Reason- A Technical Journal
ISSN 2277-1654
Volume XVIII 2019

INDUSTRIAL CASE STUDY OF LOW-PRESSURE DIE CASTING OF AlSi9Cu1Mg ALUMINIUM ALLOY TO REDUCE CASTING DEFECTS

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Paper received on: April 22, 2020, accepted after revision on: May 24, 2020
10.21843/reas/2019/42-52/196166

Abstract : Low-pressure die casting process is extensively used for casting of Al alloys. It is still challenging to reduce defects in automotive Al alloy casting to improve product quality and reduce production cost. The various parameters like metal temperature, filling pressure, pouring time, solidification time had a great influence on the casting defects. Researchers continuously attempted to reduce casting defects. In the present study, an attempt was made to study low-pressure die casting of AlSi9Cu1Mg aluminium alloy. This study was carried out at a foundry located at Pune (Maharashtra, India). The objective of this study was to identify the various casting defects and to investigate the important operating parameters' values to get defect free castings. The most important casting defects in low-pressure die-casting of aluminum alloys were identified as shrinkage, un-filling, blowhole, porosity, extra-metal, boil, and wire-mesh. The repetitive occurrence of casting defects was identified by conducting experiments at different values of temperature and pressure. It was observed that the metal temperature of 725ºC and filling pressure of 0.25 bar produced less defects; hence it was suggested to cast AlSi9Cu1Mg aluminium alloy at these values to get castings with minimum defects.

Keywords: Low-pressure die casting, shrinkage, un-filling, blow-holes, porosity, boil, Al alloy.

1. INTRODUCTION

The automobile industries were forced to use aluminium and magnesium alloys due to its low weight and good thermal and mechanical properties. Aluminium alloys had replaced various components in the automobile industry, which were previously made with steel and cast iron. For an example, automobile component like engine cylinder, engine blocks, power unit bracket, wheels, suspension components, piston head, braking components, etc. are now manufactured by light alloys like Al alloys. In this paper, the considered component is a Power Unit Bracket of an automobile. This component is generally used in non-gear four wheeler automotive vehicles. The various important requirements of this component were high fatigue strength, good surface finish, high capacity against heat and also mechanical properties like tensile strength, impact strength, hardness, etc. Low-pressure die casting (LPDC) process is used to manufacture power unit brackets owing to its ability to produce high quality as well as cost effective castings.

2. LITERATURE REVIEW

So et al. [1] investigated the contribution of microstructural changes in the low-pressure die casting process of A356 alloy. This alloy was used for automotive wheel with 5 spokes, and the porosity measurement was performed by SEM fractographic analysis. A set of conditions for optimal heat treatment, in terms of the defect susceptibility to micro-porosity variation were suggested. Cleary [2] used SPH (Smoothed particle hydrodynamics) mathematical model to study the defects in LPDC. The proposed model was able to predict various defects in LPDC like shrinkage, oxide formation, etc. in the solidified metal. Murat [3] studied the fracture initiating defects like blow-holes, cracks, un-filling in Al- alloy castings based on the size distribution. Wang et al. [4] compared A356/357 alloys with 319-type alloys and studied various defects like the oxide films, porosity and fatigue life of the cast aluminium alloys. The objective of their research was to study microstructural defects like oxide films and pores, when major defects in castings affecting the fatigue properties were absent. Zhang et al. [5] carried out experimental investigation of the casting defects in the automotive aluminium alloy casting process. In this study, the author examined the defects like macro-porosity, micro-porosity, entrained oxide films and exogenous oxide inclusions and suggested going for more sophisticated and mathematical modeling study for predicting these defects.

The literature survey of casting defects of low-pressure die casting of Al alloys revealed important defects such as, shrinkage, un-filling, porosity, blowholes, etc. It was also observed that the various defects like wire-mesh, boil and extra-metal were not addressed in the literature available on LPDC of Al alloys. During the initial phase of this industrial case study, the later defects were observed as industrially important defects and hence considered. Thus to improve productivity and cast quality there was a need to study defects. Hence, all the above casting defects observed during LPDC of Al alloy were considered and this study was carried out in an automobile foundry.

3. EXPERIMENTAL PROCEDURE

For this study, the foundry situated at Pune which was involved in LPDC of Al alloy was identified. All the experiments were performed in the foundry. The products of the foundry were cylinder blocks, cylinder heads, etc. All the castings were sent to the companies in India and abroad. The casting process started by receiving the raw material in the form of Al slab like AlSi9CuMg and then heated to the molten stage. When the casting was solidified the gates were removed. Later the heat treatment and shot blasting of the casting was done. Fettling was also done and the castings with defect seen by the naked eyes were removed. Machining was done if required followed by de-burring. Finally, castings were washed, leak tested and engraving was done. Testing and inspection involved endoscopy of castings. The company also had a Co-ordinate measuring machine, X-ray machine, and chemical composition checking machine. The experimental setup of low-pressure die casting machine is shown in Fig.1.

Fig.1: Experimental setup showing low-pressure die casting machine

The component understudy was Power Unit Bracket. The component was made by AlSi9Cu1Mg alloy. For the experimental purpose, the solidification time for the casting was kept constant at 300 sec and the cooling time was also kept constant at 80 sec. Only the metal temperature and pressure at which the metal enters the cavity were changed. The study was performed to find out the metal temperature and pressure where the defects obtained were less for the above mentioned casting component. A total of 16 experiments was conducted for different metal temperature and pressure. The range of temperatures and pressures was selected considering the upper and lower limit of the temperatures and pressures used for manufacturing the castings by the industry. The temperature was varied from 7150C to 7300C and pressure from 0.17 bar to 0.3 bar. The defects like shrinkage (SKG), un-filling (U/F), blowhole (B/H), porosity (P.S), extra metal (Ext. Mtl.), boil and wire-mesh (W/M) were occurring at different combinations of temperatures and pressure were studied and the values of temperatures and pressure having minimum defects were found out. The experiments were performed when the multi-cavity die was used and 2 castings were obtained in a single shot. Total 50 shots were taken into consideration and 100 castings were selected to study at a specific pressure and temperature. During this study only casting defects were taken into consideration and machining defects were neglected.

4. RESULTS AND DISCUSSIONS

The main objective of conducting experiments was to identify the set of important operating parameters giving castings having minimum defects. To achieve this, four sets of experiments were conducted and in each set again four experiments were conducted. The following table 1 shows the set of temperatures and pressures used for LPDC and also the total number of the defects observed at different temperature and pressure. The details of the total defects observed in each experiment were also found out. The different defects obtained for different experiments are shown in table 2. These defects are discussed in the preceding sections.

Table 1: Results of the experiments performed

Experiment No.	Metal temperature (ºC)	Filling pressure (bar)	No. of defects
1	715	0.17	15
2		0.21	15
3		0.25	12
4		0.30	12
5	720	0.17	11
6		0.21	10
7		0.25	8
8		0.30	8
9	725	0.17	7
10		0.21	6
11		0.25	3
12		0.30	7
13	730	0.17	10
14		0.21	10
15		0.25	9
16		0.30	11

Table 2: Different types of defects observed in each experiment

Exp. No.	Number of castings with the different types of defects						
	SKG	U/F	B/H	P.S	Ext. Mtl.	Boil	W/M
1	6	4	5	-	-	-	-
2	5	6	4	-	-	-	-
3	5	3	3	-	1	-	-
4	5	1	3	-	3	-	-
5	4	3	3	1	-	-	-
6	3	3	4	1	-	-	2
7	3	3	2	-	-	-	-
8	3	2	2	-	2	-	-
9	2	3	2	-	-	-	-
10	2	2	2	-	-	-	-
11	1	1	1	-	-	-	-
12	1	1	2	-	3	-	-
13	1	3	3	2	-	1	-
14	1	3	2	2	-	2	-
15	1	1	2	2	1	2	-
16	1	1	2	2	1	3	-

4.1. Shrinkage

The volumetric difference between the solid and liquid phase of the molten metal causes the shrinkage defect. The typical shrinkage was observed at different locations of the castings. Fig.2 shows the shrinkage observed on one of the casting under study at a particular location. Shrinkage, if present on the casting, affects the integrity of the whole component and fails under the high stress conditions. The present study aims to find out the combination of temperature and pressure to reduce the shrinkage.

Fig.3 shows the number of castings manufac-tured at various combinations of pressure and temperature having defects like, shrinkage, un-filling and blow-holes. As the temperature was increased the castings having shrinkage defect were reduced as shown in Fig.4. The effect of change in pressure on the shrinkage was also studied. As seen from the Fig.4, the temperature for the 1-4 experiments was minimum (715^{0}C), and the number of defects were more. The main reason for the shrinkage at low temperature was related with the solidification time. Since the metal temperature was low, the metal got solidified quickly [2]. Due to this reason, the metal got contracted and shrinkage was seen. The reverse phenomenon happened for high temperature; the solidification was slow and shrinkage was reduced resulting in low number of castings showing shrinkage defects. Similarly, when the pressure was low as shown in Fig.4, then the shrinkage occurred because the required amount of metal did not reach the end of the casting. [3] From Fig.4, it can be seen that as the pressure was increased for particular value of temperature (715^{0}C to 725^{0}C), number of castings showing shrinkage reduced.

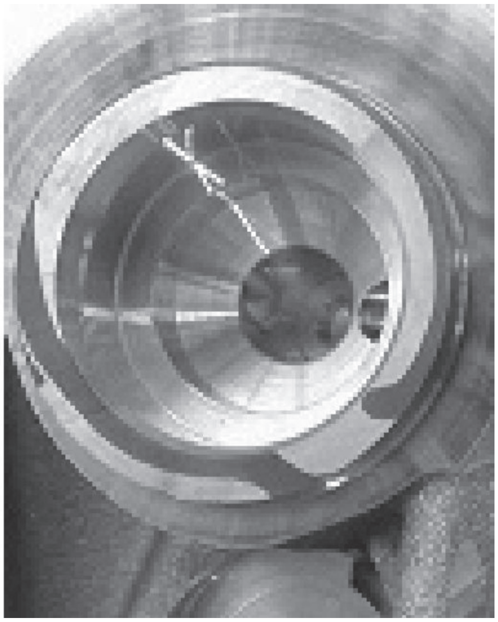


Fig.2: Shrinkage at a particular location of the casting

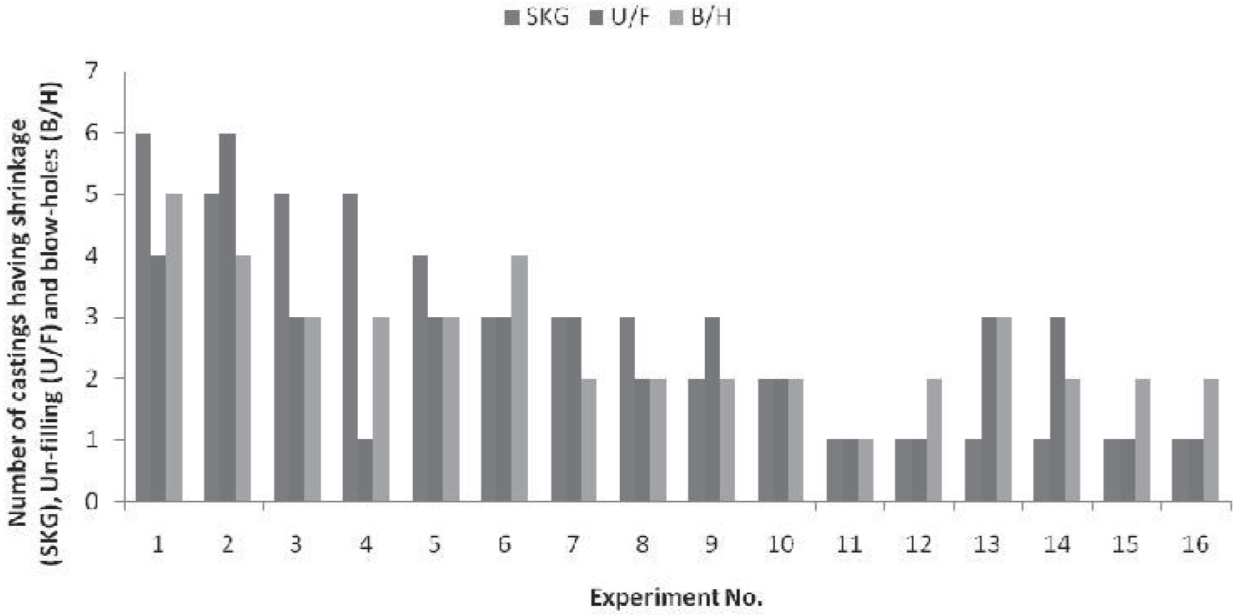
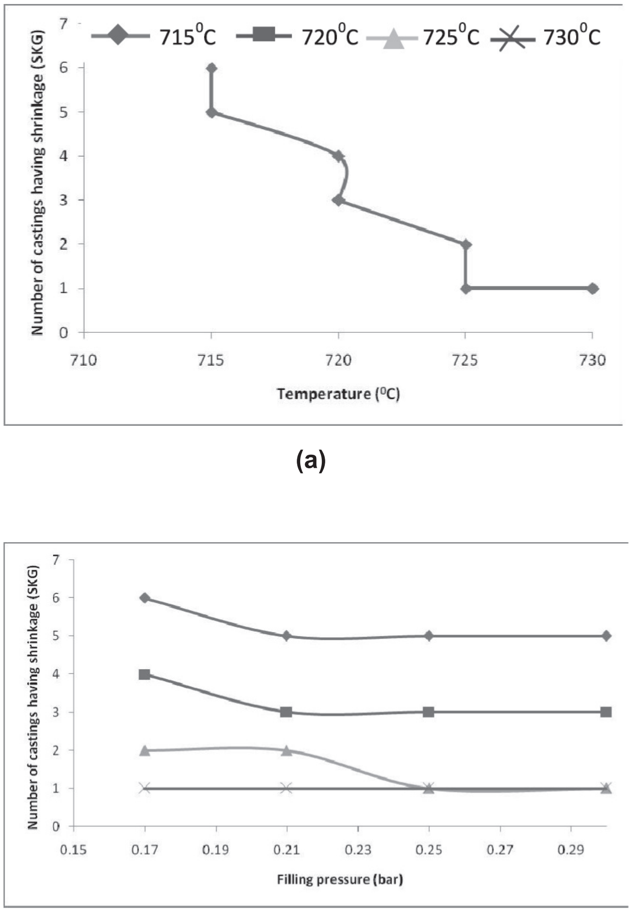


Fig.3: Shrinkage, un-filling and blow-holes observed in various castings



(a)

(b)

Fig.4: Number of castings showing shrinkage with increase in (a) temperature and (b) pressure

4.2. Un-filling

An un-filling defect occurs when the molten metal does not reach to a particular location. Fig.5 shows the un-filling defect occurred on the castings produced by LPDC. Fig.2 shows the number of castings having an un-filling defect for various temperatures and pressures. Thus from Fig.6, it can be seen that when the pressure was less (0.17 bar and 0.21 bar) it resulted in un-filling defects [9]. As seen from Fig.6, for the experiments 1, 2, 5, 6, 9, 10, 13, and 14 the pressure was minimum hence the number of castings with un-filling were more. It also resulted in the un-filling, when the temperature was minimum (715^0C) [8]. When the temperature was low, the molten metal lacked the fluidity required to reach the desired location giving rise to defect called as un-filling. Generally, there were two major causes for this defect one was low filling pressure and the second coating was not as per the required standard. These can be eliminated by keeping the pressure within the specified limits and the coating should be applied as per the standards given. The other factor that may result in un-filling was that there was some metal that remained attached to the die surface and the operator did not recognize it. The later reason is manual and was eliminated by proper instructions to the operator.

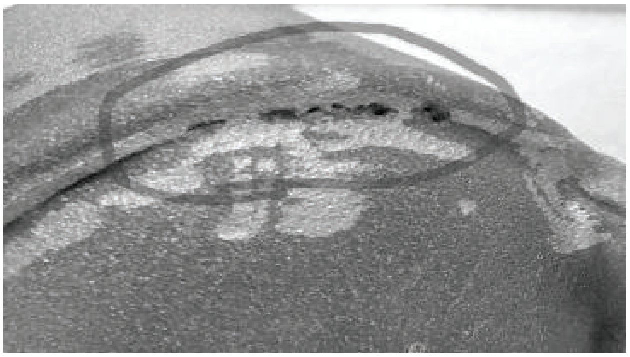
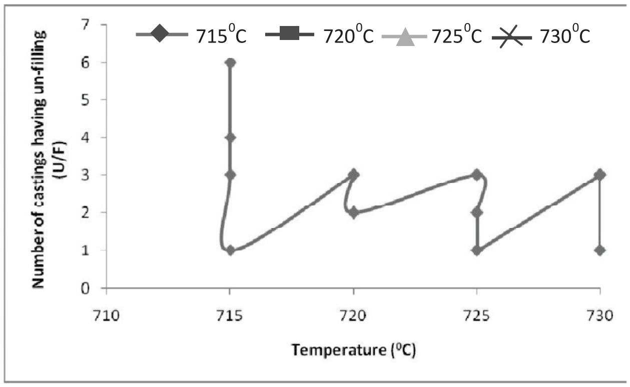


Fig.5: Un-filling at a particular location of the casting



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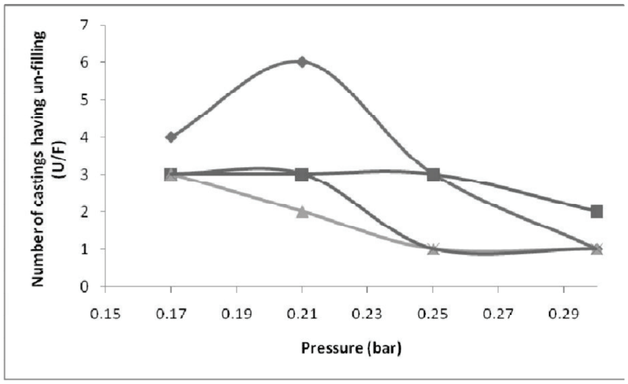
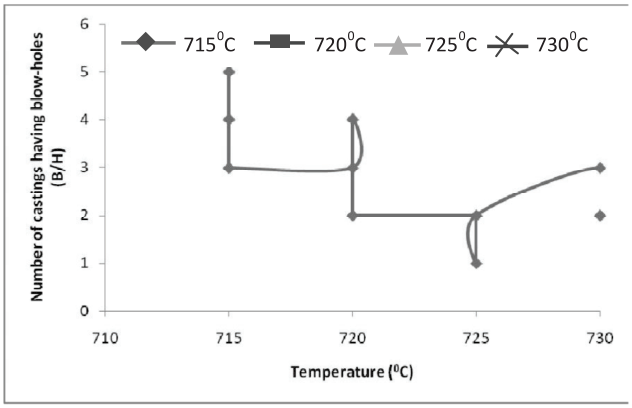


(b)

Fig.6: Number of castings showing un-filling with increase in (a) temperature and (b) pressure

4.3. Blow-holes

Fig.2 shows the blow-holes also called gas porosity, observed in various castings. It can be seen in Fig.7, as the temperature was increasing it resulted in decrease in the blow-holes defects. Also with the increase in pressure, it resulted in decreasing the blowhole defects [10]. This happened because blowhole was caused due to the gas bubbles which were formed when the temperature and the pressure were low. When the temperature was increased, the number of castings showing blow-holes was reduced as shown in Fig.7. Similar trend can be seen when the pressure was increased for the selected temperature.



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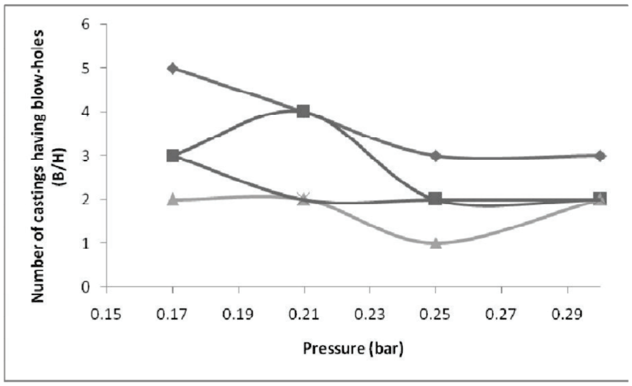

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Fig.7: Number of castings showing blow-holes with increase in (a) temperature and (b) pressure

4.4. Porosity

The remaining casting defects like porosity, extra-metal, boils and wire-mesh were studied and the number of castings showing these defects is plotted as shown in Fig.8. The number of castings showing these defects was very less as compared to previously discussed defects. Fig.9 shows the porosity observed in a various castings. It is clear that the temperature of the molten metal increased the porosity [2]. It can be seen in the figure that, as the metal temperature reached 730ºC, porosity defect came into picture dominantly. Sometimes at high pressure porosity defects were seen. This generally happened when the air was trapped in the metal and it was not cooled and resulted in the porosity.

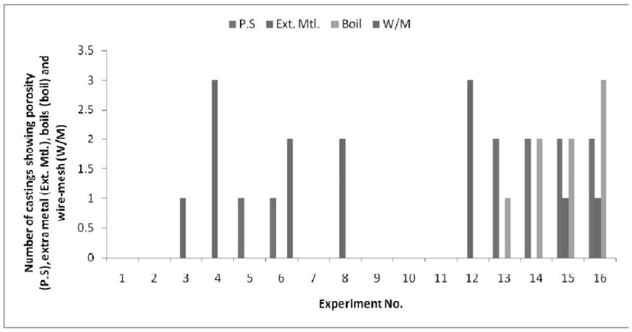
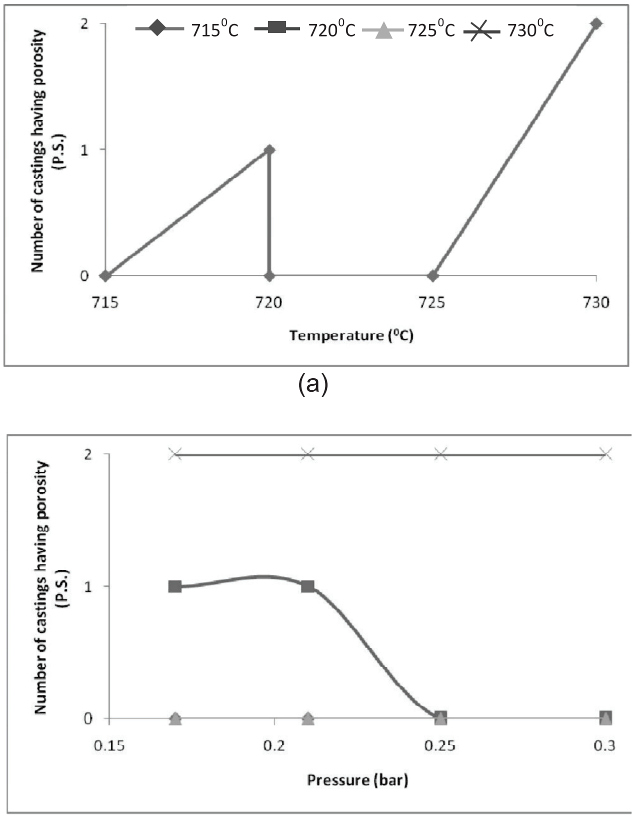


Fig.8: Porosity, extra-metal, boils and wire-mesh observed in various castings



(a)

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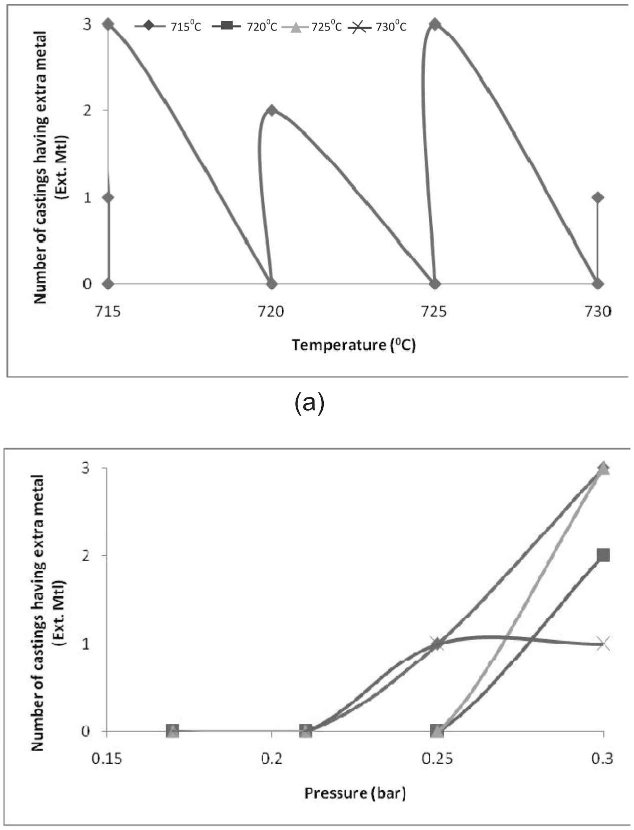
Fig.9: Number of castings showing porosity with increase in (a) temperature and (b) pressure

4.5. Extra Metal

Fig.8 shows the number of castings having defects called as extra metal. From the Fig.10 it can be seen that as the pressure at which the molten metal flowed in the die/cavity increased resulting in the formation of extra metal defects. This was because more metal flowed in the cavity than the required molten metal. These kinds of defects occurred at high pressures, or sometimes, even at the high temperatures. As shown in the Fig.10, for the experiments 4, 8, 12 and 16 the pressure was high, thus it resulted in the increased number of castings having this defect.



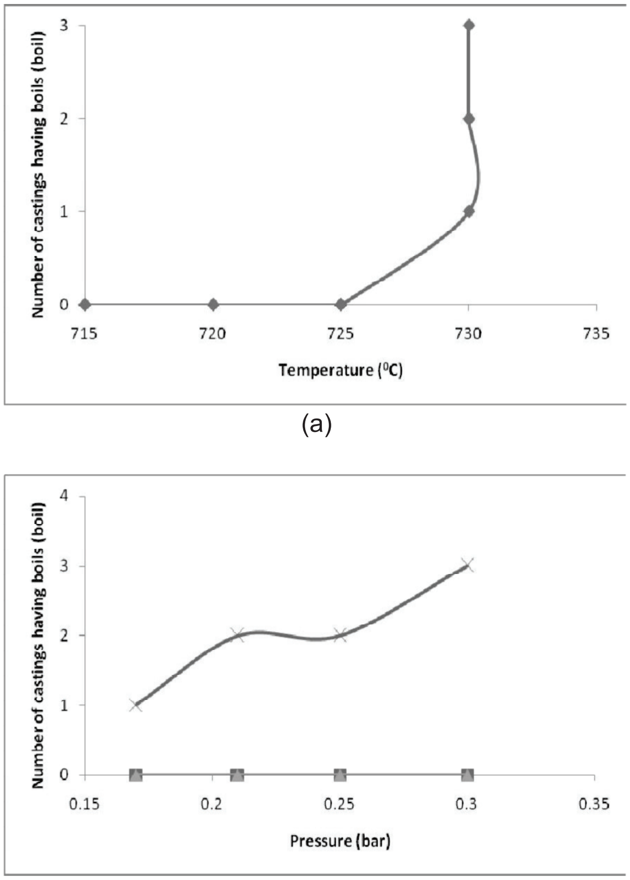
(a)

(b)

Fig.10: Number of castings showing extra metal with increase in (a) temperature and (b) pressure

4.6. Boil

Fig.8 shows the number of castings having defects called as boil. From Fig.11, it can be seen that, as the metal temperature reached its maximum value, it resulted in the formation of a defect called boil. This defect resulted in the formation of a hole like structure in the casting. This defect was the most important. It depended on the pressure as well as temperature, as high temperature and pressure resulted in the formation boil. As seen from the Fig.11, for the experiments from 13-16 the temperature limit was maximum which increased the formation of this defect.



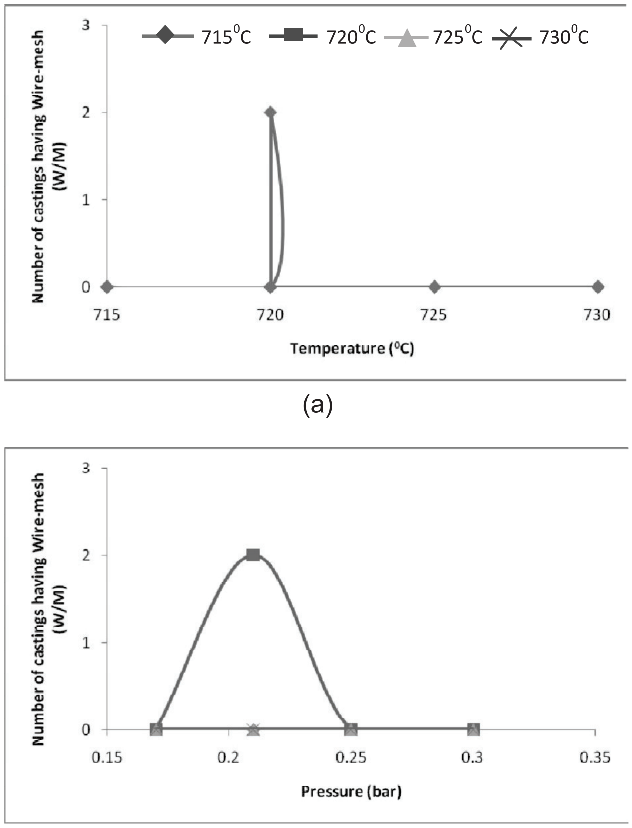
(a)

(b)

Fig.11: Number of castings showing boils with increase in (a) temperature and (b) pressure

4.7. Wire-mesh

Fig.12 shows the trend of wire-mesh defect observed for various castings manufactured at different temperatures and pressure. From the Fig.12 it can be seen that wire-mesh defect occurred only once during all the experiments. This was most probably because of the fault of the operator. Generally, wire-mesh was used to filter the oxides from the molten metal. This was fixed with the help of a magnet. But sometimes some particles of this wire-mesh got broken and thus got adhered and trapped in the cavity and this defect was seen.



(a)

(b)

Fig.12: Number of castings showing wire-mesh with increase in (a) temperature and (b) pressure

5. CONCLUSIONS

Casting defects in LPDC of aluminium alloys continue to challenge the engineers around the globe. In this study, an attempt was made to study the role of temperature and pressure in the formation of various casting defects in low-pressure die casting. The conclusions of this industrial case study are as follows.

1. It was observed that, as the metal temperature and the filling pressure go on decreasing it resulted in the formation of shrinkage. So, it was suggested that, for reducing this defect the temperature and pressure should not be minimum.

2. As the metal temperature and the filling pressure go on decreasing, it resulted in un-filling.
3. Blow-holes occurred at the low values of temperature and the pressure.
4. To reduce porosity it was suggested that the temperature should not be kept to its maximum level.
5. To reduce extra-metal defect, it was suggested to keep the pressure below the maximum limit.
6. A boil generally occur at high temperature. So, it was suggested to keep the metal temperature less than the maximum limit
7. Wire-mesh was observed as a fault of the operator. So, it was suggested to train the operator regarding awareness of this defect.
8. Considering all these defects of LPDC of AlSi9Cu1Mg, the temperature and pressure should be maintained at 725^0C and 0.25 bar, respectively to reduce casting defects.

Acknowledgements: Authors express sincere thanks to the industry at Pune (Maharashtra, India) for allowing them to perform the experiments.

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