Optimization of die-casting process parameters to identify optimized level for cycle time using Taguchi method

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Abstract- This paper reports on an optimization of Pressure die-casting process parameters to identify optimized level for improving the cycle time using Taguchi method for DOE. AlSic132 up to 20tonn machine capacity is used to calculate cycle time. There are four machining parameters i.e. melting temperature, Injection pressure, Plunger speed, cooling phase. Different experiments are done based on this parameters. Taguchi orthogonal array is designed with three levels and four process Parameters with the help of software Minitab 15. In the first run nine experiments are performed and Cycle time is calculated. Taguchi method stresses the importance of studying the response variation using the signal–to–noise (S/N) ratio, resulting in minimization of cycle time variation due to uncontrollable parameter. The Cycle time was considered as the quality characteristic with the concept of "the larger-the-better". The S/N ratio for the larger-the-better Where n is the number of measurements in a trial/row, in this case, n=1 and y is the measured value in a run/row. The S/N ratio values are calculated by taking into consideration with the help of software Minitab 15. The Cycle time values measured from the experiments and their optimum value for maximum cycle time. Every day scientists are developing new materials and for each new material, we need economical and efficient die-casting process. It is also predicted that Taguchi method is a good method for optimization of various Diecasing process parameters as it reduces the number of experiments. From the literature survey, it can be seen that there is no work done on AlSic 132 die-casting process. So in this project the Pressure die casting parameter of AlSic 132 is done in order to optimize the pressure die-casting process parameters for minimizing the Cycle time.

Keywords – Taguchi Method, Die-casting Parameters, Pressure die-casting Process, AlSic 132, Software Minitab15.

I. INTRODUCTION

The die casting process involves the use of a furnace, metal, die casting machine, and die. The metal, typically a non-ferrous alloy such as aluminum or zinc, is melted in the furnace and then injected into the dies in the die casting machine.

There are two main types of die casting machines - hot chamber machines (used for alloys with low melting temperatures, such as zinc) and cold chamber machines (used for alloys with high melting temperatures, such as aluminum). The differences between these machines will be detailed in the sections on equipment and tooling. However, in both machines, after the molten metal is injected into the dies, it rapidly cools and solidifies into the final part, called the casting. Die casting equipment was invented in 1838 for the purpose of producing movable type for the printing industry. The first die casting-related patent was granted in 1849 for a small hand operated machine for the purpose of mechanized printing type production. In 1885, Otto Mergenthaler invented the linotype machine, an automated type casting device which became the prominent type of equipment in the publishing industry. Other applications grew rapidly, with die casting facilitating the growth of consumer goods and appliances by making affordable the production of intricate parts in high volumes. Die casting is a metal casting process that is characterized by forcing molten metal under high pressure into a mold cavity. The mold cavity is created using two hardened tool steel dies which have been machined into shape and work similarly to an injection mold during the process. Most die castings are from nonferrous metals, specifically zinc, copper, aluminum, magnesium, lead, alloys. Depending on the type of metal being cast, a hot- or cold-chamber machine is used. The Taguchi method is a well-known technique that provides a systematic and efficient methodology for process optimization and this is a powerful tool for the design of high quality systems. Taguchi approach to design of experiments in easy to adopt and apply for users with limited knowledge of statistics, hence gained wide popularity in the engineering and scientific community. This is an engineering methodology for obtaining product and process condition, which are minimally sensitive to the various causes of variation, and which produce high-quality products with low development and manufacturing costs. Signal to noise ratio and orthogonal array are two major tools used in robust design. The S/N ratio characteristics can be divided into three categories when the characteristic is continuous

a) Nominal is the best

b) Smaller the better

c) Larger is better characteristics

For the maximum material removal rate, the solution is “Larger is better” and S/N ratio is determined according to the following equation.

Where, S/N = Signal to Noise Ratio,

n = No. of Measurements,

y = Measured Value

The influence of each control factor can be more clearly presented with response graphs. Optimal cutting conditions of control factors can be very easily determined from S/N response graphs, too. Parameters design is the key step in Taguchi method to achieve reliable results without increasing the experimental costs.

AlSic132 is most suitable for the manufacture of parts such as Electrical enclosures, gear box, bolts and studs. AlSic132 withstand the highest operating temperatures of all the die cast alloys. Its strength, rigidity, and corrosive resistance offer significant heat dissipating. Aluminum is used in a broad range of networking and infrastructure equipment in the telecom and computing industries.

1.1 Processing Parameters that can affect process are

1.1.1 Melting temperature

The molten metal is poured into the die under pressure the temperature is measured in degree celsus.

1.1.2 Injection Pressure

Mould filling takes place while pouring the molten metal through the runner and gate and injection pressure is measured in Bar.

1.1.3 Plunger speed

Speed with respect to material is measured in m/s.

1.1.4 Cooling time

Finally, the mold is kept for cooling phase which is measured in Sec.

1.2 Equipment

There are two basic types of die casting machines: hot-chamber machines and cold-chamber machines. These are rated by how much clamping force they can apply. Typical ratings are between 400 and 4,000 st (2,500 and 25,400 kg).

1.2.1 Hot-chamber die casting

Hot Chamber Die Casting is the process where the injection system is immersed in pool of molten metal hence the name. The furnace is attached to the machine via a feeding system called a gooseneck. As the cycle begins the piston will retracts, which allows the molten metal to fill the “gooseneck” from a port in the injection cylinder. As the plunger move downwards, it seals the port and forces the molten metal through the gooseneck and nozzle into the die. Once the metal solidifies, the plunger will pull upwards. Afterwards, the die will open and the part is ejected. The advantage this process its short cycle time as it does not require metal to be transported from a separate furnace. Unfortunately, this die casting process is only suitable for alloys that do not attack the injection cylinder.

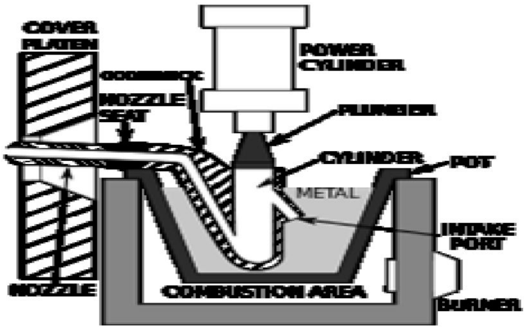


Fig. 1.1 Hot-chamber die casting

1.2.2 Cold-chamber die casting

Cold Chamber Die Casting is the process of using a ladle to transport the molten metal from the holding furnace into the unheated shot chamber or injection cylinder. This metal is then shot into the die by using a hydraulic piston. However, this process is primarily used for manufacturing aluminum parts as molten aluminum alloys have a tendency to attack and erode the metal cylinders, plungers and dies greatly shortening their tool life.

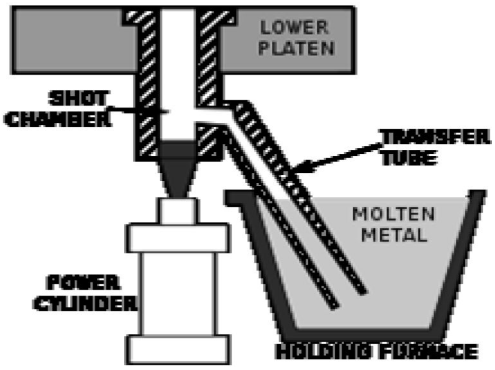


Fig. 1.2. Cold-chamber die casting

II. OBJECTIVE

- Select the component/s for study
- Identify the critical parameters for Processing the Cast components
- Capture the historical data for process parameters with its levels
- Perform DOE considering response factor as the cycle time or the quality of the component or any suitable output parameter for the study
- Trial and testing upon development for experimentation
- Validate the thesis by comparing with the experimental results

2.1 Problem Definition

The sponsoring Company whose associate concern is primarily engaged in production of Die Casting is keen to investigate the levels for the factors responsible for arriving at the best quality for the cast components. Pressure die casting is primarily affected by the process parameters such as solidification time, molten temperature, Filling time, injection pressure and plunger velocity. It is therefore essential that the optimum casting technique with minimum defects be adopted to reduce the manufacturing cost of die casting component during mass production. The optimization of the process parameters pose a challenge for defects since the interplay among the parameters needs to be captured for setting the process for each component. In manufacturing processes, there are various parameters with different adjustment levels, which may influence the final characteristics of the product. To optimize a manufacturing process, the trial and error method is used to identify the best parameters to manufacture a quality product. However, this method demands extensive experimental work and results in a great waste of time and money. Thus, design of experiments appears to be an important tool for continuous and rapid improvements in quality (Coleman and Montgomery, 1993). These experimental methods may be employed to solve problems related to a manufacturing process, to substitute a process for another one, to develop different products and to understand the influence of various factors on the final quality of a given product. The design of experiments (DOEs) is an experimental technique that helps to investigate the best combinations of Process parameters, changing quantities, levels and combinations in order to obtain results statically reliable. It is a systematic route that may be followed so as to find solutions to industrial process problems with greater objectivity by means of experimental and statistical techniques. The die casting process is controlled by several parameters. When properly determined and adjusted, they result in an improvement in quality of the die casting parts. Usually, the main controlled variables are mold temperature, dosage volume, slow and fast shots, commutation spots, injection pressure, up set pressure as well as chemical composition and liquid metal temperature.

III. DESIGN OF EXPERIMENT

3.1 Outline of experimental design procedure

The Experiments are carried out by researchers or engineers in all fields of study to compare the effects of several conditions or to discover something new. If an experiment is to be performed most efficiently, then a scientific approach to planning it must be considered. The statistical design of experiments is the process of planning experiments so that appropriate data will be collected, the minimum number of experiments will be performed to acquire the necessary technical information, and suitable statistical methods will be used to analyze the collected data. The statistical approach to experimental design is necessary if we wish to draw meaningful conclusions from the data. Thus, there are two aspects to any experimental design: the design of the experiment and the statistical analysis of the collected data. They are closely related, since the method of statistical analysis d depends on the design employed. An outline of the recommended procedure for an experimental design is shown in Figure and briefly explained below.

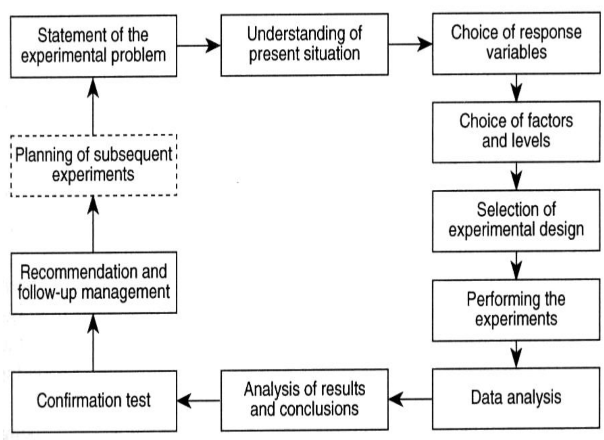


Fig. 3 1. Outline of experimental design procedure

3.2 Taguchi system of quality engineering

Dr. Genichi Taguchi has introduced more cost effective engineering methodology namely robust design to deliver high quality products at low cost through research and development. It can greatly improve an organization’s ability to meet market windows, keep development and manufacturing costs as low as possible. Robust design uses any ideas from statistical experiment design and adds a new dimension to it by explicitly addressing two major concerns faced by all products and process designers:
How to reduce economically the variation of a product’s function in the customer’s environment?

How to ensure that decisions found optimum during laboratory experiments will prove to be valid and reliable in manufacturing and customer environments?

3.3 Signal to noise ratio

In the field of communication engineering a quantity called the signal-to-noise (SN) ratio has been used as the quality characteristic of choice. Taguchi, whose background is communication and electronic engineering, introduced this same concept into the design of experiments. Two of the applications in which the concept of SN ratio is useful are the improvement of quality via variability reduction and the improvement of measurement. The control factors that may contribute to reduced variation and improved quality can be identified by the amount of variation present and by the shift of mean response when there are repetitive data. The SN ratio transforms several repetitions into one value which reflects the amount of variation present and the mean response. There are several SN ratios available depending on the type of characteristic: continuous or discrete; nominal-is-best, smaller-the-better or larger-the-better. In this section we will only discuss the case when the characteristic is continuous. The discrete case will be explained later.

1) Nominal is Best Characteristics

2) Smaller the Better Characteristics

3) Larger the Better Characteristics

There are cases where The-Larger-The-Better is applicable to characteristics such as the strength of materials and fuel efficiency. In these cases, there are no predetermined target values, and the larger the value of the characteristic, the better it is. The corresponding SN ratio of Larger-the-Better is; Note that the target value of 1/y is 0 in the larger-the-better characteristic. The SN equations are based on the loss function when there is a set of n characteristics. If we employ the loss- function approach for the nominal-is-best case, we can derive the following SN equation: This form of equation may be more desirable for three reasons. First, where yi can take a negative or positive value, it is possible for Sm to be less than V, so that equation cannot be used. Second, as y increases, SN increases. However, if y is greater than the target value m, the bigger y becomes the worse. Hence, where y is bigger than m, SN does not reflect desirable situations. Third, the SN values are not based on the concept of the loss function, and are not consistent with the loss function.

3.4 Orthogonal array

Many designed experiments use matrices called orthogonal arrays for determining which combinations of factor levels to use for each experimental run and for analyzing the data. In the past, orthogonal arrays were known as ‘magic squares’ Perhaps the effectiveness of orthogonal arrays in experimental design is magic. What is an orthogonal array?

An orthogonal array is a fractional factorial matrix which assures a balanced comparison of levels of any factor or interaction of factors. It is a matrix of numbers arranged in rows and columns where each row represents the level of the factors in each run, and each column represents a specific factor that can be changed from each run. The array is called orthogonal because all columns all columns can be evaluated independently of one another.

There are 18 orthogonal array tables in the catalogue of Taguchi, these being denoted by LN(sk) or just by LN. Here, LN(sk) is a matrix with dimension N× k, s distinct elements and the property that every pair of columns contains all possible s2 ordered pairs of elements with the same frequency. In particular, N is the number of rows and k the number of columns in the orthogonal array. Elements of an orthogonal array can be numbers, symbols or letters.

IV. SALIENT FEATURES OF TAGUCHI METHOD

1. A popular off-line quality control method aiming to reduce variability in a process and the number of experimental runs required to gather necessary data.

2. A simple, efficient and systematic method to optimize product or process to improve the performance or reduce the cost.

3. It helps to arrive at the best parameters for the optimal conditions with the least number of analytical investigations.

4. It is a scientifically disciplined mechanism for evaluating and implementing improvements in products, processes, materials, equipments and facilities. Therefore, the Taguchi method has great potential in the area of low cost experimentation. Thus it becomes an attractive and widely accepted tool to engineers and scientists

4.1Steps in Taguchi based Experiment

4.1.1Definition of the problem

The statement of the problem is “Optimization of Die Casting Process parameters to identify the optimized levels for improving cycle time using Taguchi Methods for DOE.”

4.1.2 Selection of response variables

The recovery rate of Cycle time is the “Smaller the better” type of quality characteristic

4.1.3 Selection of process parameters and their levels

1. Injection Pressure
2. Plunger Speed
3. Melting temperature
4. Cooling time

4.1.4 Various process parameters and their identified levels table.

Level	Melt temp, deg c	Inj Press, bar	Plunger speed, m/s	Cooling phase, sec
1	690	800	2	8
2	694	840	3	9
3	700	900	4	11

4.1.5 Selection of an orthogonal array

The number of levels for each control parameter defines the experimental region. We have four parameters at three different levels, from the table we has selected L9 orthogonal array for the experimentation.

V. ANALYSIS AND EXPERIMENTATION

5.1 Experimental Machine setup & Product

Fig 5.1 show experimental setup of machine that is R38 hot chamber die-casting machine having Tank Capacity: 200L, Weight of machine: 3000kg, Overall dimension: 3000X1050x1550 on which different die-casting process is carried out.

Fig. 5.1.R38 Hot chamber die-casting machine

Fig 5.2 Shows ALSI 132 handle cover that is die-casting product on which L9 experiments are performed for four different process parameters value to calculate cycle time value which is response factor.

Fig.5.2.ALSI 132 Handle cover

5.2 Taguchi Analysis on MINITAB 15

5.2.1 Create Taguchi Design on MINITAB 15

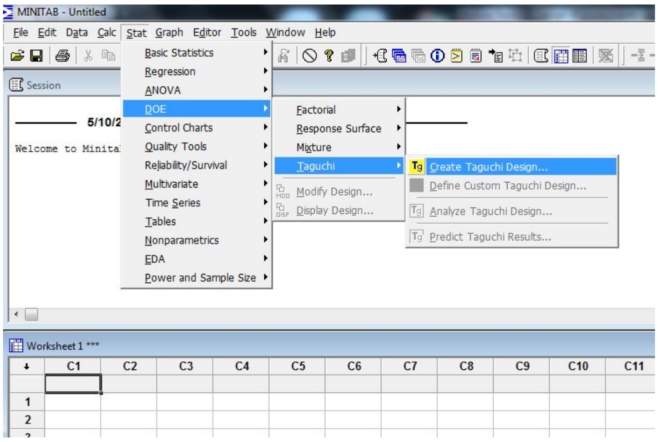


Fig.5.3. Taguchi Design

5.2.2 Selection of Available Design

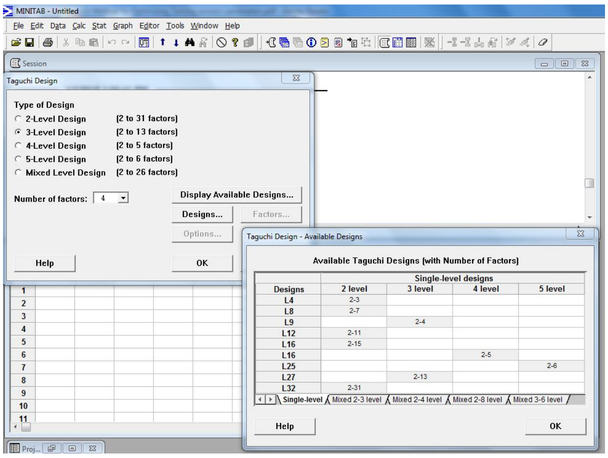


Fig.5.4.Three level type design

5.2.3 Selection of Taguchi Design

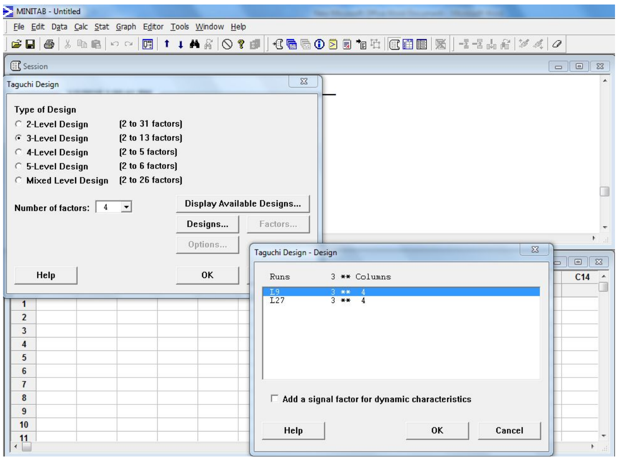


Fig.5.5. L9 orthogonal array

5.2.4 Click on Factors and write name of factors and levels of factors at desired place. Then press ok as Shown in

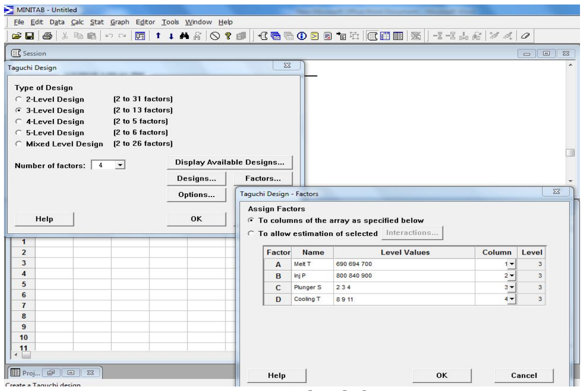
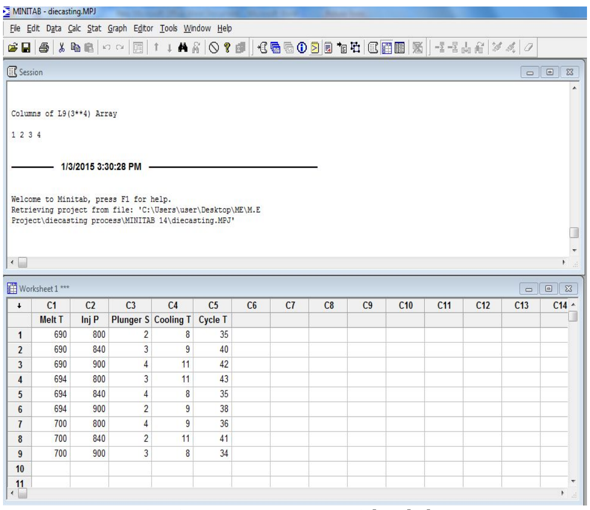


Fig.5.5. Factors & level chart

5.2.5 Experiments are performed according to the Selected Design of experiment. When experiment is Performed cycle time is calculated as given in table below.



	C1 Melt T	C2 Inj P	C3 Plunger S	C4 Cooling T	C5 Cycle T
1	690	800	2	8	35
2	690	840	3	9	40
3	690	900	4	11	42
4	694	800	3	11	43
5	694	840	4	8	35
6	694	900	2	9	38
7	700	800	4	9	36
8	700	840	2	11	41
9	700	900	3	8	34

Fig.5.6. L9 Process parameters 9 level chart

5.2.6 Finally press ok in window analyses Taguchi design. Graphs and SN ratio is generated as shown

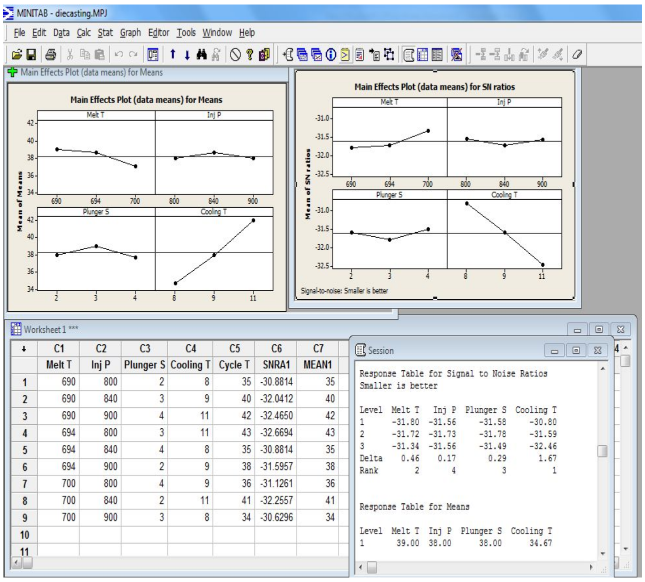


Fig.5.7. Result table

5.2.7 Experimental Response table for SN ratio & Means

Taguchi Analysis: Cycle time, versus Melt temp,de, Inj Press, b, ...

Response Table for Signal to Noise Ratios
Smaller is better

Level	Melt temp,deg c	Inj Press, bar	Plunger speed,m/s	Cooling phase,sec
1	-31.80	-31.56	-31.58	-30.80
2	-31.72	-31.73	-31.78	-31.59
3	-31.34	-31.56	-31.49	-32.46
Delta	0.46	0.17	0.29	1.67
Rank	2	4	3	1

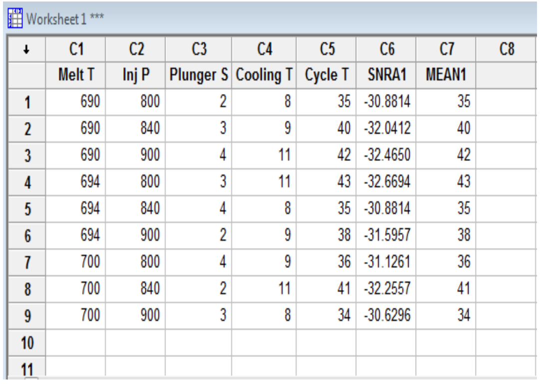
Response Table for Means

Level	Melt temp,deg c	Inj Press, bar	Plunger speed,m/s	Cooling phase,sec
1	39.00	38.00	38.00	34.67
2	38.67	38.67	39.00	38.00
3	37.00	38.00	37.67	42.00
Delta	2.00	0.67	1.33	7.33
Rank	2	4	3	1

Fig.5.8. Response table for SN ratio & Means

From the values of delta Melting temp, Injection Pressure, Plunger Speed, cooling phase we can conclude that cooling phase is most affected parameter as compared to Melting temp, Injection pressure, Plunger speed.

5.2.8 Chart shows the optimum solution of the given set of parameters is given by the value having SN ratio is largest i.e. -30.6296



Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8
	Melt T	Inj P	Plunger S	Cooling T	Cycle T	SNRA1	MEAN1	
1	690	800	2	8	35	-30.8814	35	
2	690	840	3	9	40	-32.0412	40	
3	690	900	4	11	42	-32.4650	42	
4	694	800	3	11	43	-32.6694	43	
5	694	840	4	8	35	-30.8814	35	
6	694	900	2	9	38	-31.5957	38	
7	700	800	4	9	36	-31.1261	36	
8	700	840	2	11	41	-32.2557	41	
9	700	900	3	8	34	-30.6296	34	
10								
11								

Fig.5.9. Optimum solution

Applying DOE using Taguchi optimized level has been found out with particular combinations for cycle time.

Table 5.1.DOE result table

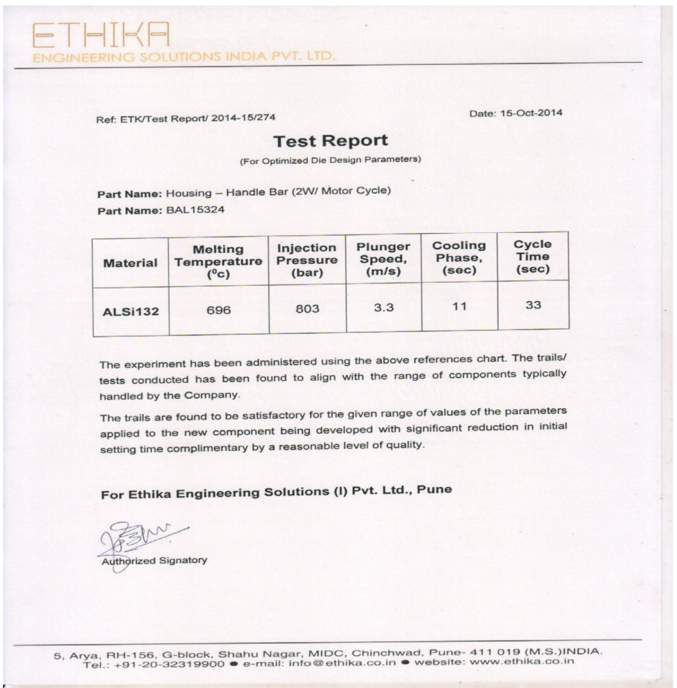
Melt. Temp	Inj Pre	Plung Speed	Cool Time	Cycle Time	SNR	Mean
700	900	3	8	34	-30.629	34

5.3 Experimentation Result

Table 5.2.Experimental result table

Melt. Temp	Inj Pre	Plung Speed	Cool Time	Cycle Time	SNR	Mean
700	900	3	8	34	-30.629	34

Experiment has been administrated on Part name-Housing handle-Bar(2W/motor cycle) Part name BAL 15324 using the above reference chart trial are found to be satisfactory for the given range value of parameters with significant reduction in initial setting time complimentary to reasonable quality of product.



ETHIKA
ENGINEERING SOLUTIONS INDIA PVT. LTD.

Ref: ETK/Test Report/ 2014-15/274

Date: 15-Oct-2014

Test Report

(For Optimized Die Design Parameters)

Part Name: Housing – Handle Bar (2W/ Motor Cycle)
Part Name: BAL15324

Material	Melting Temperature (°c)	Injection Pressure (bar)	Plunger Speed, (m/s)	Cooling Phase, (sec)	Cycle Time (sec)
ALSi132	696	803	3.3	11	33

The experiment has been administered using the above references chart. The trails/ tests conducted has been found to align with the range of components typically handled by the Company.

The trails are found to be satisfactory for the given range of values of the parameters applied to the new component being developed with significant reduction in initial setting time complimentary by a reasonable level of quality.

For Ethika Engineering Solutions (I) Pvt. Ltd., Pune

Authorized Signatory

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Fig.5.10. L9 Test report

VI. VALIDATION

The experiment has been administrated using the above reference chart. The test conducted has been found to align with the range of components typically handled by company. The trials are found to be satisfactory for the given range of values of the parameters applied to the new component being developed with significant reduction in initial setting time complimentary by a reasonable level of quality. The hypothesis shall be validated by producing the component per the results determined by the Analytical method (DOE/ Taguchi Methods) without adversely affecting the quality norms. Visual inspection will be done while attempting to identify the defects. Process validation of Die is effected through trial lot production of defect-free components with the needful attributes for physical appearance and/or properties.

VII. CONCLUSIONS

The Taguchi's approach has been carried out for optimizing the parameters of die-casting process. Four input parameters have been optimized using SNR. The smaller-the-better quality characteristic has been used for minimizing the Cycle time. An L9 orthogonal array with four parameters and three levels has been used for predict set of parameter which gives value of predicated Cycle time. 9 numbers of experiments were done for those sets of parameters. Experimental values of performance were put in the Minitab software14 and software predicated Cycle time is 34 for set of Melting Temp 700 deg C, Inj Pres 900 bar, Plunger speed 3m/s & Cooling time 8 sec. This suggested set of parameter which gives optimum performance of porosity. Validation experiment was done for that set of parameter and compared with predicated value. This experimental value of % of porosity is very closer to the predicated values. Result obtained from validation experiments using optimum parameter combination gives excellent agreement with predicated results. The performance of the optimized model is better than the original model and also prove that taguchi parameter design concept is more powerful and efficient tool for minimize the cycle time.

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