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IDENTIFYING OPTIMIZED LEVELS FOR THE PROCESSING FACTORS OF THERMOPLASTIC ABS TO REDUCE CYCLE TIME FOR INJECTION MOLDING

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ABSTRACT

Injection molding is the most widely used polymeric fabrication process. It evolved from metal die casting, however, unlike molten metals; polymer melts have a high viscosity and cannot simply be poured into a mould. Instead a large force must be used to inject the polymer into the hollow mould cavity. More melt must also be packed into the mould during solidification to avoid shrinkage in the mould. The injection molding process is primarily a sequential operation that results in the transformation of plastic pellets into a molded part. Identical parts are produced through a cyclic process involving the melting of a pellet or powder resin followed by the injection of the polymer melt into the hollow mould cavity under high pressure. Accuracy and quality are the first need of customers that must be fulfilled by offering high quality products. The different process parameters like Melt temperature, holding time, injection pressure, holding pressure, rate of cooling, velocity of flow of molten plastic etc., need to be set correctly in order to get desired quality at optimum cycle time. For injection molding process, there are various techniques by which we can improve the quality of product. In my dissertation work I am going to optimize the process parameters by using analytical methods i.e.-Statistical modeling for historical data, for the same I got sponsorship from Able Technologies (India)Pvt. Ltd. and new case study is considered. Initially using Taguchi method, Design of Experimentation (DOE) performed, for this Minitab software is used for arriving at the optimum level for the factors. Finally the results obtained by DOE have been used as input parameters for the machine and component is produced according to input parameters, then for getting optimum value, each parameter is varied from set value to its minimum value by keeping other parameters to its constant value, simultaneously component is checked quality. Such practice can be developed for developing new component simply by referring historical data of similar components. Minimum or optimum value is the second last value at which we get defect free part. The same procedure is repeated for other parameters for getting their optimum values. Finally the results obtained by analytical and experimentation found good agreement with least deviations.

KEYWORDS: *ABS, Injection molding, Design of Experimentation*.

I. INTRODUCTION

Increasing the productivity and the quality of the plastic injected parts are the main challenges of plastic based industries, so there has been increased interest in the monitoring all aspects of the plastic injection molding parameters. Most production engineers have been using trial- and-error method to determine initial settings for a number of parameters, including melt temperature, injection pressure, injection velocity, injection time, packing pressure, packing time, cooling temperature, and cooling time which depend on the engineers' experience and intuition to determine initial process parameter settings. However, the trial-and-error process is costly and time consuming. Chang et al [1] studied the relationship between input process parameters for injection molded Dogbone bar and outputs as weld line width and tensile impact using Taguchi method. He considered 7 input parameters such as melt and mold temperatures, injection and hold pressures, cooling and holding times, and back pressure and found that the melt and mold temperature, injection pressure, and holding time are the most effective, while hold pressure, holding time and back pressure are least important parameter. Loera et al [2] introduced a concept for deliberately varying the wall thicknesses of an injection molded part within recommended dimensional tolerance to reduce part warpage using Taguchi method. From the results, it is seen that varying wall thicknesses exhibited better warpage characteristics compared to the constant wall thicknesses. Wen-ChinChen et al [3] in this research Taguchi method, back-propagation neural networks (BPNN), and Genetic algorithms (GA) are applied to the problem of process parameter settings for Multiple-Input Single-Output (MISO) Plastic injection molding. Taguchi method is adopted to arrange the number of experimental runs. Injection time, velocity pressure switch position, packing pressure, and injection velocity are engaged as process control parameters, and product weight as the target quality. Then, BPNN and GA are applied for searching the final optimal parameter settings. Olivier de Weck, Pedro Saraiva, and José Cabral Struct studied that the design of injection molding systems for plastic parts relies heavily on experience and intuition. Recently, mold makers have been compelled to shorten lead times, reduce costs and improve process performance due to global competition. They have studied that, recently mold makers have been compelled to shorten lead times, reduce costs and improve process performance due to global competition. In this paper a framework, based on a Multidisciplinary Design Optimization (MDO) methodology, which tackles the design of an injection mold by integrating the structural, feeding, ejection and heat-exchange sub-systems to achieve significant improvements. To validate it single objective optimization is presented leading to a 42% reduction in cycle time. They also perform multiple objective optimization simultaneously minimizing cycle time, wasted material and pressure drop [4].P.K. Bharti et.al.[5] have studied that a number of research works based on various approaches including mathematical model, Taguchi technique ,Artificial Neural Networks (ANN), Fuzzy logic, Case Based Reasoning (CBR), Genetic Algorithms (GA), Finite Element Method(FEM), Non Linear Modeling, Response Surface Methodology, Linear Regression Analysis, Grey Rational Analysis and Principle Component Analysis using cavity pressure signals have been described. A review of literature on optimization techniques has revealed that there are, in particular, successful industrial applications of design of experiment-based approaches for optimal settings of process variables. Taguchi methods and response surface methodology are robust design techniques widely used in industries for making the product/process insensitive to any uncontrollable factors such as environmental variables. Taguchi approach has potential for savings in experimental time and cost on product or process development and quality improvement [5]. Mohd. Muktar Alam, Deepak Kumar [6] have revealed that injection moulding has been a challenging process for many plastic components manufacturers and researchers to produce plastics products meeting the requirements at very economical cost. Since there is global competition in injection moulding industry, so using trial and error approach to determine process parameters for injection moulding is no longer hold good enough. Since plastic is widely used polymer due to its high production rate, low cost and capability to produce intricate parts with high precision. It is much difficult to set optimal process parameter levels which may cause defects in articles, such as shrinkage, warpage, line defects. Determining optimal process parameter setting critically influences productivity, quality and cost of production in plastic injection moulding (PIM) industry. In this paper optimal injection moulding condition for minimum shrinkage were determined by the DOE technique of Taguchi methods. The various observation has been taken for material namely Polypropylene (PP). The determination of optimal process parameters were based on S/N ratios [6].Alireza Akbarzadeh and Mohammad Sadeghi [7] have studied Parameter in Plastic Injection Molding Process using Statistical Methods and IWO Algorithm. They studied that Dimensional changes because of shrinkage is one of the most important problems in production of plastic parts using injection molding. They also investigated the effect of injection molding parameters on the shrinkage in polypropylene (PP) and polystyrene (PS). The relationship between input and output of the process is studied using regression method and Analysis of Variance (ANOVA) technique. The selected input parameters are melting temperature, injection pressure, packing pressure and packing time. Effect of these parameters on the shrinkage of above mentioned materials is studied using mathematical modeling. For modeling the process, different types of

regression equations including linear polynomial, Quadratic polynomial and logarithmic function, are used to interpolate experiment data [7].
[8] James Henderson, Aaron K. Ball, James Z. Zhang have studied that Optimizing the parameters of the injection molding machine is critical to improve manufacturing processes. Their research focuses on the optimization of injection molding machine parameters using one material. They suggested that, process improvements are made based on the results of a designed experiment. Companies that use injection molding machines will have a need for optimizing the machine to decrease cycle time and increase profits. Having a process that is efficient is necessary in this world market to compete with world class companies. Cutting down the cycle time for each part is a major concern with the injection molding machine. Using a design of Experiments (DOE) has proven to be a major tool in discovering which parameters and interactions are significant to further improve an injection molding process. As proven here the only significant parameter was cooling time and it was the only parameter that had any major effect on the overall cycle time. Mini Tab and Excel would be a more effective way to do a statistical analysis on the injection molding machine when the designed experiment has increased the parameters and therefore increased the data involved in the analysis. Using these software packages could help engineers statistically analyze other manufacturing processes which may include high speed machining, pharmaceutical products, and electronic components to decrease cycle time or to even improve quality.[9]Mohammad Saleh Meiabadia,*, Abbas Vafaeesefatb, Fatemeh Sharific have conclude that plastic injection molding is one of the well-known manufacturing techniques that should be able to produce complex- shaped and large-sized products in short time at low cost. To avoid the high costs and time delays associated with problems discovered at the start of manufacturing, it is necessary to consider the combined effects of part geometry, material characteristics, mold design and processing conditions on the manufacturability of a part. Final optimal process parameter setting are recognized as one of the most important steps in injection molding for improving the quality of molded products. Since the quality of injection molded plastic parts are mostly influenced by process conditions, how to determine the optimum process parameters becomes the key to improving the part quality. Previously, production engineers used trial-and-error or Taguchi's parameter design method to determine optimal process parameters setting for plastic injection molding. Trial-and-error method is costly and time consuming. Besides, the optimum process parameters may not be achievable by this method. They have one the optimization of the process parameters by ANN and Genetic Algorithm. [10] Wen-Chin Chen and Shi-Bo Lin have used BPNN and GA for optimization of the process parameters of PIM. They concluded that Determination of optimal process parameter settings is acritical work that influences the capacity, quality, and cost of product manufacture. Engineers have conventionally used trial-and-error processes or Taguchi's process parameter design method to determine the final optimal process parameter settings. However, the application of these methods has some shortcomings and may cause engineers to make undesirable final optimal process parameter settings. This research proposes an effective process parameter optimization approach that integrates Taguchi's parameter design method, back-propagation neural network, genetic algorithms, and engineering optimization concepts. The proposed approach can effectively solve the flaw in the Taguchi method, which yields the global optimum while utilizing genetic algorithm to break away from local optimum.

II. METHODOLOGY

2.1 Statistical analysis-

There are various techniques to analyze and solve work related problems. They are usually recognized as "BASIC PROBLEM SOLVING TECHNIQUES". Every technique has its own merit and demerit. The members of quality circle need to be trained in the application of these techniques. In this work, an experimental DOE (design of experiments) methodology was used for optimizing process parameters of die casting process.

2.1.1 Concept of design of experimentation (DOE) –

DOE is a systematic approach to investigation of a system or process. A series of structured tests are designed in which planned changes are made to the input variables of a process or system. The effects of these changes on a pre-defined output are then assessed. The experimental design is the manner in which the researcher randomly assigns the treatment to the experimental units. DOE is important as a formal way of maximizing information gained while minimizing resources required. It has more to offer than 'one change at a time' in an experimental method.

A designed experiment is extremely helpful in discovering the key variables influencing the quality characteristics of interest in the process. A designed experiment is an approach to systematically varying the controllable input factors in the process and determining the effect these factors have on the output product parameters. Statistically designed experiments are invaluable in reducing the variability in the quality characteristics and in determining the levels of the controllable variables that optimize process performance and product quality also result from using designed experiment. Designed experiments are a major off line quality control tool, because they are often used during development activities and early stages of manufacturing, rather than as a routine on line or in process procedure. They play a crucial role in reducing variability. Following are the steps for performing DOE,

- Choosing appropriate responses (output variables).
- Choosing appropriate factors (input variables).
- Setting appropriate factor ranges or levels.
- Creating documentation for the experiment.
- Managing the experiment as it takes place.
- Reporting and presenting results (ANOVA).
- Decision Making.

2.2 Historical study-

Initially similar parts of same material, size and shapes, which are produced on the same machine, are observed and their process parameters studied in detail. From the group of observed parts, two parts found similar in shape i.e. –1) Housing retainer and 2) Flexicap, then their process parameters observed and studied carefully. Then their actual readings of process parameters were recorded after certain interval of time (10 min.) during their actual production and found in the following range and finally the mean readings of melting temperature, injection pressure and plunger velocity are calculated for further reference, which are shown in the tables.

2.2.1 Housing Retainer –

- Material – Acrylonitrile Butadiene styrene (ABS)
- Melting temperature- 200^0C.
- Composition-

Table 1: Percentage of individual alloying elements.

Acrylonitrile	Butadiene	Styrene
15-35%	5-30%	40-60%

Fig.1: Housing Retainer

Table 2: Input process parameters.

Melt temp in deg c	Injection Press in bar	Hold press in bar	Cool Time in sec	Remark
224	77	48	35	Ok
224	77	48	35	Ok
225	78	48	35	Ok
225	78	48	35	Ok
226	78	48	35	Ok
226	79	48	35	Ok

- Mean input process parameters for Housing Retainer - .

Table 3: Input process parameters

Melt temp. in deg c	Injection Press.in bar	Hold press.in bar	Cool Time in sec
225	78	48	35

2.2.2 Flexi Cap –

- Material – Acrylonitrile Butadiene styrene (ABS)
- Melting temperature- 200^{0}C.
- Composition-

Table 4: Percentage of individual alloying elements.

Acrylonitrile	Butadiene	Styrene
15-35%	5-30%	40-60%

Fig.2: Flexi Cap

Table 5: Input process parameters.

Melt temp in deg c	Injection Press in bar	Hold press in bar	CoolTime in sec
220	75	46	33
220	76	46	33
221	76	46	34
221	77	46	34
220	76	46	33
220	76	46	33

- Mean input process parameters for Flexi Cap–

Table 6: Input process parameters.

Melt temp. in deg c	Injection Press. in bar	Hold press. in bar	Cool Time in sec
220	76	46	33

By referring the mean readings for both parts, it can be concluded that the range of process parameters available for my case study would lie nearer to these readings. For the same, range for each parameter is decided and Design of experimentation (DOE) performed by using Minitab software.
The following table shows, the optimum solution for given set of parameters is given by value having maximum SN ratio i.e.: -33.2552

Table 7: Input process parameters for Tray Adapter.

Melt temp in deg c	**Inj Press in bar**	**Hold press in bar**	**Cool Time in sec**	**Cycle Time, sec**	**SN ratio**	**Mean**
217	74	44	30	54	-34.6479	54
217	76	46	33	53	-34.4855	53
217	80	48	35	52	-33.9794	50
220	74	46	35	50	-33.9794	50
220	76	48	30	51	-34.1514	51
220	80	44	33	50	-33.9794	50
226	74	48	33	48	-33.8039	49
226	76	44	35	47	-33.4420	47
226	**80**	**46**	**30**	**46**	**-33.2552**	**46**

2.3 Taguchi analysis-

The ranking shows that melt temp plays very imp role, then followed by Melt temp, injection pressure, holding pressure, cooling time parameter.

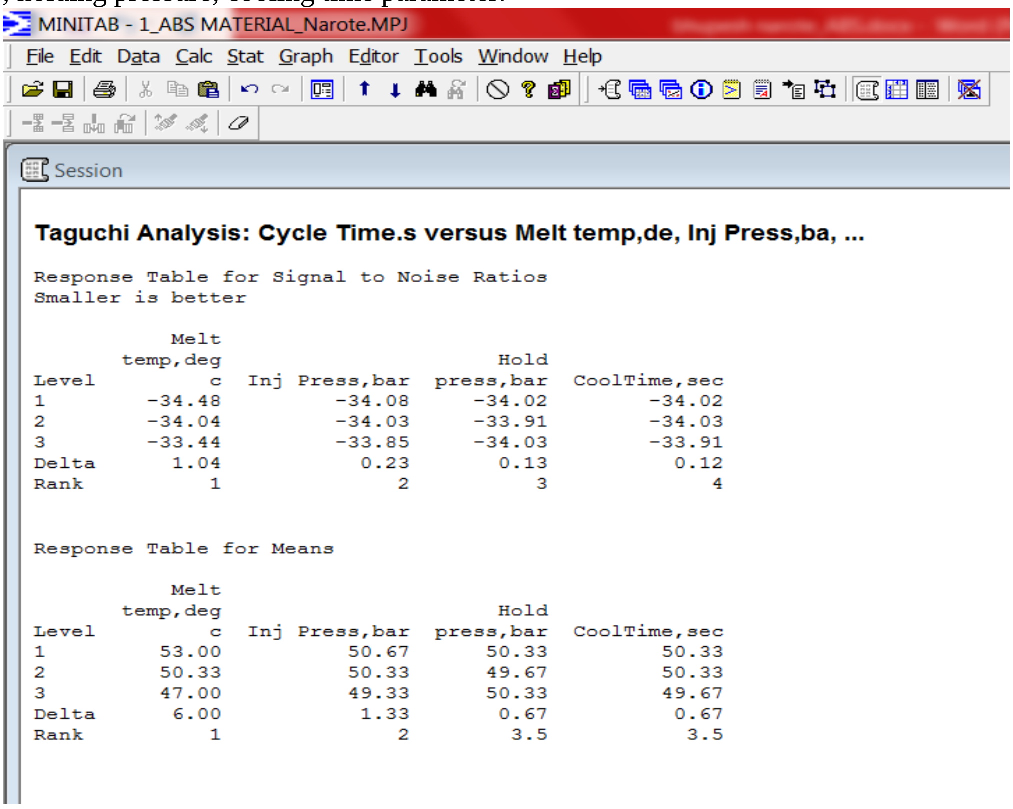

Fig.3: Taguchi analysis.

2.4 Regression analysis-

After carrying out DOE analysis, the software gives best possible values of coefficients for given set of parameters. From the given set best one selected on the basis of minimum cycle time. After solving four equations by taking related constants from each set, the cycle time for equation no-1 is minimum i.e.- **55.53481**, as compared to remaining three equations. So parameters or constant from set can be used for forming regression equation of best fit.

- **215.29-0.65079*224-0.22619*77+0.0000*45-0.1228*28= 55.53481 ------ (1).**
- 17.82+0.06433*224+0.09649*77+0.1474*45+0.1171*28= 60.57145------ (2).
- 12.08-10.12*224-2.34*77+0.00*45-1.05*28= -2464.38------(3).
- 0.00+0.001*224+0.079*77+1.000*45+0.354*28= 61.219------(4).

Regression Analysis: Cycle Time.s versus Melt temp,de, Inj Press,ba, ...

```
The regression equation is
Cycle Time.sec = 215 - 0.651 Melt temp,deg c - 0.226 Inj Press,bar
                 + 0.000 Hold press,bar - 0.123 CoolTime,sec


Predictor             Coef  SE Coef      T      P
Constant            215.29    17.82  12.08  0.000
Melt temp,deg c   -0.65079  0.06433 -10.12  0.001
Inj Press,bar     -0.22619  0.09649  -2.34  0.079
Hold press,bar      0.0000   0.1474   0.00  1.000
CoolTime,sec       -0.1228   0.1171  -1.05  0.354


S = 0.722086   R-Sq = 96.5%   R-Sq(adj) = 92.9%


Analysis of Variance

Source          DF      SS      MS      F      P
Regression       4  56.803  14.201  27.24  0.004
Residual Error   4   2.086   0.521
Total            8  58.889
```

Fig.4: Regression analysis.

2.5 Graphical analysis-

Graph of process parameters Vs SN ratio, which shows that the nature of graph is straight line up to midpoint, but as the line crosses this point, suddenly line changes its slope. The point at which line changes its slope by this we can conclude that, the optimum range for all process parameters lies in between start and end points of that graphs. In order to get optimum level for all parameters then variation is expected to be done in between start and end points ‘, which is shown in the graph on next page.

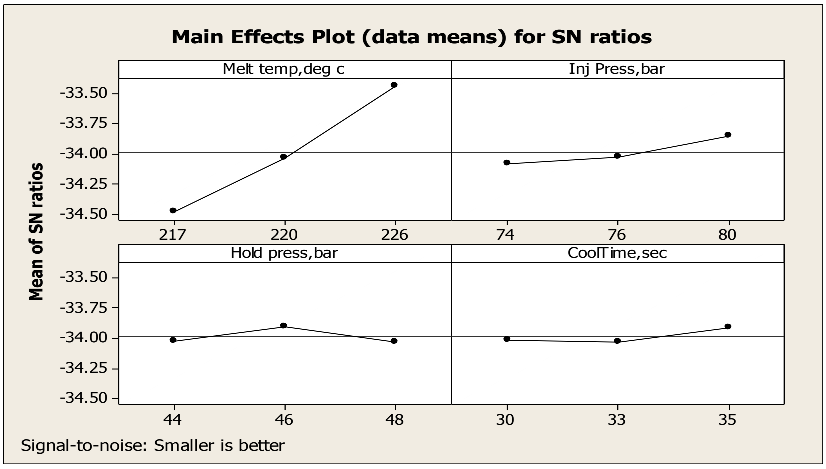

Fig.5: Graph of process parameters Vs SN ratio.

Similarly graph of process parameters Vs mean, which shows that the nature of graph is straight line up to midpoint, but as the line crosses this point, suddenly line changes its slope. The point at which line changes its slope by this we can conclude that, the optimum range for all process parameters lies in between start and end points of that graphs. In order to get optimum level for all parameters then variation is expected to be done in between start and end points ', which is shown in the below graph.

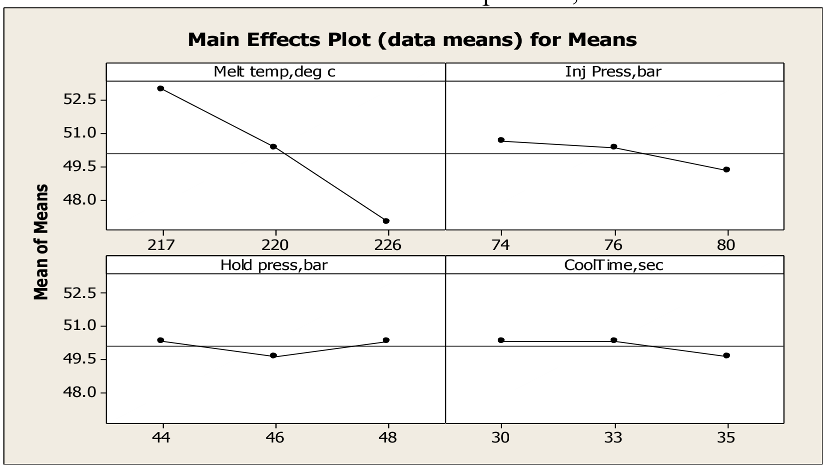

Fig.6: Graph of process parameters Vs Mean.

The SN ratios graph states the steep slope in melt temperature when compared to injection pressure, holding pressure, cooling time.

III. EXPERIMENTAL WORK

After completing the analytical method, the results achieved by design of experiment (DOE) are used as input for experimentation. For the same experimental set up is made ready and a injection moulding machine of De-Tech 100 LNC 4E of100ton capacity is selected. On the same machine mould for tray adapter is fitted. Before running the machine, it is necessary to understand the effect of individual parameter on cycle time, for the same Taguchi analysis is referred, which shows that melt temperature can greatly minimize the cycle time, then followed by injection pressure, holding pressure and cooling time. The optimum parameters obtained by DOE are set as input for machine, which are shown in the following table.

Table 8: Input process parameters for Trey Adapter.

Melt temp. in deg c	Injection Press. in bar	Hold press. in bar	Cool Time in sec
226	78	45	28

At initial stage of trial with given set of parameters the actual component produced, but it did not give the desired quality because its dimensions got oversized due to minute expansion of mould because of excess pressure and surface of moulded part had small holes due to excess plunger velocity. Then the parameters which are responsible for formation of such defects have been randomly changed by using our past experience and again trial conducted for second time and finally we got Ok component.

3.1. Case study details-

- **Name of component-**Trey Adapter.
- **Material** – ABS.
- **Composition-**

Table 9: Percentage of individual alloying elements.

Acrylonitrile	Butadiene	Styrene
15-35%	5-30%	40-60%

Fig.8: Tray Adapter

- **Type of machine and its tonnage-** De-Tech 100 LNC 4E (100 ton)
- **No. of cavities-** Two.

3.2. Experimental results

The randomly changed parameters cannot be assumed to be optimum. So all parameters which affect the cycle time are varied from set value to its minimum/maximum value by keeping other parameters to its constant value during actual experimentation. Minimum/Maximum or optimum value is the second last value at which we get defect free casting. While doing it so casting is checked for quality.

By referring Taguchi analysis, which shows that melt temperature can greatly minimize the cycle time, then followed by injection pressure, plunger velocity and cooling time and accordingly process parameters are varied as per their rank. For safer side and for avoiding defects, values of few process parameters are kept at lower side. The optimum results obtained for all process parameters are shown in the following different tables.

According to Taguchi analysis, melt temperature is the major parameter for which greater attention is required to be paid for reducing cycle time. According to graph of melt temperature Vs SN ratios and melt temperature Vs mean, which show that the nature of graph is straight line up to 220^{0}C and suddenly line changes its slope as it crosses this temperature. The point at which line changes its slope by this we can conclude that, the optimum range for melt temperature lies nearer in between 215to226^{0}C. So variation of melt temperature is expected to be done from 215 to226^{0}C. In both graphs line starts at 215^{0}C and ends at 226^{0}C, but in actual practice while selecting range instead of taking 215^{0}C as a starting range, temperature variation is done from 215 to 226^{0}C, because if we take 215^{0}C as a starting point and if moulding is produced accordingly and if it found to be ok, then the temperature 215^{0}C may not be assumed to be optimum, there may be changes that optimum level for melt temperature could be 224^{0}C or 226^{0}C. So for this reason 229^{0}C is taken as starting range for variation of melt temperature. The temperature 223^{0}C is the extreme last range, because under this temperature fluidity of plastic starts to get affected due to fall in temperature. Similarly, by referring both graphs for temperature, then variation is done in between start and end point. In this way optimum value for temperature is obtained.

Table 10: Optimum temperature reading.

Melt temperature in ^{0}C.	Injection pressure in bar.	Holding pressure in bar.	Cooling time in sec.	Defect	Remark
229	70	41	31	-----	Ok
228	70	41	31	-----	Ok
227	70	41	31	-----	Ok
226	70	41	31	-----	Ok
225	70	41	31	-----	Ok
224	70	41	31		Ok
223	70	41	31	Incomplete filling of mould cavity	Not ok

Above table shows **225^{0}C** is the optimum temperature reading for tray adapter.

Similarly for injection pressure, according to graph of injection pressure Vs SN ratios and injection pressure Vs mean, which show that the nature of graph is straight line up to 76bar and suddenly line changes its slope as it crosses this pressure. The point at which line changes its slope by this we can conclude that, the optimum range for injection pressure lies in between 74-80 bar. But in actual practice usually a lower value say 72bar or 74bar is selected for safer side and during experimentation 72bar is taken as starting range. The optimum value for the same is obtained in the following way.

Table 11: Optimum injection pressure reading.

Melt temperature in ^{0}C.	Injection pressure in bar.	Holding pressure in bar.	Cooling time in sec.	Defect	Remark
224	72	41	31	-----	Ok
224	73	41	31	-----	Ok
224	74	41	31	-----	Ok
224	75	41	31	-----	Ok
224	76	41	31	-----	Ok
224	**77**	41	31	-----	Ok
224	78	41	31	-----	Ok
224	79	41	31	Excess pr.,flash	Not ok

Above table shows **77bar** is the optimum injection pressure reading for tray adapter.

Similarly for holding pressure, according to graph of holding pressure Vs SN ratios and holding pressure Vs mean, which show that the nature of graph is straight line up to 46bar and suddenly line changes its slope.The point at which line changes its slope by this we can conclude that, the optimum range for holding pr. lies in between 44-46 bar. But in actual practice usually a lower value say 41bar is selected for start of variation during actual experimentation. The optimum value for the same is obtained in the following way.

Table 12: Optimum holding pressure reading.

Melt temperature in ^{0}C.	Injection pressure in bar.	Holding pressure in bar.	Cooling time in sec.	Defect	Remark
224	**77**	41	31	-----	Ok
224	**77**	42	31	-----	Ok
224	**77**	43	31	-----	Ok
224	**77**	44	31	-----	Ok
224	**77**	**45**	31	-----	Ok
224	**77**	46	31	-----	Ok
224	**77**	47	31	-----	Ok
224	**77**	48	31	-----	Ok

Above table shows **45bar** is the optimum holding pressure reading for tray adapter.

As holding pr. Does not affect moulded part so we can keep its value about 45 bar.

Similarly for cooling time, according to graph of cooling time Vs SN ratios and cooling time Vs mean, which show that the nature of graph is straight line up to 33 and suddenly line changes its slope as it crosses this cooling time. The point at which line changes its slope by this we can conclude that, the optimum range for cooling time lies in between 30-33 sec. But in actual practice usually a higher value say 33 sec is selected for ease of variation and avoiding defects. The optimum value for the same is obtained in the following way.

Table 13: Optimum cooling time reading.

Melt temperature in ^{0}C.	Injection pressure in bar.	Holding pressure in bar.	Cooling time in sec.	Defect	Remark
224	**77**	41	33	-----	Ok
224	**77**	41	32	-----	Ok
224	**77**	41	31	-----	Ok
224	**77**	41	30	-----	Ok
224	**77**	41	29	-----	Ok
224	**77**	41	**28**		Ok
224	**77**	41	27	shrinking	Not ok
224	**77**	41	27	shrinking	Not ok

Above table shows **28sec** is the optimum cooling time reading for case gear meter.

After getting the optimum readings for each parameters then by using similar set up cycle time is noted by using stop watch for given optimum readings, which is shown in the following table.

Table14: Cycle time for optimum process parameters.

Melt temperature in ^{0}C.	Injection pressure in bar.	Holding pressure in bar.	Cooling time in sec.	Cycle time in Sec.	Defect	Remark
224	**77**	41	28	**53.55**	-----	Ok
224	**77**	41	28	**54.02**	-----	Ok
224	**77**	41	28	**54.09**	-----	Ok
224	**77**	41	28	**53.57**	-----	Ok
224	**77**	41	28	**52.33**	-----	Ok
224	**77**	41	28	**54.22**	-----	Ok
224	**77**	41	28	**54.01**	-----	Ok

224	**77**	41	28	**53.03**	-----	Ok
224	**77**	41	28	**52.38**	-----	Ok
224	**77**	41	28	**53.57**	-----	Ok
224	**77**	41	28	**54.1**	-----	Ok
224	**77**	41	28	**54.36**	-----	Ok
224	**77**	41	28	**52.40**	-----	Ok
224	**77**	41	28	**52.02**	-----	Ok
224	**77**	41	28	**53.16**	-----	Ok
224	**77**	41	28	**53.21**	-----	Ok
224	**77**	41	28	**53.22**	-----	Ok
224	**77**	41	28	**52.06**	-----	Ok
224	**77**	41	28	**53.54**	-----	Ok
224	**77**	41	28	**53.6**	-----	Ok
Mean cycle time =				**53.322**		

IV. COMPARISON BETWEEN DOE AND EXPERIMENTAL RESULTS

Majorly DOE results are in agreement with the experimental results, within small deviation or difference. Each parameter has its own effect on cycle time as well as on die cast quality. If we referrer the following table we can state that values obtained by both techniques are almost closer to each other and the results of the two applied methods proved that the deviations are acceptable.

Table 15: DOE and Experimental results.

	Melt temperature in ^{0}C.	Injection pressure in bar.	Holding pressure in bar.	Cooling time in sec.	Cycle time in Sec.
DOE.	**226**	**80**	**46**	**30**	**46**
Experimentation.	224	**77**	41	28	53.55
Difference.	2(↓)	3(↓)	5(↓)	2(↓)	7.55(↑)
Percentage of increase/decrease.	0.885%	3.75%	8.69%	0.289%	16.41%

V. CONCLUSION

The conclusions drawn from the work carried out are as follows,

- Basically the quality of die casting depends upon its process parameters, which need to be determined and adjusted if needed, for getting better quality.
- The optimum cycle time in terms of the good quality of the injection moulding part were obtained by using the following optimum process parameters with Temperature= 224^{0}C, Injection pressure=77 bar, Holding pressure = 45 m/sec and cooling time= 28 sec.
- The four different criteria used to evaluate the optimum cycle time presented a good correlation among themselves.
- The results obtained by DOE are in agreement with the experimental results without affecting the quality of the injection moulded part.
- Comparison of the results of the two applied methods proved that the deviations are acceptable.
- The utilization of DOE methodology proved to be very efficient, in the analysis of this problem.

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