Optimization of Process Parameters to Improve the Casting Properties in Cold Chamber Die Casting Process

Rahul Kapoor[1], Vishal S Sharma[2],Harwinder Singh[3]
[1]Research Scholar, Department of Mechanical Engineering
I.K Gujral Punjab Technical University, Kapurthala
[2] Prof., Department of Industrial and Production Engineering
Dr B R Ambedkar Natrional Institute of Technology Jalandhar-144011, INDIA
[3]Prof.,Department of Mechanical Engineering
Guru Nanak Dev Engineering College, Ludhiana

Abstract This paper focuses on the parametric optimi- zation of process parameter in cold chamber die casting for an industrial component (crank case). Three controllable factors of the cold chamber die casting process (namely: 1st phase pressure, 2nd phase pressure and limit switch position) were studied at three levels each by Taguchi's parametric approach and single-response optimization was conducted to identify the main factor controlling surface hardness, weight of casting and dimensional accuracy (Dd). Castings were produced using aluminium alloy at recom- mended parameters through cold chamber die casting process. Analysis shows that in cold chamber die casting process the percentage contribution of 1st phase pressure, limit switch position and 2nd phase pressure for surface hardness is 84.17, 11.43 and 1.93 % respectively. While in the case of weight of cast component, the contribution of limit switch position is 52.26 %, followed by 1st phase pressure and 2nd phase pressure 34.77 and 9.65 % respectively. Further for Dd, contribution of 1st phase pressure is 64.55 %, limit switch position 27.71 % and 2nd phase pressure contributes 4.87 %.

Keywords Cold chamber die casting · Dimensional accuracy · Hardness · Weight of casting

Introduction

Die casting are amongst the highest volume, mass produced items manufactured by the metal work industry, and they canbe found in thousands of consumer, commercial and indus-trial products [1–3]. Cold chamber die casting is used for casting alloys that require high pressure and have high melting temperature such as brass, aluminum, magnesium, copper based alloys and other high melting point nonferrous alloys [2–5]. In cold chamber die casting process, at first stage, with die closed and plunger withdrawn position, molten metal is poured into the chamber. After this plunger forces metal to flow into die, maintaining pressure during the cooling and solidification. Then plunger is withdrawn, die is opened, and part is ejected. Cold chamber die casting process is used for higher temperature metals e.g. aluminum, copper and their alloys [6–8]. Figure 1 shows cold chamber die casting process.

For the present work, crank case (Fig. 2) has been selected as a benchmark for cold chamber die casting.

Literature Review

Faura et al. [3] analyzed a plunger acceleration law that is expected to minimize air entrapment in the slow shot phase of pressure die casting in horizontal cold chambers, and thus to reduce porosity in manufactured parts. The study is carried out using results from an analytical model of the flow of molten metal in the shot sleeve. The results for the surface profiles of the wave formed during plunger movement using plunger acceleration laws which are typically used in pres- sure die casting are compared with those corresponding to the proposed law. Some analytical predictions for the wave profiles and for the mass of trapped air are compared with numerical results obtained from a finite-element code, which solves momentum and mass conservation equations.

Sabau and Vishwanathan [9] developed a comprehen- sive methodology that takes into account solidification,

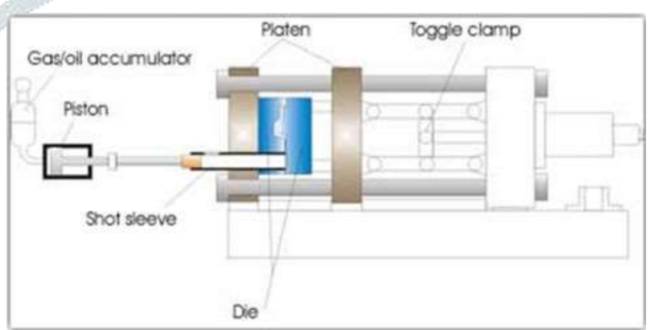

Fig. 1 Cold chamber die casting process [7]

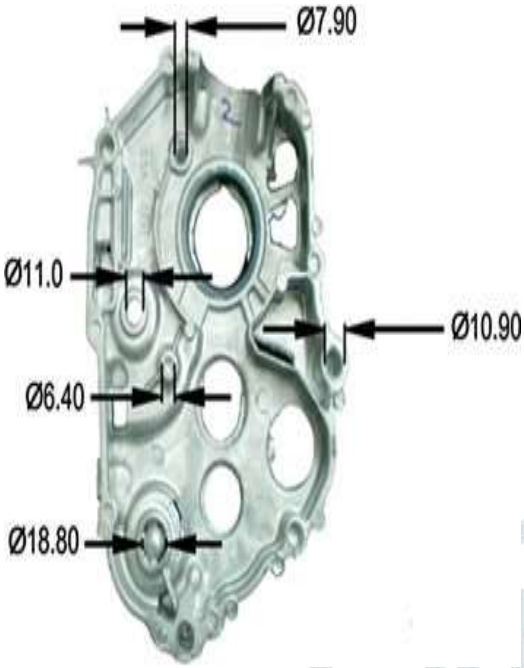

Fig. 2 Dimensions of the crank case

Table 1 Input parameters for final experiment

Levels: Parameters	1	2	3
1st phase pressure	12 N/mm^2	14 N/mm^2	16 N/mm^2
2nd phase pressure	24.52 N/mm^2	29.42 N/mm^2	34.32 N/mm^2
Limit switch position	220 cm	240 cm	260 cm

Table 2 Observations of final experimentation for Dd for initial dimension of inner diameter 7.90 mm

Sr. no.	Variable 1 (1st phase pressure) (N/mm^2)	Variable 2 (2nd phase pressure) (N/mm^2)	Variable 3 (limit switch position) (cm)	Dd (mm)		
				L1	L2	L3
1	12	24.52	220	0.38	0.39	0.39
2	12	29.42	240	0.35	0.35	0.34
3	12	34.32	260	0.19	0.19	0.18
4	14	24.52	240	0.11	0.14	0.13
5	14	29.42	260	0.04	0.03	0.04
6	14	34.32	220	0.15	0.14	0.15
7	16	24.52	260	0.24	0.21	0.23
8	16	29.42	220	0.3	0.31	0.3
9	16	34.32	240	0.36	0.32	0.34

Table 3 S/N ratio of Dd for initial dimension of inner diameter 7.90 mm

Run1	Run2	Run3	Sum reciprocal	S/N ratio	Average
0.38	0.39	0.39	0.1495333	8.2526199	0.3867
0.35	0.35	0.34	0.1202	9.2009553	0.3467
0.19	0.19	0.18	0.0348667	14.575896	0.1867
0.11	0.14	0.13	0.0162	17.90485	0.1267
0.04	0.03	0.04	0.0013667	28.643374	0.0367
0.15	0.14	0.15	0.0215333	16.668887	0.1467
0.24	0.21	0.23	0.0515333	12.879118	0.2267
0.3	0.31	0.3	0.0920333	10.360548	0.3033
0.36	0.32	0.34	0.1158667	9.3604149	0.3400

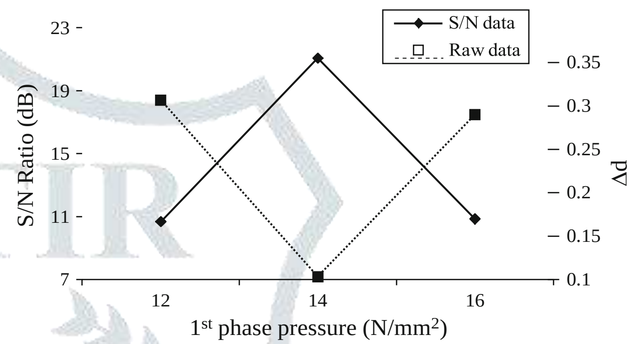

Fig. 3 Variation of S/N ratio and Dd w. r. t. to 1st phase pressure

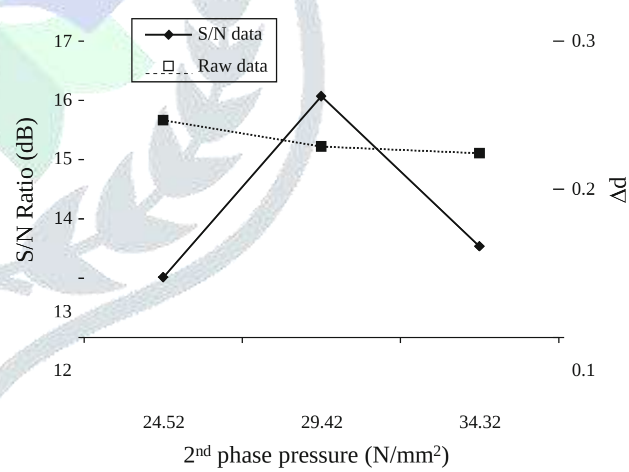

Fig. 4 Variation of S/N ratio and Dd w. r. t. to 2nd phase pressure

shrinkage-driven inter-dendritic fluid flow, hydrogen precipitation, and porosity evolution for the prediction of the micro porosity fraction and distribution in aluminum alloy castings. The approach may be used to determine the extent of gas and shrinkage porosity, i.e. the resultant micro porosity which occurs due to gas precipitation and that which occurs when solidification shrinkage cannot be compensated for by the inter-dendritic fluid flow. The results showed that

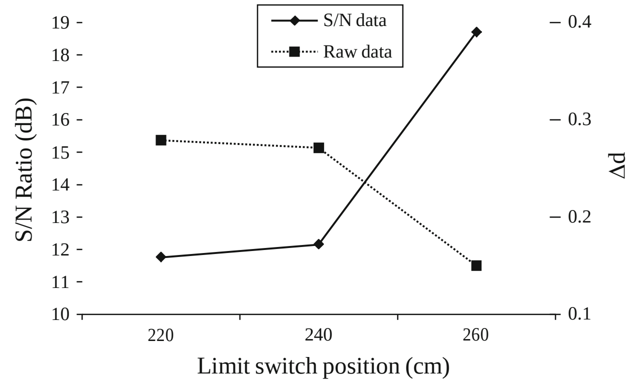

Fig. 5 Variation of S/N ratio and DD w. r. t. limit switch position

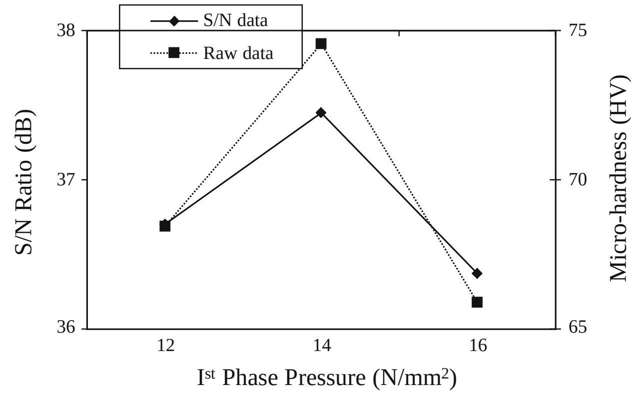

Fig. 6 Variation of S/N ratio and hardness w. r. t 1st phase pressure

Table 4 Observation of final experimentation for Vickers hardness (HV)

Sr. no.	Variable 1 (1st phase pressure) (N/mm^2)	Variable 2 (2nd phase pressure) (N/mm^2)	Variable 3 (limit switch position) (cm)	Vickers hardness (HV)		
				L1	L2	L3
1	12	24.52	220	65	68	68
2	12	29.42	240	68	67	67
3	12	34.32	260	70	72	71
4	14	24.52	240	72	74	74
5	14	29.42	260	75	75	75
6	14	34.32	220	76	75	75
7	16	24.52	260	69	68	68
8	16	29.42	220	66	65	63
9	16	34.32	240	64	65	65

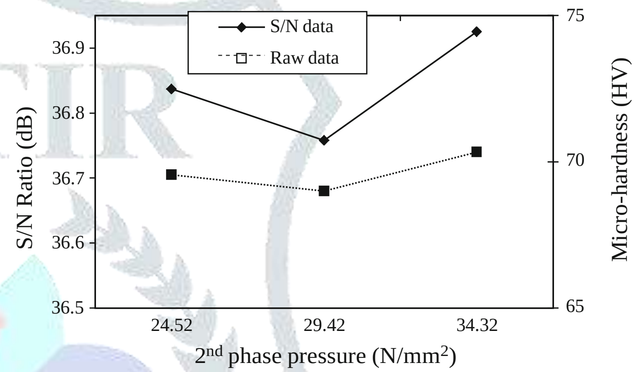

Fig. 7 Variation of S/N ratio and hardness w. r. t 2nd phase pressure

Table 5 S/N Ratio for hardness

H1	H2	H3	Sum reciprocals	S/N ratio	Average
65	68	68	0.000223	36.51557	67
68	67	67	0.000221	36.56397	67.33333
70	72	71	0.000198	37.02344	71
72	74	74	0.000186	37.30385	73.33333
75	75	75	0.000178	37.50123	75
76	75	75	0.000176	37.53924	75.33333
69	68	68	0.000214	36.69204	68.33333
66	65	63	0.000239	36.20871	64.66667
64	65	65	0.000239	36.21291	64.66667

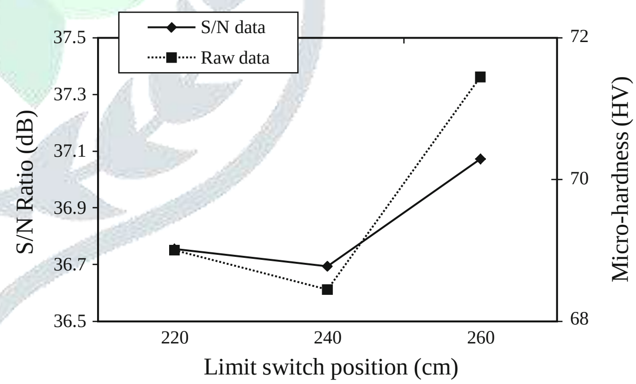

Fig. 8 Variation of S/N ratio and hardness w. r. t limit switch position

the effect of micro porosity on the inter-dendritic fluid flow cannot be neglected.

Han and Vishwanathan [5] proposed a mechanism of soldering of an aluminum alloy die casting to a steel die. A soldering critical temperature was postulated, at which iron begins to react with aluminum to form an aluminum rich liquid phase and solid intermetallic compounds. The critical temperature was used to predict the onset of die soldering. They discussed factors affecting the soldering tendency and also suggested methods for reducing die soldering. Matthew et al. [8] determined the effects of process variables on the quality of high pressure die cast components with the aid of in-cavity pressure sensors.

Table 6 Observation of final experimentation for weight of the casted component

Sr. no.	Variable 1 (1st phase pressure) (N/mm^2)	Variable 2 (2nd phase pressure) (N/mm^2)	Variable 3 (limit switch position) (cm)	Weight (gm) L1	L2	L3
1	12	24.52	220	1107	1109	1108
2	12	29.42	240	1124	1120	1122
3	12	34.32	260	1138	1135	1136
4	14	24.52	240	1134	1132	1135
5	14	29.42	260	1173	1177	1175
6	14	34.32	220	1139	1134	1137
7	16	24.52	260	1147	1146	1145
8	16	29.42	220	1118	1120	1122
9	16	34.32	240	1097	1091	1094

Table 7 S/N Ratio for weight

W1	W2	W3	Sum square	S/N ratio	Average
1107	1109	1108	8.146E−07	60.890788	1108
1124	1120	1122	7.944E−07	60.99983	1122
1138	1135	1136	7.744E−07	61.110099	1136.3333
1134	1132	1135	7.781E−07	61.089692	1133.6667
1173	1177	1175	7.243E−07	61.400732	1175
1139	1134	1137	7.74E−07	61.11262	1136.6667
1147	1146	1145	7.614E−07	61.183686	1146
1118	1120	1122	7.972E−07	60.984333	1120
1097	1091	1094	8.355E−07	60.780281	1094

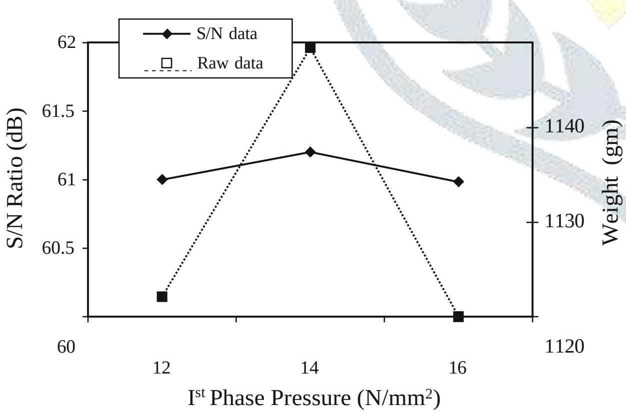

Fig. 9 Variation of S/N ratio and weight w. r. t. 1st phase pressure

The effects of set intensification pressure, delay time, and casting velocity have been investigated. The in-cavity pressure sensor has been used to determine how condi- tions within the die-cavity are related to the process parameters regulated by the die casting machine, and in turn the effect of variations in these parameters on the integrity of the final part. Porosity was found to decrease with increasing intensification pressure and increase with

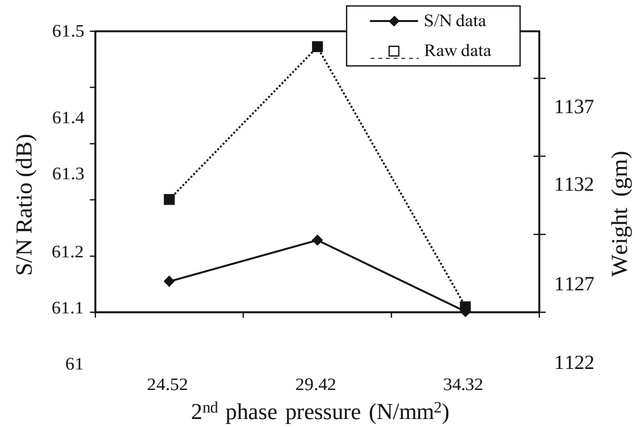

Fig. 10 Variation of S/N ratio and weight w. r. t. 2nd phase pressure

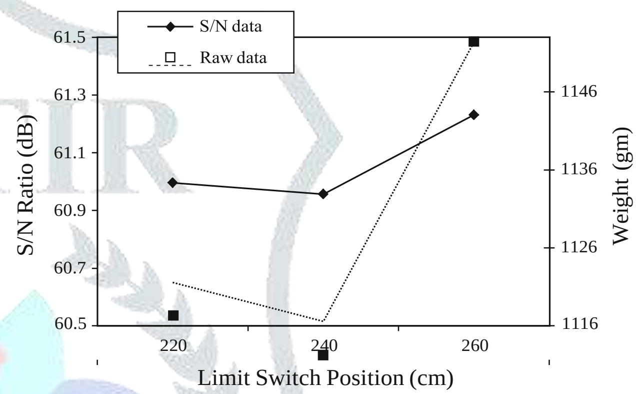

Fig. 11 Variation of S/N ratio and weight w. r. t. limit switch position

Table 8 Percentage contributions of input parameters for Dd

	Sum square	V	F	Percentage contribution (%P)
1st phase pressure	212.26634	106.13317	22.535712	64.549466
2nd phase pressure	16.030358	8.015179	1.7018974	4.8747769
Limit switch position	91.1271	45.56355	9.6747045	27.711439
Error	9.4191094	4.7095547		2.8643189

increasing casting velocity. Zhi-peng et al. [10] focused on the determination of the interfacial heat transfer coefficient (IHTC) at the metal-die interface in the high pressure die casting (HPDC) process. Experiment was conducted and a ‘‘step shape’’ casting was used to cast a magnesium alloy AM50 against a H13 steel die. Based on the temperature measurements inside the die, IHTC was determined by applying an inverse approach. The influences of the step thickness and process parameters on the IHTC were inves- tigated. Results show that the shape of IHTC profiles is different at different steps and the duration for IHTC to

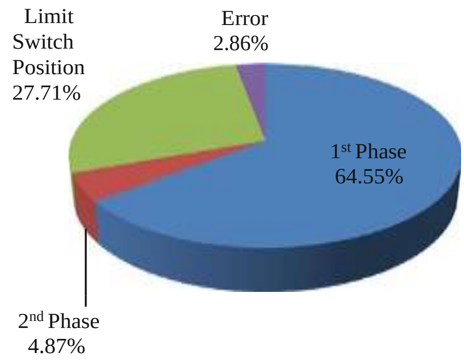

Fig. 12 Contribution of various input parameters for Dd

Table 9 Percentage contributions of input parameters for surface hardness

	Sum square	V	F	Percentage contribution (%P)
1st phase pressure	1.826599	0.913299	34.18867	84.17277
2nd phase pressure	0.041987	0.020994	0.785883	1.93485
Limit switch position	0.248046	0.124023	4.642702	11.43037
Error	0.053427	0.026714		2.462008

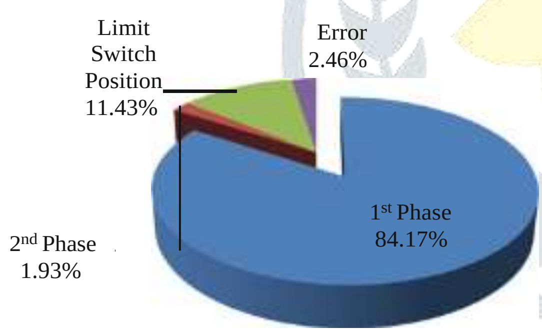

Fig. 13 Contribution of various input parameters for surface hardness

maintain a higher value grows as the step thickness increases. Kumar [7] evaluated the main effects i.e. thermal characteristics (temperature of the molten metal), injection pressure of the molten metal, type of coating (oil coating, oil ? graphite coating), and the type of cooling (air cooling, water cooling and oil cooling) on density of the material, hardness of the material and the surface roughness of the material in cold chamber die casting by Taguchi's parametric approach. An experimental model for encompassing three responses namely surface roughness, density and hardness has been employed to carry out the experimental study and subsequent analysis.

Table 10 Percentage contribution of input parameters for weight

	Sum square	V	F	Percentage contribution (%P)
1st phase pressure	0.0882484	0.0441242	10.521276	34.776018
2nd phase pressure	0.0245043	0.0122521	2.9214877	9.6564052
Limit switch position	0.1326219	0.0663109	15.811638	52.262273
Error	0.0083876	0.0041938		3.3053041

The literature review reveals that lot of work has been reported on optimization of various output parameters of cold chamber die casting process by changing various input parameters such as use of different coolant and spray's, die coating, pouring metal temperature, heat transfer coefficient, metal flow rate etc. But hitherto very less has been reported on effect of different phases of pressure bifurcation (i.e. 1st phase pressure, 2nd phase pressure and limit switch position) in cold chamber die casting components.

The proper range of pressure has to be selected for efficient functioning of cold chamber pressure die casting process.

In the present work, the effect of 1st phase pressure, 2nd phase pressure and limit switch position for cold chamber pressure die casting process as a case study of industrial component (crank case) were taken as a input parameter for the outer parameters namely surface hardness, weight of casting and dimensional accuracy.

Experimentation

Pilot experiments were conducted for finding out the ranges for the input parameters (1st phase pressure, 2nd phase pressure and limit switch position). On the basis of the pilot experiments the ranges were selected. Finally for the present experimentation work Taguchi L9 orthogonal array has been used. Table 1 shows the various input parameters and their levels used for the final experimentation. Table 2 shows the observation of final experimentation for dimensional accuracy (Dd) according to L9 orthogonal array. 'Dd' is basically the amount by which the metal component shrinks or changes its dimensions after casting. Generally, the dimensions on the drawing (Fig. 2) and that of the final products on coordinate measuring machine are compared. The difference in both sizes gives the Dd. Table 3 shows signal to noise (S/N) ratio of Dd for initial dimension of inner diameter 7.90 mm. For calculation of S/N ratio, smaller the better type case has been judicially selected in order to reduce the Dd. The output parameters for study are:

- Hardness
- Dimensional accuracy (Dd)
- Weight of the casted component

Based upon Table 3, Figs. 3, 4, 5 show the variation of S/N ratio and Dd w. r. t. to 1st phase pressure, 2nd phase pressure and limit switch position respectively.

Table 4 shows of final experiment observation for hardness based upon L9 orthogonal array.

Hardness depends upon the input parameters like 1st phase pressure, 2nd phase pressure and limit switch position. Table 5 shows the observation of hardness (H1, H2 and H3), S/N ratio (for maximum the better type case) and average based upon Taguchi's L9 OA.

Based upon Table 5, Figs. 6, 7, 8 show the peak values of the S/N ratio and hardness w. r. t. 1st phase pressure, 2nd phase pressure and limit switch position for best setting as an input parameter.

Tables 6 and 7 show the observation of final experimentation and S/N ratio for weight (maximum the better type case) of the component according to design of L9 orthogonal array.

Based upon Table 7, Figs. 9, 10, 11 show the values of the S/N ratio and weight w. r. t. 1st phase pressure, 2nd phase pressure and limit switch position.

Percentage Contribution of Input Parameters for Dd

The Dd is highly influenced by the 1st phase pressure, 2nd phase pressure and limit switch position. Table 8 and

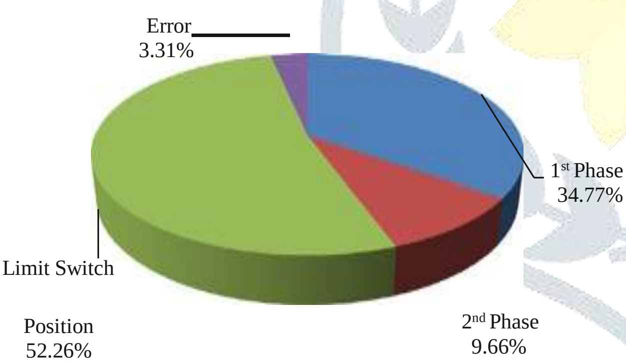

Fig. 14 Contribution of various input parameters for weight

Fig. 12 show the contribution of various input parameters for the Dd.

Percentage Contribution of Input Parameters for Surface Hardness

Hardness of crank case influenced by various input parameters (like: 1st phase pressure, 2nd phase pressure and limit switch position). Table 9 and Fig. 13 shows contribution of various input parameters for surface hardness.

Percentage Contribution of Input Parameters for Weight

The weight of the crank case is influenced by all the selected input parameters. Table 10 and Fig. 14 show the contribution of various input parameters for the weight.

The results are valid for 95 % confidence level having critical F-ratio 19. Finally confirmatory experiments were conducted at optimized conditions suggested by Taguchi design for surface hardness, weight and Dd. Figure 15 shows comparison of surface hardness, weight and Dd at initial and final experimental conditions.

Conclusions

On the basis of experimental observations made on cold chamber pressure die casting process (as a case study of crank case), following conclusions can be drawn:

Surface hardness is obtained best at 1st phase pressure 14 N/mm^2, 2nd phase pressure 34.32 N/mm^2 and limit switch position 260 cm. Weight of the casting produced is best at 1st phase pressure 14 N/mm^2, 2nd phase pressure 29.42 N/mm^2 and limit switch position 260 cm. In case of dimensional accuracy of casting, the best conditions are 1st phase pressure 14 N/mm^2, 2nd phase pressure 29.42 N/mm^2 and limit switch position 260 cm. In the present research work optimized settings of input parameters has been made independently for surface hardness, weight of casting (by considering maximum the better type case) and Dd

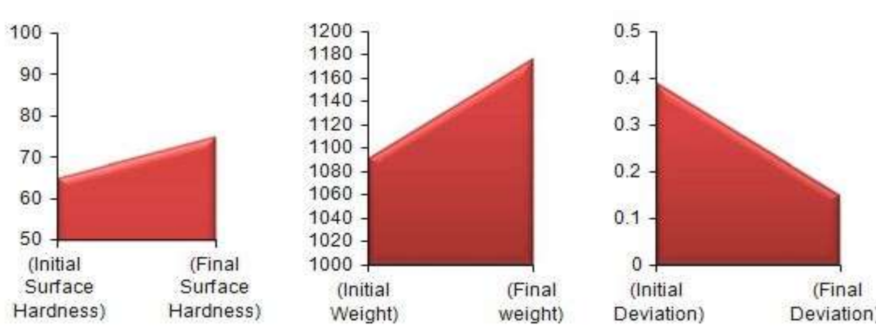

Fig. 15 Improvement in surface hardness, weight and Dd

(by considering minimum the better type case). Further model may be developed for all three outputs (by consideringnominal the best type case).

Results of this research work reveals that percentage improvement in surface hardness for crank case is 17.1 %. In case of weight percentage improvement for casting is 7.30 %. Further for dimensional accuracy the percentage improvement is 92.23 % for the component under study.

The percentage contribution of input parameters in cold chamber pressure die casting process for surface hardness is, 1st phase pressure 84.17 %, 2nd phase pressure 1.93 % and limit switch position 11.43 %. While in the case of weight of cast component, contribution of 1st phase pressure is 34.77 %, 2nd phase pressure contributes 9.65 % and limit switch position 52.26 %. Further for dimensional accuracy contribution of 1st phase pressure 64.55 %, 2nd phase pressure contributes 4.87 % and limit switch position 27.71 %.

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