or tree. A heating device at 300°C is used to combine specified wax pattern, which are then pressed against each other and left to cool and harden.

Figure 3. 6 Wax Tree Assembly

3.3.5 Production of Ceramic Slurry

The structure of the ceramic mould for investment casting was made up with 65% of zirconium silicate, 25% of quartz, 10% of refined kaolin and sodium silicate. The refractory materials ' particle sizes are about 325 mesh. Carboxymethyl Cellulose (CMC) was used as binder of the ceramic slurry and the specific density of 3 the slurry was about 2.40. The viscosity of the slurry was maintained about 305 units (Torsion viscometer with probe size 11x16). Using the stirrer, the slurry was correctly mixed and through regular monitoring the optimal quality and accuracy were ensured.

(a)

(b)

Figure 3. 7 (a) Primary Coating Mixer (b) Primary Slurry Drum

3.3.6 Development of Ceramic Shell

A two-step process was used in which the pattern was dipped into the slurry, then binders and refractory powders are sprayed on it. The first coat of the mould was formed in the ceramic slurry. It was a fine, dense and uniform layer that prevented air bubbles from getting caught. The pattern has been stripped and placed above to remove excess liquid from the pattern. Once the first layer is completely dried, the pattern is again immersed in the same slurry to ensure any missing pattern area. It was allowed to air dry and the PVA (Polyvinyl acetate) was applied on top of the inner surface. A fine grog layer of 150µm was developed by spraying. The mould was dried again and the second layer was formed in the same slurry to increase the thickness of the shell. After each dip, the mould was allowed to dry 10- 20 minutes. PVA was then applied and the 250µm grog layer particle size was deposited. The investment process was repeated in the slurry, air drying, and application of PVA and grog layer to create the shell mould. Additionally, this ceramic slip and grog was added up to 6-7 mm wall thickness. The sealing coat was added to the mould without any additional grog surface. The sealing coat was used to bind any remaining refractory material to the ground to prevent loose particles from falling out of the finished investment mould. The smooth surface of a sealed mould made easier to handle. The shell construction process took time, as each slurry coat had to be air-dried. before subsequent layers are applied. Use electric fans, the air drying time of the ceramic investment has been reduced.

(a)

(b)

Figure 3. 8 (a) Zircon Sand Application (b) Ceramic Shell Assembly

3.3.7 Dewaxing of the Shell

In the investment casting process, the most crucial component is to dewax investment shells. This determines the casting destiny because the wax's texture and dimensional characteristics are passed to the ceramic shell and thus to the final casting.To melt and strip the inner casting wax from ceramic shells, a dewaxing autoclave was used. Then the ceramic shell was fired and used as the metal casting mould cavity.

The dewaxing process was conducted in a dewaxing autoclave which In some cases, high pressure of up to 85 psi (5.8 bar) and a substantial increase of up to 140 psi (9.6 bar) are generally involved. There was a 15-20 minute dwelling after heating, and then a controlled depressurization at 15-30 psi / min (1-2 bar / min) to minimize shell cracking possibilities.

(a) (b)

Figure 3. 9 (a) Dewaxing Tank (b) Ceramic Shell of the Test Bar

3.3.8 Preheating of the shell and Ladder

The ceramic shells and ladder were heated 900-1000^{0}C for 2-3 hrs. The residual waxes from the shell were removed by this step and the shells were ready for pouring molten metal.

(a) (b)

Figure 3. 10 (a) Preheating of ceramic shell (b) Preheating of ladder

3.3.9 Metal Pouring

The metal heated up to 1500-1600°C and then poured into the shell and keep the shell in the air for cooling. Same way other 8 castings were done with the variation of process variables given in the table 3.2.

(a) (b)

Figure 3. 11 (a) Checking the Temp. With Thermostat (b) Metal Heating

(a) (b)

Figure 3. 12 (a) Pouring Metal Into the shell (b) Cooling in the Air

3.3.10 Shell Knock Off

The ceramic materials outside the casted product then removed by shell knocking process.

Figure 3.13 Shell Knock Off

3.3.11 Cut Off Residual Parts

The residual parts of the casted product was removed by grinding machine.

3.3.12 Individual Castings

The final casted parts were then taken for heat treatment which necessary for metal testing.

Figure 3. 14 Final Casting

3.4 Selection of Mechanical Properties

In this study following mechanical properties was tested-

1. Tensile strength

2. Hardness

3. Bending

We have got tensile strength and hardness test report successfully but there was no observation in hardness test.

3.4 Methodology for Optimization

3.4.1 Taguchi Method

Dr. Taguchi from Nippon Telephones and Telegraph Company, Japan, has developed an ORTHOGONAL ARRAY based system. This system giges optimal setting of control parameters to achieve better result.

Taguchi methods are statistical methods which Genichis Taguchi has developed for improving the quality of produced products and have been used for engineering more recently, marketing and advertising (Selden 1997). The goals and improvements brought about by Taguchi methods have been welcomed by professional statisticians, especially by Taguchi's designs. After World War II, with very limited resources, Japanese manufacturers were suffered horribly. Taguchi has reshaped Japan's manufacturing process by reducing costs.

Like many other professionals, he understood that all processes of production are affected by external influences, noice. Nevertheless, Taguchi has used methods to classify those causes of noise that have the greatest impact on product seasonality. Due to better production processes at significantly lower costs, successful manufacturers around the globe adopted his ideas. "Orthogonal Arrays" (OA) provide a set of experiments that are well balanced (minimum).

The ideology of Taguchi is based on the following three fundamental concepts. Value should be included in the material rather than in the test. Through minimizing the deviations from the goal, value is the best achieved. The material or system should be configured to be resistant to uncontrollable variables in the environment. The cost of error should be measured as a function of standard deviation and system-wide failure estimation.

The concept of experimental design is at the heart of product and process design. The product characteristics can be calculated and the statistical output estimated by choosing combinations of the different factor rates. Taguchi is the matrix setting the controllable factors (design parameters) for each run or experiment; the matrix setting the uncontrollable or noise factors is called the outer array. Each run consists of a structure parameter setting and a noise factor setting associated with it. The internal and external arrays are respectively referred to as the configuration and noise matrices.

Experimental design strategy

Taguchi suggests the setting of tests with Orthogonal Array (OA). OA's are common squares of Graeco-Latin.

An experiment is designed to choose the most suitable OA and assign the parameters and interactions of consideration to the corresponding columns. The use of linear graphs and triangular tables suggested by Taguchi makes determining parameters easy. The results of the experiments are evaluated in the Taguchi system to achieve one or more of the following goals-

- To calculate the influence of individual criteria and associations.
- To estimate the response under the optimum condition
- To establish the best or the optimum condition for a product or process

The selection of a specific orthogonal array is based on the number of different factor levels. Here we selected 3 factors at 3 levels to conduct the experiments. Now the Degree of Freedom

(DOF) can be calculated by the formula as (DOF)R = P*(L – 1)

(DOF) R = degree's of freedom P = number of factors

L = number of levels (DOF) R = 3(3 – 1) = 6

Nevertheless, the total DOF orthogonal array (OA) should be greater than or equal to the total DOF needed for the experiment. We therefore picked the L9 orthogonal array for further experiments. This set of 9 experiments is stated. The L9 OA with four reasons, three grades and their responses are shown in the Table 3.3

Table 3. 3 Experimental layout Based on L9 Orthogonal Array

Expt.No	**A**	**B**	**C**
1	1	1	1
2	1	2	2
3	1	3	3
4	2	1	2
5	2	2	3
6	2	3	1
7	3	1	3
8	3	2	1
9	3	3	2

Optimization Process Flow Diagrams

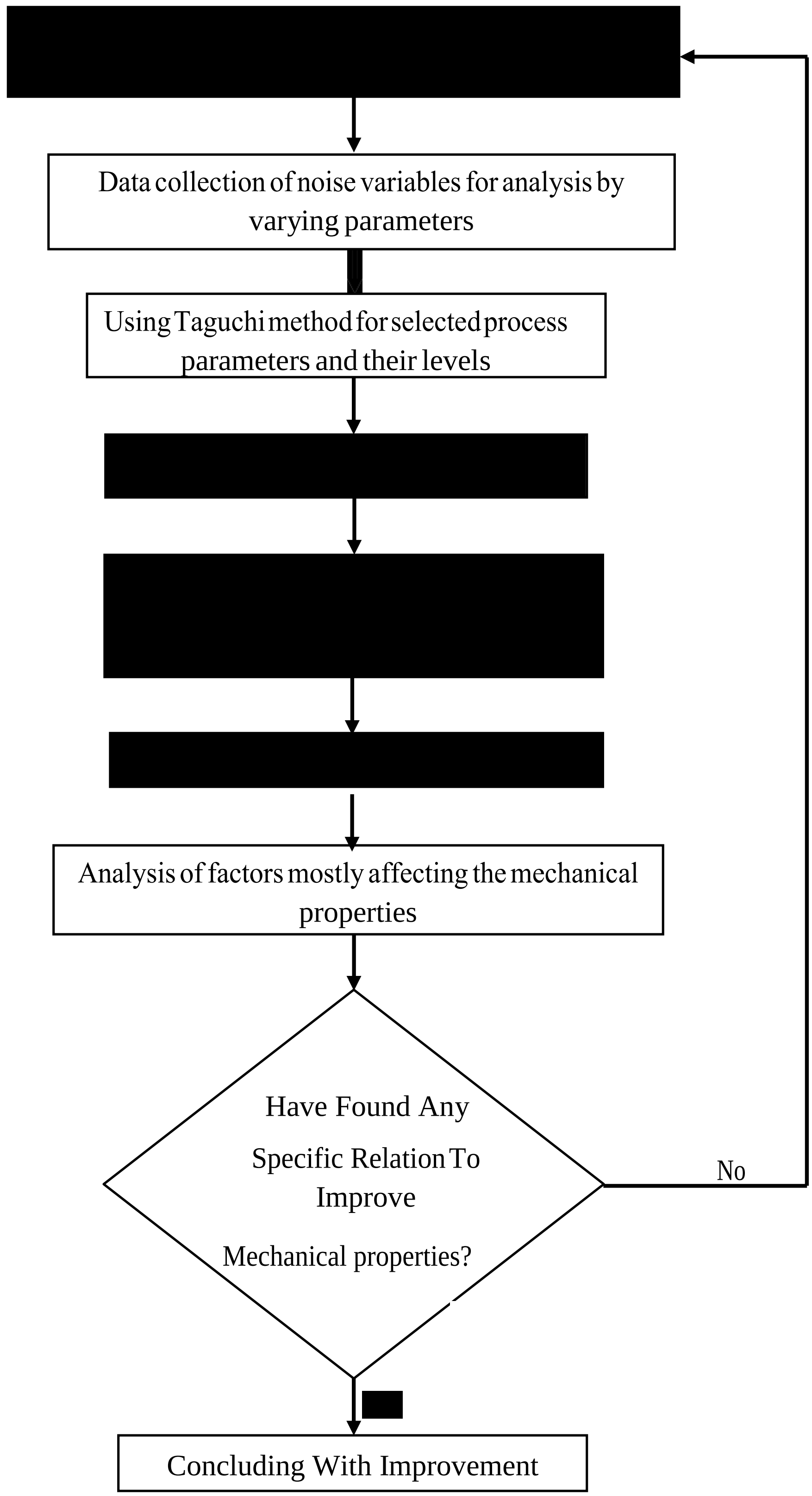


Figure 3. 15 Optimization Flow Chart

CHAPTER IV

RESULTS AND DISCUSSION

Table 4.1 shows experimental results of investment casting according to process parameters of Taguchi L9 orthogonal array for Brinell hardness number and Ultimate Tensile Strength. Experiment no. 2 provides the maximum Brinell hardness number (149), where preheat time, preheat temperature, and pouring temperature are 2 hrs, 950°C and 1550°C respectively. On the other hand, experiment no. 6 gives the maximum ultimate tensile strength (460 MPa), where preheat time, preheat temperature, and pouring temperature are 2.5 hrs, 1000°C and 1500°C respectively.

Table 4. 1 Experimental results of investment casting for Taguchi L9 orthogonal array

Expt. No.	Preheat Time(hrs)	Preheat Temperature(°C)	Pouring Temperature(°C)	Brinell Hardness Number (BHN)	Ultimate Tensile Strength(MPa)
1	2	900	1500	143	455
2	2	950	1550	149	430
3	2	1000	1600	143	452
4	2.5	900	1550	147	425
5	2.5	950	1600	144	455
6	2.5	1000	1500	148	460
7	3	900	1600	145	447
8	3	950	1500	146	457
9	3	1000	1550	148	435

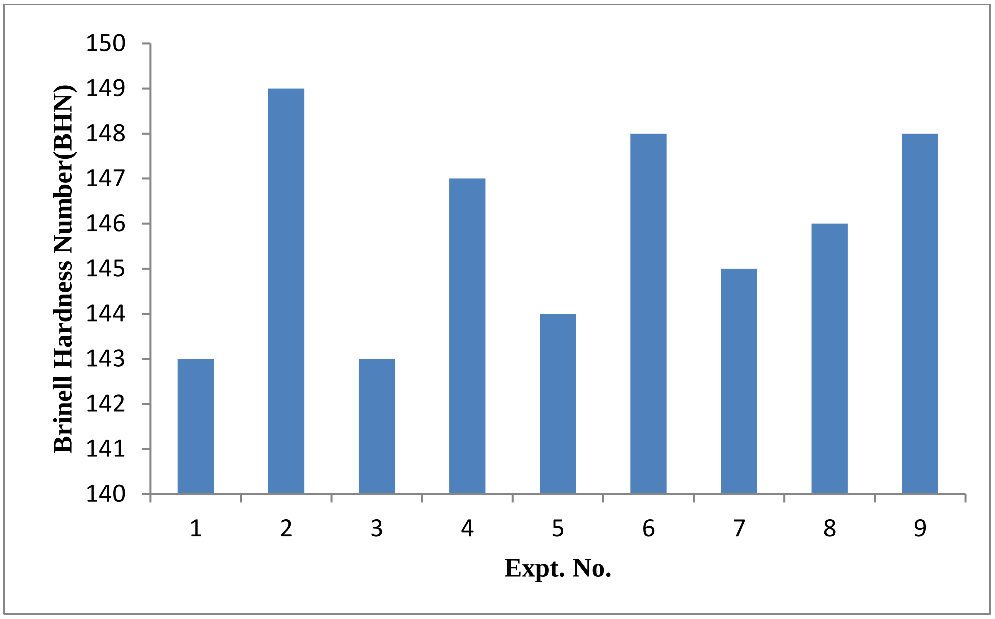


Figure 4. 1 Comparison of Brinell hardness number of Different Experiment

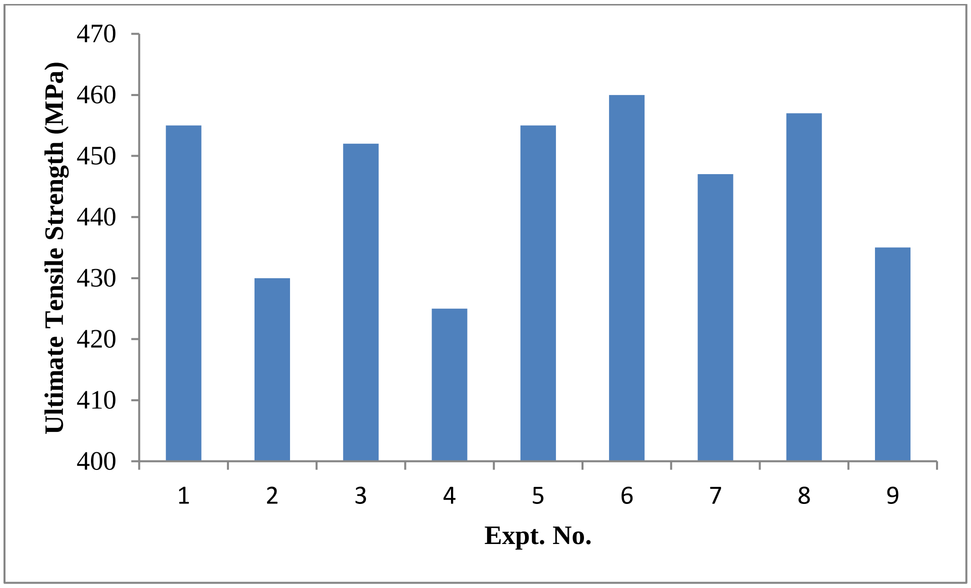


Figure 4. 2 Comparison of Tensile Strength of Different Experiment

4.1 Taguchi Analysis

4.1.1 Brinell Hardness Number

Table 4. 2 Response Table for Means of Brinell hardness number

Level	Preheat Time(hrs)	Preheat Temperature(°C)	Pouring Temperature(ºC)
1	145.0	145.0	145.7
2	146.3	146.3	148.0
3	146.3	146.3	144.0
Delta	1.3	1.3	4.0
Rank	2.5	2.5	1

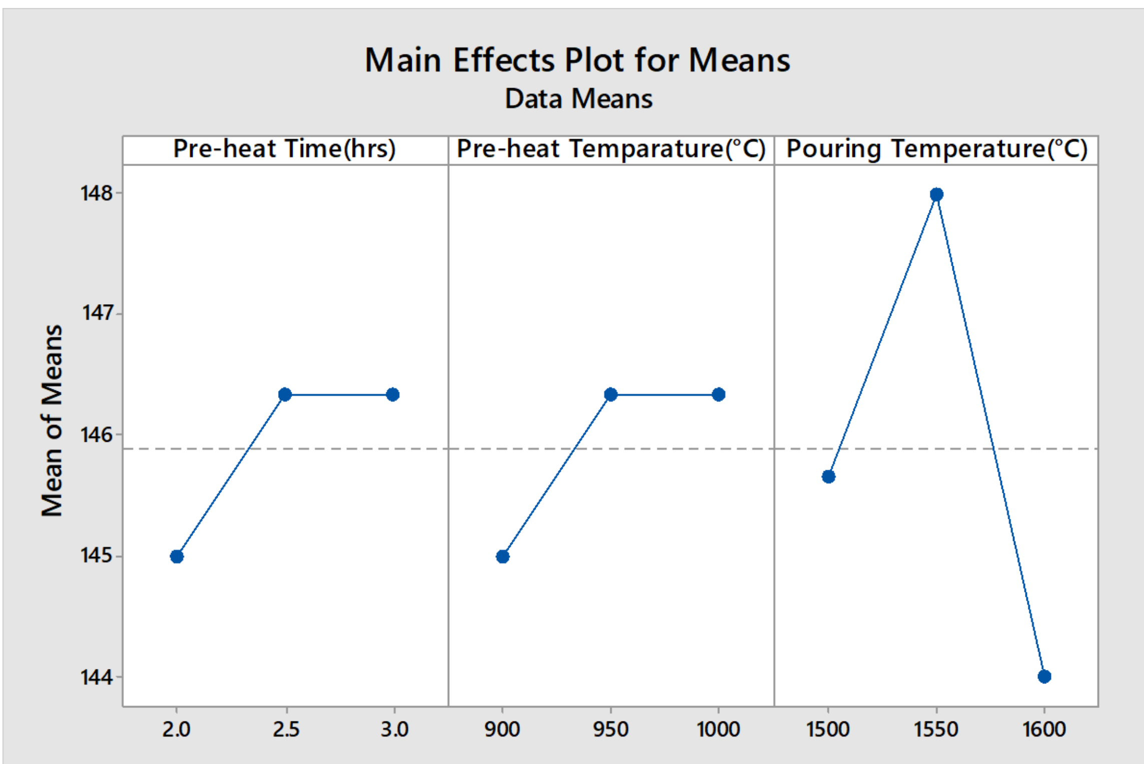


Figure 4. 3 Main Effect Plots for Mean Values of Brinell hardness number

From table 4.2 and figure 4.1, it was found that pouring temperature was the most crucial factor as the most variation of Brinell hardness number for investment casting is from this factor, and also delta or response range is maximum for this factor that is seen in table 4.2 and so it is ranked as 1. But it is specific point sensitive, level value of 1550°C results in maximum response value. Increasing the temperature may cause less BHN. Also BHN is below average for both level values of 1500°C and 1600°C. For level value of 1600°C, response is very much concerning as it is the lowest point that is not expected. This level value should be avoided while selecting value for pouring temperature. Responses for preheat time and preheat temperature seem alike. Very poor response in case of 2.0 hrs preheat time, 2.5 hrs presents better result than previous , but 3 hrs is not satisfactory, it may be for some random errors in this process.. Preheat temperature of 950°C is economical. No further improvement after increasing it to 1000°C.

4.1.2 Ultimate Tensile Strength

Table 4. 3 Response Table for Means of Ultimate Tensile Strength

Level	Preheat Time (hrs)	Preheat Temperature(°C)	Pouring Temperature(°C)
1	445.7	442.3	457.3
2	446.7	447.3	430.0
3	446.3	449.0	451.3
Delta	1.0	6.7	27.3
Rank	3	2	1

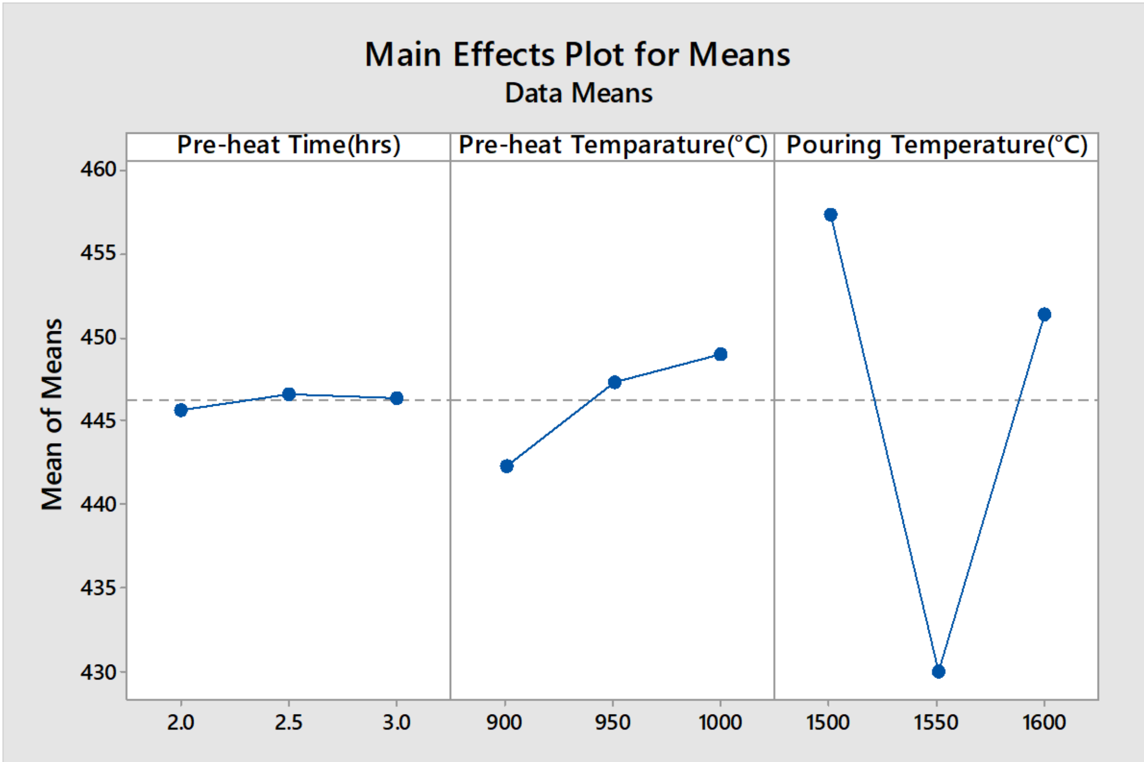


Figure 4. 4 Main Effect Plots for Mean Values of Ultimate Tensile Strength

Table 4.3 and figure 4.4 indicate that preheating time has very little effect on the ultimate tensile strength for casting investment. Preheat time of 2 hrs provides strength below mean value, level value of 2,5 hrs shows a little bit better response than other twos. Preheat temperature has linearly increasing relation for improving ultimate tensile strength. Level value of 1000°C provides improve result and it may be possible make further improvement by increasing level value to a certain point. Pouring temperature is very sensitive to specific point value. The worst result is obtained from level value of 1550°C, but much better or it can be said the best result from level value of 1500°C. After increasing to 1600°C, it again starts to improve strength from previous point. So there is a scope to check its possibility to get better response by increasing value after 1600°C pouring temperature.

4.2 Analysis of Variance (ANOVA)

The F Distribution is a probability distribution of the F Statistic. The distribution is an asymmetric distribution mainly used for ANOVA test. This F distribution has a minimum value of zero; there is no limit for maximum value. The distribution's peak happens just to the right of zero and the higher the F value after that point, the lower the curve. The F distribution is actually a collection of distribution curves. F statistic can be used when deciding to support or reject the null hypothesis. In F test results, it will have both an F value and an F critical value.

The value that is calculated from experimental data is called the F value. In general, if calculated F value in a test is larger than F critical value, the null hypothesis can be rejected. However, the statistic is only one measure of significance in an F Test. It is also important to consider the p value. The p value is determined by the F statistic and is the probability that the results could have happened by chance.

The F value should always be used along with the p value in deciding whether the results are significant enough to reject the null hypothesis. If a large F value is found (one that is bigger than the F critical value found from F table), it means something is significant, while a small p value means all the results are significant. The F statistic just compares the joint effect of all the variables together. To put it simply, reject the null hypothesis only if the alpha level is larger than the p value.

4.2.1 Brinell Hardness Number

Table 4. 4 ANOVA for Brinell hardness number at 95% Confidence Level

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage Contribution
Preheat Time(hrs)	2	3.566	1.778	0.37	0.729	8.72%
Preheat Temperature(°C)	2	3.566	1.778	0.37	0.729	8.72%
Pouring Temperature(°C)	2	24.222	12.111	2.53	0.283	59.21%
Error	2	9.556	4.778			23.36%
Total	8	40.889				

From this ANOVA table (table 4.4), the maximum percentage of contribution was found 59.21% for pouring temperature. From F-distribution table, for numerator 2 and denominator 2, critical value $F_{critical}$=19.00. In this study, calculated F-value is 2.53 which is smaller than critical F-value.

So, P-value is 0.283 or 28.3% which is higher than 5% that indicates the high probability of accepting the decision on high contribution for the factor of pouring temperature. Similarly, the minimum percentage of contribution was found 8.72% both for preheat time and preheat temperature. Here, calculated F-value is 0.37 which is smaller than 19.00. So, P-value is 0.729 or 72.9% which is greater than 5% that also indicates the high probability of acceptance. In this analysis, combinational effects of factors that are not considered, contribute 23.36% as error.

4.2.2 Ultimate Tensile Strength

Table 4. 5 ANOVA for Ultimate Tensile Strength at 95% Confidence Level

Source	DF	Adj SS	Adj MS	F-Value	P-Value	Percentage Contribution
Preheat Time(hrs)	2	1.56	0.778	0.07	0.933	0.12%
Preheat Temperature(°C)	2	72.22	36.111	3.35	0.230	5.42%
Pouring Temperature(°C)	2	1238.22	619.111	57.44	0.017	92.85%
Error	2	21.56	10.778			1.62%
Total	8	1333.56				

From this ANOVA table (table 4.5), the maximum percentage of contribution was found 92.85% for pouring temperature. From F-distribution table for numerator 2 and denominator 2, critical value $F_{critical}$=19.00. In this study, calculated F-value is 57.44 which is larger than critical F-value. So, P-value is 0.017 or 1.7% which is smaller than 5% that indicates the high probability of rejecting the decision on high contribution for the factor of pouring temperature. Similarly, the minimum percentage of contribution was found 0.12% for preheat time. Here, calculated F-value is 0.07 which is smaller than 19.00. So, P-value is 0.933 or 93.3% which is greater than 5% that also indicates the high probability of acceptance. In this analysis, combinational effects of factors that are not considered, contribute 1.62% as error.

4.3 Regression Analysis

The regression analysis is a computational way to examine the relationship between various process parameters. In this study, the optimal mechanical properties for investment casting are obtained by means of regression analysis using MINITAB 17. By providing input and output parameters in the Taguchi L9 orthogonal array in DOE, the regression equation function is created. It helps to determine the outcome of cause from one aspect to another. In the case of investment casting, the equations are developed based on the value of three variables.

4.3.1 Brinell Hardness Number

The regression equation of Brinell hardness number for the investment casting is as follows:

Brinell hardness number (BHN) = 155.7 - 0.0167 Pouring Temperature (°C) + 1.33 Preheat Time (hrs) + 0.0133 Preheat Temperature (°C)

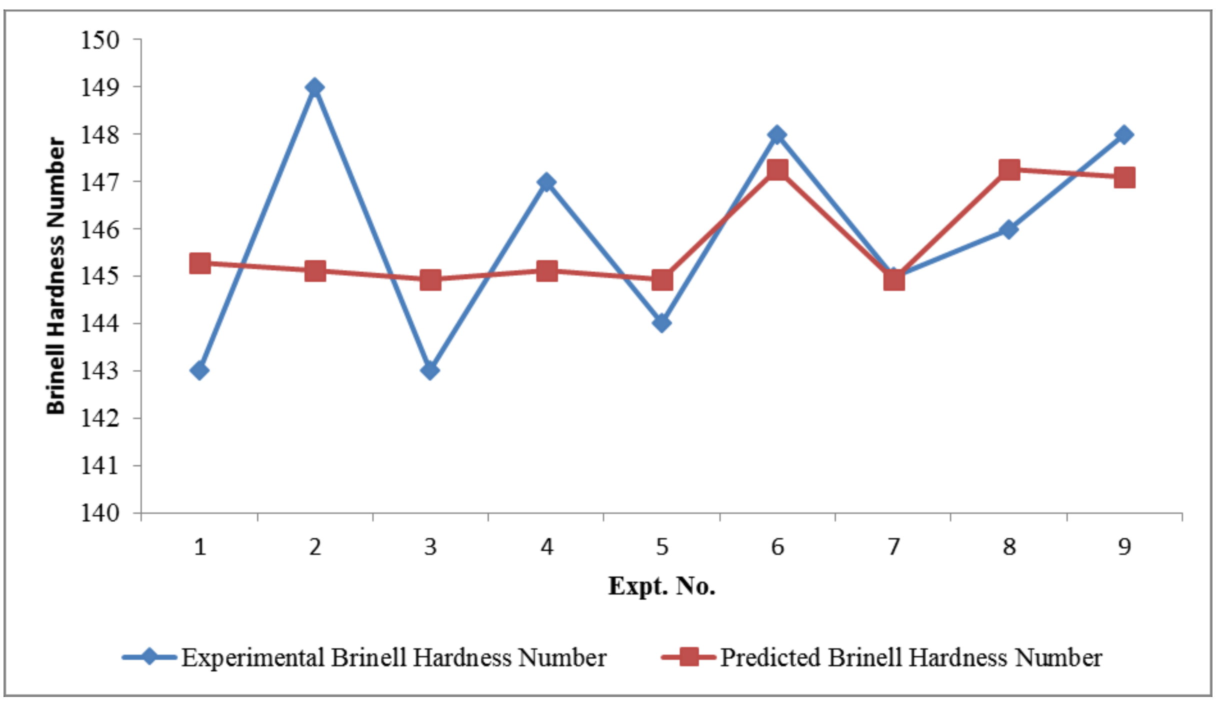


Figure 4. 5 Comparison of Predicted and Experimental Brinell hardness number

Figure 4.5 shows the comparison between experimental and predicted Brinell hardness number. The figure shows the nature of the two line graphs that are not similar initially but gets closer in the ending. The experimental Brinell hardness number values for the experiment no. 5, 6, 7 and 9 almost match with predicted value.

4.3.2 Ultimate Tensile Strength (UTS)

The regression equation of UTS is as follows:

Ultimate Tensile Strength (MPa) = 474 - 0.060 Pouring Temperature (°C) + 0.7 Preheat Time (hrs) + 0.067 Preheat Temperature (°C).

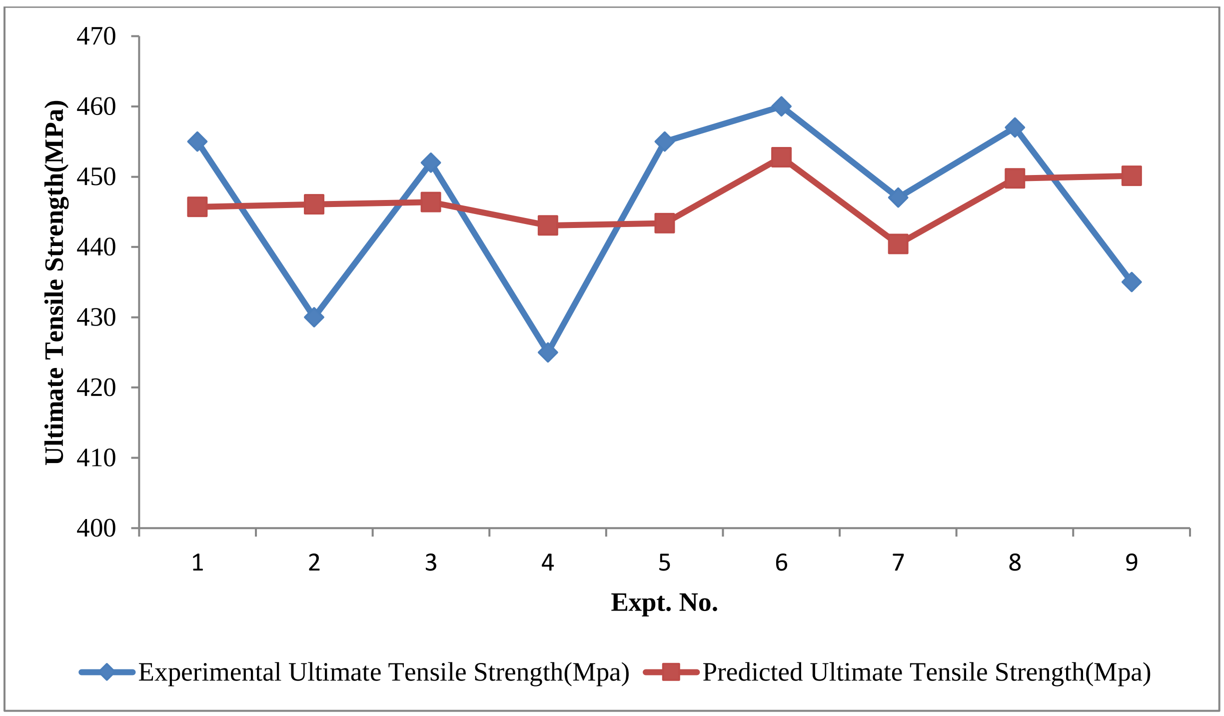


Figure 4. 6 Comparison of Experimental and Predicted UTS

Figure 4.6 highlights the distinction between experimental and predicted UTS. The figure shows the nature of the two line graphs that looks like parallel in the most portion of the full segment except 2 or 3 points. The experimental ultimate tensile strength values for the experiment no. 1, 3, 6, 7 and 8 almost match with predicted value.

CHAPTER V

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Fabrication and mechanical tests of investment casting were performed carefully. From result and discussion, the following conclusion can be drawn:

1. The combination of preheat time: 2 hrs, preheat temperature: 950°C and pouring temperature: 1550°C values were the optimum setting for obtaining maximum Brinell hardness number. On the other hand, the combination of preheat time: 2.5 hrs, preheat temperature: 1000°C, and pouring temperature: 1500°C values were the optimum setting for obtaining maximum ultimate tensile strength.
2. From Taguchi analysis, it is seen that pouring temperature is the most influential factor to improve hardness and tensile strength.
3. From the ANOVA table, maximum contribution on the Brinell hardness number (59.21%) and ultimate tensile strength (92.85%) were found for pouring temperature.

The regression equation showed a very close relation between predicted

5.2 RECOMMENDATION AND SCOPE OF FURTHER RESEARCH

In this study we have used only three parameters such as preheat temperature, preheat time and pouring temperature to optimize mechanical properties. Not only these three factors but also other factors such as wax and binder mixing ratio, composition of ceramic shell, water and alcohol based slurry mixer, cooling methods, composite casting materials can be used to optimize investment casting. Actually optimization can be done each every process of investment process.

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