Optimization for Shrinkage Porosity on Aluminium Alloy ADC-12 Material

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Abstract— In this research paper we talk about various type process for pressure die casting like cold chamber die casting and hot chamber die casting and major problem occurred during process on aluminium alloy during process Casting defects are irregularities in the material that have a negative influence on the component; either it is caused from material failure, construction errors or as an effect of process parameters. Defects depend on several factors both in the material, for example the alloy, as well as the surrounding environment such as weather conditions. In the die casting industry today there are many cast defects like shrinkage, porosity and gas blow.
Key words: Pressure die casting, Cold chamber die casting, ultrasonic test

I. PRESSURE DIE CASTING

Die casting is a quick, reliable and cost-effective manufacturing process for production of high volume; metal components that are net-shaped have tight tolerances. Basically, the pressure die casting process consists of injecting under high pressure a molten metal alloy into a steel mold (or tool). This gets solidified rapidly (from milliseconds to a few seconds) to form a net shaped component. It is then automatically extracted. Depending upon the pressure used, there are two types of pressure die casting namely High Pressure Die Casting and Low Pressure Die Casting.

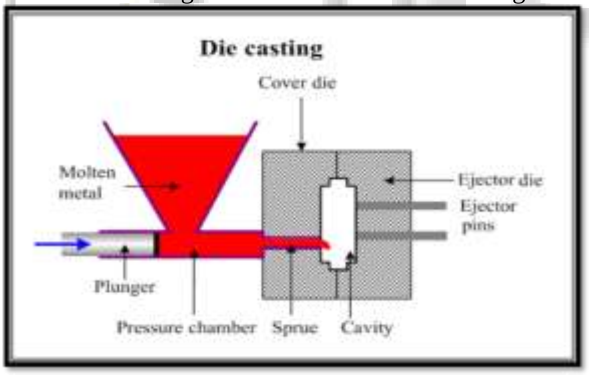

Fig. 1: Pressure die casting[1]

A. *Type of Pressure Casting*

thair are mainly two type of pressure die casting (1) hot chamber die casting (2) cold chamber die casting

1) *Hot Chamber Die Casting*

The workings of a hot chamber process goes like this. The molten metal for casting is placed in the holding furnace at the required temperature adjacent to(sometimes as part of the machine itself) the machine. The injection mechanism is placed within the holding furnace and most of its part is in constant touch with the molten metal. When pressure is transmitted by the injection piston, the metal is forced through the gooseneck into the die. On the return stroke, the metal is drawn towards the gooseneck for the next shot. This process ensures minimum contact between air and the metal to be injected. The tendency for entrainment of air in the metal during injection is also minimized. The hot-chamber process is applicable only for zinc and other low melting point alloys that does not affect and erode metal pots cylinders and plungers.

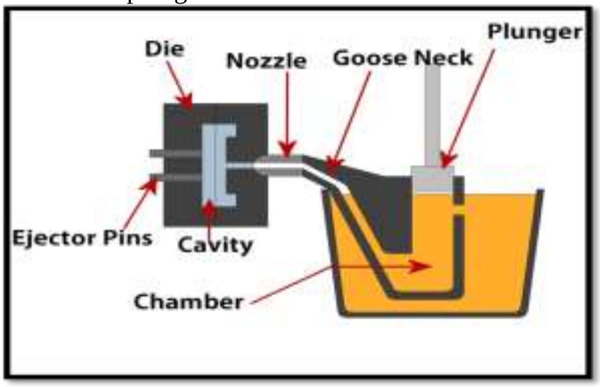

Fig. 2: Hot chamber die casting[2]

2) *Cold Chamber Die Casting*

The difference of this process with the hot-chamber process is that the injection system is not submerged in molten metal. On the contrary, metal gets transferred by ladle, manually or automatically, to the shot sleeve. The metal is pushed into the die by a hydraulically operated plunger. This process minimizes the contact time between the injector components and the molten metal. Which extends the life of the components, however the entrainment of air into the metal generally associated with high-speed injection can cause gas porosity in the castings. In the cold chamber machine, injection pressures over 10,000 psi or 70,000 KPa is obtainable. Generally steel castings along with aluminum and copper based alloys are produced by this method.

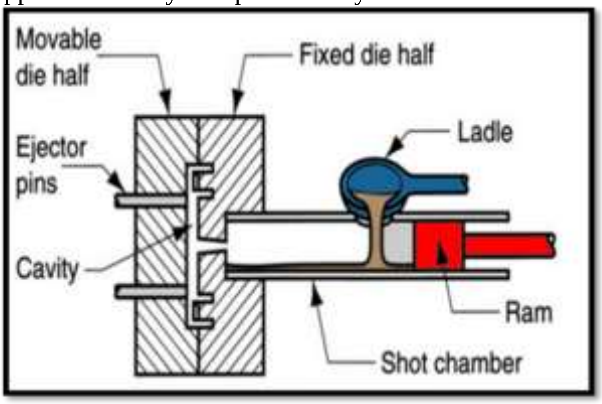

Fig. 3: Cold chamber die casting [2]

B. *Type of Defects on Pressure Die Casting*

In pressure die casting their is various kind of defects occurred in casting but their is main defects in pressure die casting is shrinkage, porosity and gas blow.

1) Shrinkages:

Shrinkage occurs during solidification as a result of volumetric differences between liquid and solid state. For most aluminum alloys, shrinkage during solidification is about 6% by volume. Lack of adequate feeding during casting process is the main reason for shrinkage defects. Shrinkage is a form of discontinuity that appears as dark spots on the radiograph.

Fig. 4: Shrinkage[3]

2) Porosity:

The main reason of gas holes and porosity defects is the trapped hydrogen gas in the molten metal during casting. Increase in hydrogen content will increase the porosity in the casting and the pore size Main factor of gas porosity during solidification is the dissolved hydrogen level in melts and it has to be avoided otherwise it will significantly decrease the mechanical and surface finish properties of the final casting product. When aluminum combines with the water vapor in the atmosphere hydrogen gas is released.

$$2Al+3H_2O=6H+ Al_2O_3$$

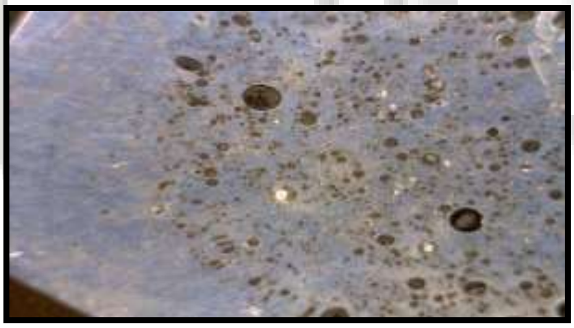

Fig. 5: Porosity [4]

3) Cracks:

Cracks are irregular shapes formed when the molten metal pulls itself apart while cooling in the mould or after removal from the mould. Hot tear occurs when the crack appears during the last stages of solidification .If hot tear occurs the crack faces are usually heavily oxidized. Hot tear commonly occur in metals and alloys that have a wide freezing range, and the isolated regions of liquid become subjected to thermal stresses during cooling and fracture results.

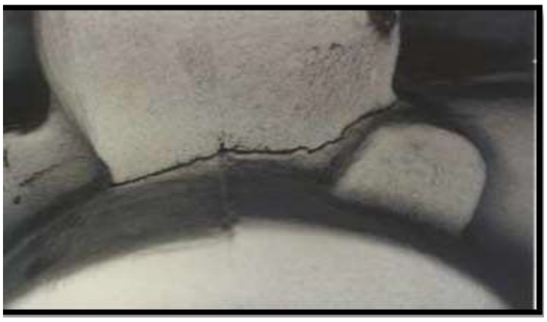

Fig. 6: Cracks [5]

II. LITERATURE REVIEW

S.J. swillo et al.(april 2013) presents a vision based approach and neural network techniques in surface defects inspection and categorization. Depending on part design and processing techniques, castings may develop surface discontinuities such as cracks and pores that greatly influence the material's properties, the developed vision system uses an advanced image processing algorithm based on modified Laplacian of Gaussian edge detection method and advanced lighting system. The defect inspection algorithm consists of several parameters that allow the user to specify the sensitivity level at which he can accept the defects in the casting advanced learning process has been developed, based on neural network techniques. Finally, as an example three groups of defects were investigated demonstrates automatic selection and categorization of the measured defects, such as blowholes, shrinkage porosity and shrinkage cavity.[6]

Z. Ignaszak et al.(jan-2015) concerns the problem of discontinuity in high pressure die castings (HPDC). The compactness of their structure is not perfect, the discontinuities present in these castings are the porosity as follow: shrinkage and gas (hydrogen and gas-air occlusions) origin. The mixed gas and shrinkage nature of porosity makes it difficult to identify and indicate the dominant source. The selected parameters of metallurgical quality of AlSi9Cu3 alloy before and after refining. This alloy was served to cast the test casting by HPDC method

1) The hydrogen concentration in the liquid alloy is possible to estimate using the "density index" - DI (solidification of test cup at 80mbar). DI factor for the well refined alloy should be less than 3.0 %. This guarantees the good metallurgical quality of alloy.
2) The most effective reduction of hydrogen content is possible by means of the rotor and argon blowing
3) In the high-pressure Die casting (HPDC) the degassed liquid Al-Si alloy does not ensure the complete elimination of gas porosity
4) The distribution of porosities depends on the turbulence of jet stream and free surface jet face. [7]

Mahesh N Adke et al.(dec-2014) 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 these 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.

Software predicated Cycle time is 34 for set of Melting Temp 700 deg C, Injection Pressure 900 bar, Plunger speed 3m/s & cooling time 8 sec. This suggested set of parameter which gives optimum performance of porosity.[8]

Javed Gulab Mulla et al.(march-2014) research that Die casting is a manufacturing process that can produce geometrically complex metal parts through the use of reusable moulds, called dies. 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, 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

Statistical Modeling for the historical data over factors and the levels, the software Minitab would be deployed for arriving at the optimized levels for the factors. The hypothesis shall be validated by producing the component as 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.[9]

Yoshihiko Hangai et al.(april-2014) In the die-casting process, the formation of pores in components is unavoidable. This porosity has a harmful effect on the strength and pressure tightness of die castings. To eliminate the porosity in components, its predominant cause has to be identified as being due to either shrinkage or gas. In practice, however, it is frequently difficult to tell the difference between porosity due to shrinkage and that due to gas from observing die castings. Accurate identification enables die casters to take corrective action. To identify the porosity accurately and to take corrective action in the die-casting process, the quantitative estimation of the morphology of pores such as their shape or spatial distribution can be a source of useful information. In this study, two types of fractal analyses are proposed to characterize the porosity in terms of the shape of individual pores and the spatial distribution of multiple pores

1) The distributions of Dp were significantly different in the surface region (gas-origin-rich pores) and inner region (pores of both origins). Therefore, Dp appears to be an indicator of the predominant cause of porosity formation, shrinkage or gas.
2) The relationship between the fractal dimension Dp and the cumulative frequency of porosity has a fractal nature.
3) It was shown that Dp s quantitatively expresses differences in the distribution of Dp Therefore, Dp appears to be an indicator of whether the predominant cause of porosity formation is shrinkage or gas. That is, Dp s indicates the extent of porosity formation due to shrinkage, and thus, the action that should be taken by die casters to manufacture pore-free die castings.[10]

Aneta Wilczek et al. (2015)find a new way of the image segmentation method for porosity detection in aluminum pressure die casting using results from X-ray analysis and public domain software is proposed. The results of the research allowed verifying the possibility of using the aforesaid methods in controlled technological parameters of the casting process, and thus permitted confirming the quality of the manufactured castings. It was found that the radiographic method was the most preferred means for evaluating the quality of products and for optimizing the technological process for aluminum pressure casting. It permits a fast analysis of casting defects in the finished products.

The proposed method can be widely applied through using public domain software. The great advantage of their research is the use of the radiographic method combined with computer image analysis (with the algorithm of porosity segmentation as described and presented in this paper) which allows detecting even the smallest casting defects. Moreover, the obtained results allow determining the causes of their formation. An analysis of the shape and size of the detected porosity allows carrying out a quality evaluation of the products and optimization of the technological process of production in an aluminum pressure foundry.[11]

Arvind Kumar Dixit et (aug-2014)al. Presently with the increasing use of Aluminium alloy wheels in automotive industry the Aluminium foundry industry had to focus on the quality of the products. The quality of a foundry industry can be increased by minimizing the casting defects during production. Casting defect analysis is carried out using techniques like historical data analysis, cause-effect diagrams, design of experiments and root cause analysis. The major defects for the rejections during production were identified as shrinkages, inclusions, porosity/gas holes and cracks.

The factors that influence the formation of shrinkage cavities are as follows

1) *Metal Quality*
   - Solidification range
   - Shrinkage during solidification
2) *Pouring Condition*
   - Pouring temperature
   - Rate of pouring
   - Feeding systems
3) *Die Condition*
   - Initial temperature of the die
   - Conductivity of the die
4) *Casting Parameter*
   - Thickness
   - Shape
5) *Factors Depending On the Molten Metal Quality*
   - Inclusion content[12]

Ferencz Peti et al.(jan-2011) analysis on 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 made from non-ferrous metals, specifically zinc, copper, aluminium, magnesium. Depending on the type of metal being cast, a hot- or cold-chamber machine is used. The main causes for gas porosities can be grouped in more categories and are the following (1) Shot end parameters(2) Metal volume(3) Clamping & Ejection(4) Metal, The most known methods for the control of the porosity are with X-Ray; by cutting the parts and polishing the section of the part and for analyze using a microscope; by Computerized Tomography, The purpose of the flow simulation is to develop and improve the shape of the part and also of the runner in order to have an optimum filling of the cavities and to identify the last filled areas where the overflows have to be placed in order to assure good wenting of the cavities and minimize gas porosity defects, for controlling porosity The simplest way is to do a good process definition and setup since the beginning and to keep it under control by assuring the stability of the process.

The stability of the process can be assured by monitorizing and keeping under control the process parameters.[13]

W. Orlowicz et al. (march-2012)study presents the research results of effect that refining process has on porosity and mechanical properties of high pressure die castings made of AlSi12S alloy. The operation of refining was carried out in a melting furnace with the use of an FDU Mini Degasser. Mechanical properties (tensile stress, yield stress, Elongation, Hardness) were assessed on samples taken from high pressure die castings. The effect of molten metal transfer operation and the time elapsing from completion of the refining process on the alloy mechanical properties was determined

The refining of AlSi12S alloy with the refining parameters used in this study (rotational speed 500 rpm, argon flow rate 22 l/min, refining time 12 minutes) allowed for effective reduction of alloy porosity by 1%. It was found that the porosity content of high pressure die castings material is much higher than that observed in the liquid alloy taken from the pressure machine furnace. This is an effect of increased alloy gassing during transfer to the loading chamber, interaction between piston lubricant and mould coating combustion products, and turbulent flow of metal occurring when the pressure mould cavity is filled. Transfer of liquid alloy and time elapsing from completion of refining resulted in an increase of its gassing and consequential increase of pressure casting porosity.[14]

Kulkarni Sanjay Kumar et al.(2013) in paper discusses the study and examined effect of die casting process parameters on porosity in aluminium alloy SAE 308 by using Taguchi method. In any die casting industry porosity is a very serious problem faced by production department and also being an invisible defect it is not identified visually in running production. It is shown in this work that die casting parameters which are related with machine such as first phase speed, second phase speed, first phase length and injection pressure all have significant influence on porosity level. The experiment have been performed as per the combination of levels of different process parameters suggested by L9 orthogonal array and conformation experiments have been performed to validate the optimum levels of different parameters

Consequently the higher level of injection pressure 270 kg/cm² has the most significant effecting. This was expected because the injection pressure stage of the die casting procedure is more significant than others, as confirmed by literature and experimentation. The predicted mean estimation of casting porosity was calculated as 0.0625 percentages with a confidence interval of between0.05384 and 0.0.07116 percentages. The results are valid within the above range of process parameters and for the specified SAE 308 alloy casting.[15]

III. CONCLUSION

From this review paper, it conclude that

- Reduction of turbulence in the cavity and runner. The use of tapered runner can help a continuous acceleration of molten metal during mould filling.
- Adjustment of plunger speed to allow molten metal filling the sprue at low speed and filling the cavity at high speed.
- Increased gate speed, metal pressure can help the reduction of porosity.
- Proper furnace operation and maintenance procedures can reduced defects in pressure casting.
- The hydrogen content change is stable between 700oC and 720oC temperature of molten metal. Between these temperature limits, the specific gravity values are in the range of change between 2.63 and 2.655. In this range, there is stability in the hydrogen content of molten metal can help reduced most of defects like shrinkage and porosity.

IV. EXPERIMENTAL SETUP

Fig. 7: 120-Tone Cold chamber die casting machine

Fig. 8: Aluminium melting furnace

Fig. 9: ultrasonic test

V. EXPERIMENTAL RESULT

Sr. No.	Melt Temp ,deg c	Inj Press, bar	Cooling Time (sec)	Porosity %
1	600	300	4	2.87
2	600	300	5	2.66
3	600	300	6	2.21
4	600	320	4	2.89

5	600	320	5	2.64
6	600	320	6	1.87
7	600	340	4	2.34
8	600	340	5	1.67
9	600	340	6	1.50
10	650	300	4	3.56
11	650	300	5	2.53
12	650	300	6	2.35
13	650	320	4	3.11
14	650	320	5	2.97
15	650	320	6	2.89
16	650	340	4	2.91
17	650	340	5	2.22
18	650	340	6	1.96
19	700	300	4	3.65
20	700	300	5	3.61
21	700	300	6	3.31
22	700	320	4	3.80
23	700	320	5	3.70
24	700	320	6	3.56
25	700	340	4	2.99
26	700	340	5	2.96
27	700	340	6	2.87

A. Summary of ANOVA Calculation for ADC-12 Porosity Percentage

Source	Df	Adj SS	Adj MS	F-Value	% Contribution
Temperature	2	5.417222	2.708611	53.813819	51.18%
Inj Pressure	2	2.407089	1.203544	23.911628	22.75%
Cooling Time	2	0.875911	0.875911	17.402320	16.55%
Error	20	1.006667	0.050333	1	9.51%
Total	26	75.6			100%

B. Main Effect Plots for Porosity on ADC-12

The relation between all the process parameters of porosity like temperature, injection pressure, cooling time is shown in Fig.

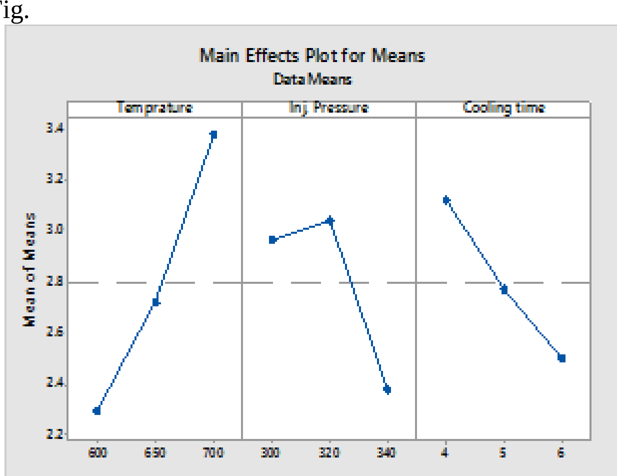

Fig. 10: Effect of Temperature, Injection pressure, Cooling time on ADC 12 Material Porosity

This analysis was made with the help of a software package MINITAB 17. The main effect plots for SN ratio were shown in Fig. these show the variation of individual response with the three parameters i.e. temperature, injection pressure and cooling time separately. In the plots, the x-axis indicates the value of each process parameter at three level and y-axis the response value. Horizontal line indicates the mean value of the response.

In the present investigation, from the graph we can say that rate of change of porosity was increasing and porosity was increasing as we increase the temperature from 600 to 700 deg C. Here value of change of porosity was increasing because at high temperature, more temperature was make ADC 12 molten metal soft due to softness more possibility of hydrogen gas on mold, due to more hydrogen gas possibility of porosity increased on casting part, which increase porosity on casting parts.. For our experiment the variation of injection pressure values increased from 300 to 340 bar at that time porosity on part are decreased because high pressure decreased part design defects on mold and shape of part are much better at higher pressure . As we move cooling time from 4sec to 6 sec porosity was decreased because of more cooling time on casting increased the way of removing gas and batter solidification on mold for parts. When we compare all three plots, the Temperature was having domination on porosity as compared to other two parameters.

C. Regression Analysis for ADC-12 Porosity

The regression equation is…

Porosity% = 2.02 + 0.01089 (T) - 0.01481 (P) - 0.3111 (t)

Where T = Temperature

P = Injection pressure

t = Cooling time

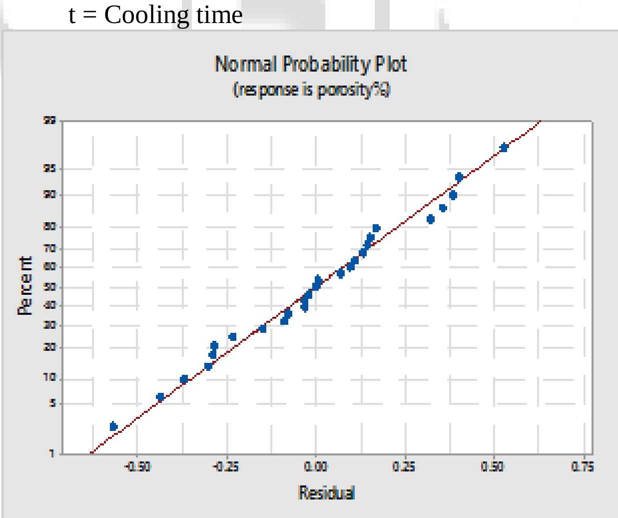

Fig. 11: Main effect residual plot for ADC-12 material porosity

D. Optimization

1) Calculation of ADC-12 porosity percentage GRC

Run Order	GRC for ADC-12 porosity percentage	Grade No
1	0.456349206	12
2	0.497835498	11
3	0.61827957	5
4	0.452755906	14
5	0.502183406	10

6	0.756578947	3
7	0.577889447	7
8	0.871212121	2
9	1	1
10	0.358255452	22
11	0.527522936	9
12	0.575	8
13	0.416666667	20
14	0.438931298	18
15	0.452755906	15
16	0.44921875	16
17	0.614973262	6
18	0.714285714	4
19	0.348484848	25
20	0.352760736	24
21	0.388513514	21
22	0.333333333	27
23	0.343283582	26
24	0.358255452	23
25	0.435606061	19
26	0.440613027	17
27	0.456349206	13

From Table it is found that experiment no.9 has the best multiple performance characteristic among 27 experiments, because it has the highest grey relational grade of 1.

VI. Conclusion

1) In aluminium material ADC-12 porosity percentage temperature, injection pressure, and Contact time is affected respectively 51.18%, 22.75%, 16.55% from this study it shows that temperature is highly affected on ADC-12 material porosity. The pooled error associated with the ANOVA of ADC-12 material porosity was 9.51%.
2) From Regression analysis, it concludes that Experimental value of porosity in ADC-12 material is near by the standard value of porosity in aluminium at 95% confidence level.
3) From this optimization technique of Grey relational analysis it concluded that the best combination set of porosity in ADC-12 material is Temperature 60`c, Injection pressure 360 bar and Cooling time 6 sec.
4) For validation in ADC-12 material temperature 600`c, injection pressure 360 bar and cooling time 6 sec perfumed three different test for same combination and porosity percentage is nearly 1.50% in all test result
5) Hence it concludes that this combination set is best for cold chamber die casting machine for ADC-12 material for temperature range from 600-700 C, injection pressure 300- 340 bar and cooling time 4-6 sec.

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