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Procedia Materials Science 6 (2014) 1312 – 1328

Procedia Materials Science

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3rd International Conference on Materials Processing and Characterisation (ICMPC 2014)

Analysis and Optimization of Gating System for Commutator End Bracket

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Abstract

A well-designed runner and gating system is very important to produce good quality die castings by providing a homogenous mould filling pattern. Flow analysis of the component is done in order to visibly analyse the cavity filling process. In this study, a Commutator End (CE) bracket, a cold chamber die casted product was chosen. Initially when the component was casted numerous defects such as Cold shuts, Misrun, Shrinkage porosity and Gas porosity were found. This in turn led to rejection of number of components. In order to improve the quality of the castings produced, the gating system was changed from the existing flat gate to modified spoon fed gate. The component was designed using Pro- Engineer and flow analysis was carried out using Rotork Flow 3D Software. The process parameters like metal temperature, fill velocity and filling time are considered for optimizing the process. Quality assessment for the die casting parts was made by microstructure analysis.

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Keywords: Commuter End Bracket; Flow 3D analysis; microstructure analysis.

1. Introduction

Aluminium alloy die-casts are often used in automobile products that suffer repeated loading and thermal cycling in usage. Therefore, all factors that affect the mechanical properties of die-casts should be recognized and reliability of these components must be guaranteed. Among these casting defects it was identified that, ADC12 aluminium alloy has less defects comparing to other alloys. Therefore several applications such as automotive, electronics, aerospace,

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Selection and peer review under responsibility of the Gokaraju Rangaraju Institute of Engineering and Technology (GRIET)
doi:10.1016/j.mspro.2014.07.110

and construction appliances are generally manufactured in a large quantity by the high pressure die casting process using ADC12 aluminium alloy. Several advantages of this alloy in the die casting process are high production rate and the ability to form small complex shapes. The die casting process involves the injection of liquid aluminium into a die cavity under high pressures. Tian et al [10] investigated the effect of melt cleanliness on the formation of porosity defects in automotive aluminium high pressure die castings. It was found that the increase in inclusion in the melt such as amorphous oxides, oxide films and sludge particles increases the probability of rejection. Paul Cleary et al [3] discussed the advances in modelling of casting processes smoothed particle hydrodynamics (SPH). They aimed at improving the visualization of the analysis results by comparing the SPH results of various parameters of free surface motion. Avalle et al [1] studied about the influence of casting defects on static and fatigue strength of die cast aluminium alloy. The casting defects that existed include cold fills dross and alumina skins. The batches of specimen varying in runner and sprue design were analyzed. They found that there were no significant variations in the fatigue strength between the acceptable and non-acceptable components. Shuhua Yue et al [14] developed an integrated CAD/CAM/CAE system and applied it in the primary stage, and the software packages like pro-E, magmasoft, etc were used to establish a primary expert system for the die casting. They concluded that this integrated system reduced the lead time and shortened the cycle time of die design resulting in an increase in productivity. Guilherme et al [5] investigated the influence of speed injection parameters in the first and the second phases and of the upset pressure over the influence of die castings quality. They concluded from the experiment results and the results obtained through the analysis that both the results coincide regarding the trend to porosity and cold shuts occurrence.

Seo et al [7] made an attempt to improve the fuel efficiency by substituting aluminium alloy for steel parts. Semi-solid die casting process was used to improve the mechanical properties of aluminium-alloy parts. They proposed a die structure for semi-solid die casting and verified it by experiments. Sung and Kim [8] used computer simulations to analyze the flow of molten metal and concluded that as the in gate velocity in thin plate castings increased, the cold shot had decreased. They calculated results for automobile valve body mid-plate through simple equations which were in agreement with experimental data. Kong et al [6] established an integrated optimization for high pressure die casting processes .They used infrared thermograph technology to optimize the internal cooling system thereby improving the productivity of the process and the quality of castings. Verran et al [12] applied the Design Of Experiments (DOEs) method for analysing the influence of three injection parameters namely slow shot, fast shot and upset pressure .The presence of porosity in die cast products were analysed using various combinations of injection parameters. Variation in the three different injection parameters influencing the integrity of the components were studied using variance analysis and the results were evaluated. Dorum et al [4] studied the structural behaviour of Al-Si castings using axial crushing and three-point bending tests. The components were modeled with non-linear explicit FE-code LS-DYNA using shell elements. The fracture criterion of Cockcroft and Latham were used to predict the failure in HDPC components. They proposed a novel modelling approach for different material properties through the thickness. Verran et al [11] investigated the influence of speed injection parameters in the first and the second phases and of the upset pressure over the influence of die castings quality. They concluded from the experiment results and the results obtained through the analysis that both the results coincided regarding the trend to porosity and cold shuts occurrence.

Teng et al [9] established a relationship between ductility and the pore size of an aluminium casting. They concluded that the tensile fracture strain decreases with the area of the largest pore a linear fashion. The tensile ductility is more sensitive to pore size than shear ductility. Cleary [2] applied Smoothed Particle Hydrodynamics (SPD) to predict the metal shrinkage, oxide formation, feeding, solidification front dynamics, residual pressure distribution in the solidified metal and cavity defect formation in Low pressure die casting. Laihua Wang et al [13] performed a quantitative study on the gas level of High Pressure Die Castings using vacuum fusion method. They found that the major part of the gas was from air entrapment during cavity filling and also that the gas content was unevenly distributed. Rodrigo González et al [5] studied the fatigue strength of A319 aluminium alloy castings using fully reversible tension and compression tests. They concluded that fatigue cracks originated from pores and single cracks occurred at nominal reversible stress of 120 MPa and multiple cracks occurred above this limit.

Nomenclature

d	=	plunger diameter
k	=	0.0346
Ti	=	6400 °C
Tf	=	5700 °C
Td	=	1800 °C
S	=	25%
Z	=	3.8
V_{of}	=	Volume of overflow and feed system
Casting average wall thickness	=	2.5 mm
Weight of component	=	440 gm
Component Volume (V_c)	=	120650.8 mm^3
Density	=	2.74x10-3g/mm^3
Projected area of component (A_c)	=	15580 mm^2
Shrinkage	=	0.0055 mm/mm
Wall Thickness	=	2 mm – 10mm
Draft Angle	=	1.5°
Angular Tolerance	=	±0.5°
Specific injection pressure (P_i)	=	600 bar
Factor of safety	=	1.05
Stroke length for 350T machine	=	420 mm.
Fill ratio	=	0.30

2. Problem Identification

Due to the existing Flat gate system in the existing model, the following defects occur in the casting leading to rejection and loss in quality. Hence, a new optimized gate design is necessary in order to remove defects from the casting.

2.1 Casting Defects in the existing Model

2.1.1 Flow Mark

Flow mark is the occurrence of visible metal flow marks on the casting surface. They show traces of metal flow. It can be removed by proper polishing of the mould cavity. The main causes for this defect is Non parallelism between platens of die, less draft provided and worn out Tie bar guide bushes

Figure 1: Flow mark on casting

2.1.2 Blow Holes

Blow-holes are produced because of gas entrapped in the metal during the course of solidification which is shown in figure 2. They are smooth-walled cavities, essentially spherical in shape. The main causes for this defect is low velocity and pressure and excess machining stock and bad Chill vent design

Figure 2: Blow holes on casting

2.1.3 Gas Porosity

Gas porosity is the formation of bubbles within the casting after it has cooled which shown in figure 3. Gas porosity may present itself on the surface of the casting as porosity or the pore may be trapped inside the metal which reduces strength. The main causes for this defect is low velocity and pressure of molten metal, excess machining stock and bad Chill and vent design.

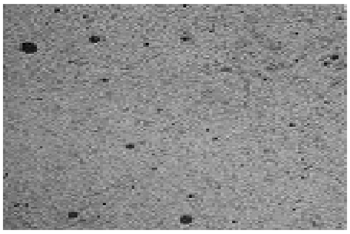

Figure 3: Gas porosity on casting

2.2 Analysis and causes for defects

Since, the gas porosity defects is to be reduced as per the customer requirement, the reason for the defects are analyzed

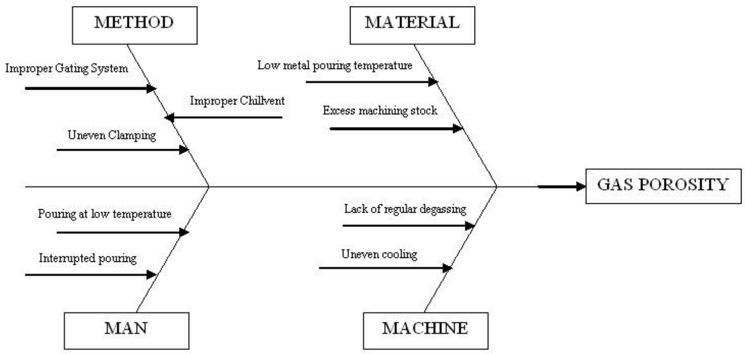

Figure 4: Cause and effect diagram for the gas porosity defect

Figure 4 shows the various causes and the subsequent effects of various activities due to which gas porosity occurs. The arrow marks indicate the various causes for the gas porosity defect. The filling pattern of gating system plays a significant role for the assessment of the quality of cast products. Particularly the pouring process of light metals is very dynamic and complex. The flow velocities in some areas of gate are very high. The solidification of the melt during the mould filling, continuously changes the properties of liquid and solid phases. In addition, the interaction between metal-mould and metal-core has to be continuously monitored. All above mentioned properties have to be taken under consideration during modelling and simulation of the filling process.

3. Design of Runner and Gating System

3.1 Modelling of Commutator end bracket

A commutator end bracket is formed to include bases for mounting the commutator end bracket to a motor. Windows are punched into side pieces of the bracket for receiving brushes for communication with a commutator. The brushes are retained by a clip received within channels formed along the edges of the side pieces. The initial design of the commutator end bracket was done using Pro Engineer. A parting line was created in order to separate the fixed and movable die portions. Then, a suitable draft was provided on either side of the parting line to ensure easy removal of the casting.

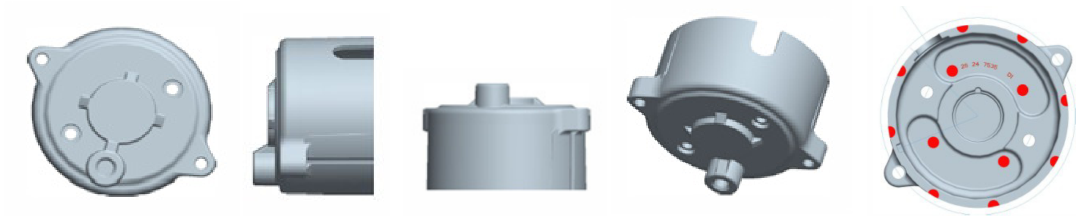

Figure 5: Model of commutator end bracket

3.2 Draft analysis of commutator end bracket

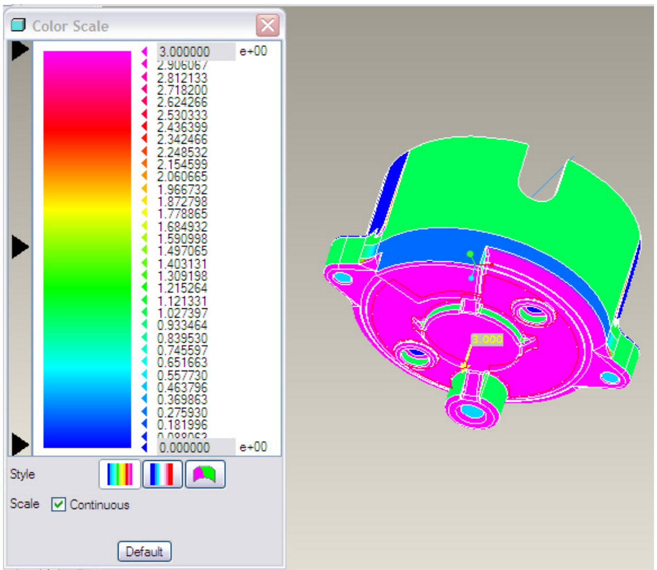

Figure 6: Draft analysis of commutator end bracket

The draft analysis shown in figure 6 was carried out to ensure that sufficient draft was provided while designing the component. A minimum draft angle of 1degree was given to the component on either side of the parting line in order to effect easy removal of the component from the die. The green region in figure 6 shows that a draft angle of 1 degree was provided.

3.3 Runner Design

Runners should be shaped in such a way to minimize the surface area to volume ratio. Multiple runners must be placed as far as possible to minimize heat concentrations in the die. Various types of runner are shown in figure 7

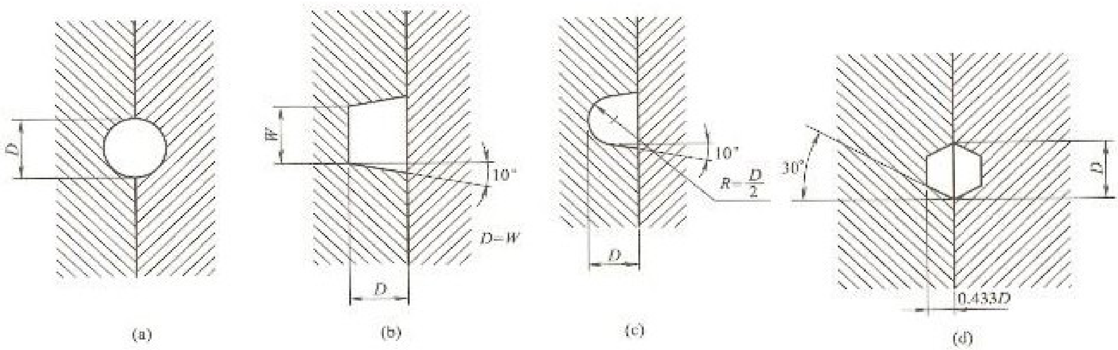

Figure 7: Runner profiles (a) fully round (b) trapezoidal (c) modified trapezoidal (d) hexagon

The criterion of efficient runner design is that the runner should provide a maximum cross sectional area from the standpoint of pressure transfer and a minimum contact on the periphery from heat transfer.

3.4 Gating system

The gate is the most restrictive orifice in the total fluid flow concept of the filling operation in the die-casting die. It is the point at which the metal enters into the die cavity. There exists a geometrical &mathematical relationship for the dimensioning of the gating of die casting dies. Most of the casting defects such as bad surface, improper filling, flow marks, cold shuts, soldering and thermal imbalance are caused due to improper gating. The location, size, and type of gate are 3 important factors in gating.

3.4.1 Existing gate flat gating system

It is a type of gating where the metal flows perpendicularly to the side walls of the casting. In this type, when the metal flows into the cavity it is directly met with an obstruction thereby reducing the flow velocity and causing turbulent flow into the cavity.

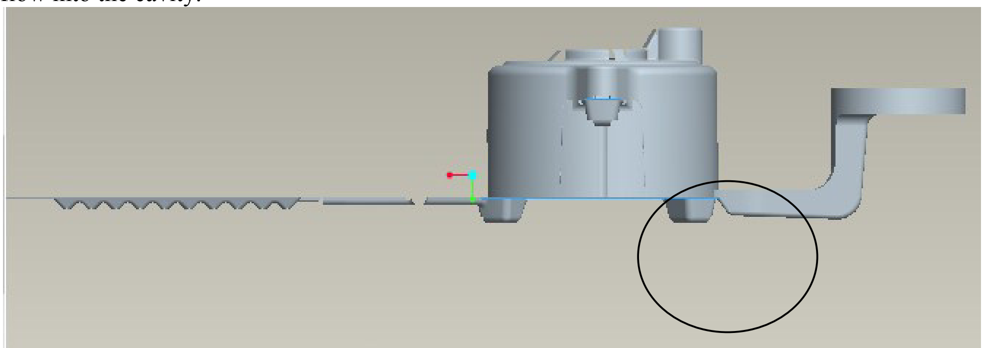

Figure 8: Flat gating system

3.5 Die design calculations

Tonnage Calculation

Projected area including overflow and feed system	=	A_c x Factor = 15580x 1.4 = 22232 mm^2.
Injection Pressure x FOS	=	P_s x P_i x FOS = 22232x600x10^{-2}x1.05
	=	140.06 T
Total Tonnage required for locking	=	140.06+ 65.59 +59.47 = 265 T

Hence we can select 350 T machine according to obtained tonnage from the calculation.

Shot Weight

$V_c + V_{of}$ (Excluding biscuit)	=	120650.8 x 1.4 = 168911.12 mm^3
Actual shot volume (V_s)	=	168911.12+ $\pi d^2 t/4$ mm^3
Stroke length for 350T machine	=	420 mm.
Volume delivered by machine	=	πd^2 x (420/4) x 0.3
d	=	38.06 mm
Shot weight (W_s)	=	V_c x ρ
	=	120650.8 x π/4(60) 2x 2.54 x 10-3
	=	0.341 kg

Available plunger sizes in 350T machines are 60, 65, 70 mm hence we can select 60 mm plunger tip

Fill ratio calculation

The fill ratio is the ratio of metal volume to shot sleeve volume. This value for fill ratio is acceptable for the process, since it is Vacuum Assisted Die casting. The value was calculated as 0.083

Fill ratio = Metal volume/ Shot sleeve volume
= (120650.8 x π x (60) 2 x515)/4
= 0.083

Fill Time Calculation

Fill Time = k $[T_i - T_f + s*z]$ T/ $[T_f - T_d]$
t = {0.0346 [640 – 570 + 25 x 3.8] x 2.5}/ [570 – 180]
= 14.27/390 = 0.0365 s

Gate calculations

Calculate fill rate using the formula
Fill rate = Volume of the metal flow through gate/ Cavity fill time
= 1206508mm3/sec

Table 3: Suggested die filling time for Zn and Al per second

Average wall thickness (mm)	Suggested Die filling time for Zn/sec	Suggested filling time for Al/sec
1.5	0.01-0.03	0.02-0.06
1.8	0.02-0.04	0.04-0.08
2.0	0.02-0.06	0.04-0.12
2.3	0.03-0.07	0.06-0.14
2.5	0.04-0.09	0.08-0.18
3.0	0.05-0.10	0.07-0.15
3.8	0.05-0.12	0.07-0.18
5.0	0.06-0.20	0.09-0.30
6.4	0.08-0.30	0.12-0.45

Calculate the area of the gate
Gate area = Fill rate/ Gate velocity = 1206508/40500
= 29.79 mm^2

(Gate Velocity must be 40.50m/s)
Calculate the length of the gate
Gate length = Gate Area/ Gate thickness = 29.79/1.6
= 18.5mm

Table 4: Gate thickness for different alloys

Material	Gate thickness (mm)
Al Si - alloy	1-1.4
Al Si Cu –alloy	1.2-2.5
Zn Al4 – alloy	0.35-0.8
Zn Al4 Cu alloy	0.5-1.2
Mg Al2	0.6-2
58-60 Brass	1.5-3

Calculate area of the runner
Runner area = 2×gate area = 2×29.79=59.58mm2
Calculate the width of the runner
Runner width = √ (2× runner area) = √ (2 ×59.58)
= 10.91mm

Calculate the depth of the runner

Runner depth = Runner width/2 = 10.91/2 =5.45mm

But in the component Gate length available is 55mm.

Therefore Gate Area kept is = 1.6x55 = 88 mm^2

Thumb rule is that if Gate Area is equal to ¼ of the component mass then we will get a good filled casting.

Component Mass = 440 gm

Therefore minimum gate area required = 440/ 4 = 110 mm^2

Hence gate thickness of 1.6mm, gate length of 55mm and gate velocity of 40m/sec will produce atomization.

3.5.1 Proposed design- spoon fed gating system

It is a type of gating where the metal flows along the side walls of the casting thereby causing smooth flow of molten metal and uniform fill of the cavity.

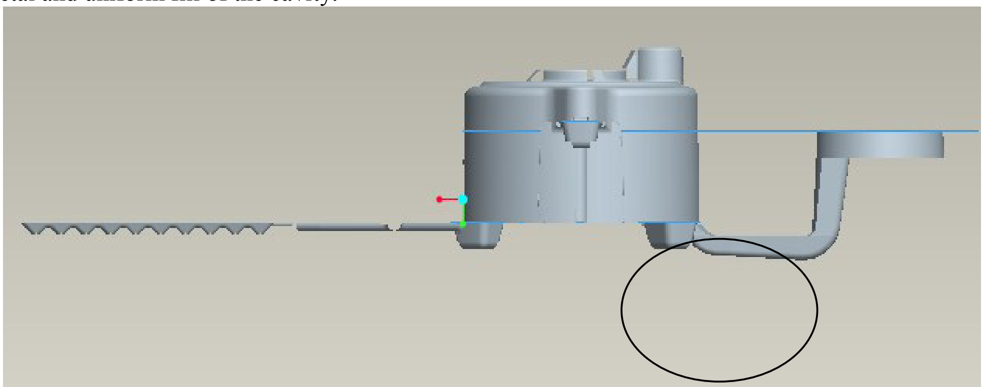

Figure 9: Spoon fed gating system

4. Results and Discussion

The flow analysis was carried out for the existing Flat gating system and the optimized spoon fed gating system in order to accurately track the metal as it enters the die cavity under high pressure and high velocity. A major challenge when designing a casting is determining whether or not the final part has defects. Designers can often produce a good quality part by following best-practices for designing gating, runners, risers, pour temperatures and chill sizing. This work used FLOW-3D package, which enables casting designers to quickly and accurately identify and locate defects allowing parts to be produced with higher quality in a shorter amount of time.

4.1 Flow Simulation

4.1.1 Initial Conditions for flow analysis

The material which was used for analysis is Alloy ADC12. The various boundary conditions which were considered while doing the flow analysis of the component was metal temperature of 6600 ° C and die temperature of 1500 °C with a fill time of 40milliseconds. The design values that were considered for reference are gate velocity of 40 m/sec with specific injection pressure of 600 Kg/cm sq. The plunger velocity at 1st stage and 2nd stage were 0.25 m/s and 1.75m/s respectively.

4.1.2 The Pressure distribution in Isometric view

The objective of performing a pressure simulation on the component is that the component should have uniform pressure distribution when the metal is fully filled inside the cavity. This is also used to detect the possibilities of turbulence that might occur during the flow of the metal inside the cavity. A negative pressure during the flow may indicate possibilities of turbulence. Turbulence of metal flow may cause various casting defects in the component like gas porosities, shrinkage porosity etc.

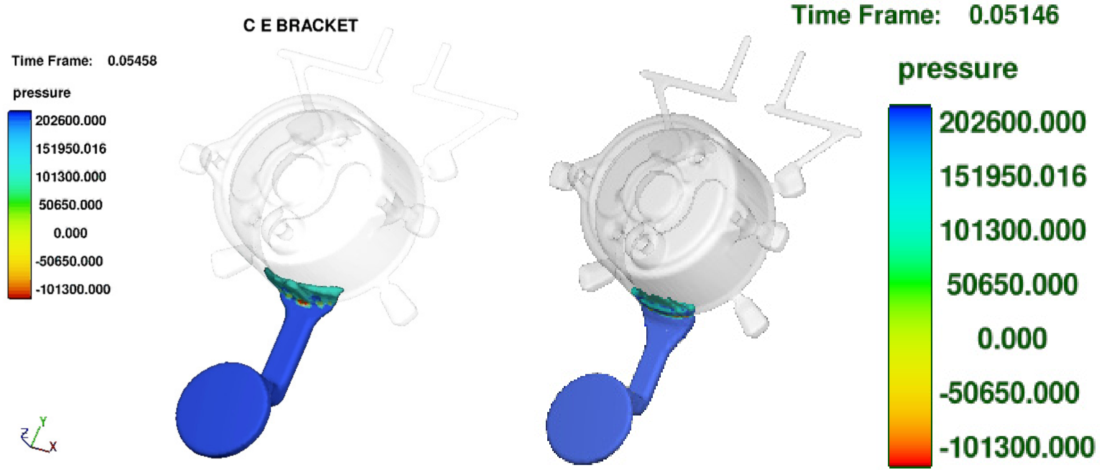

Figure 10: Pressure Simulations at Gate Entry

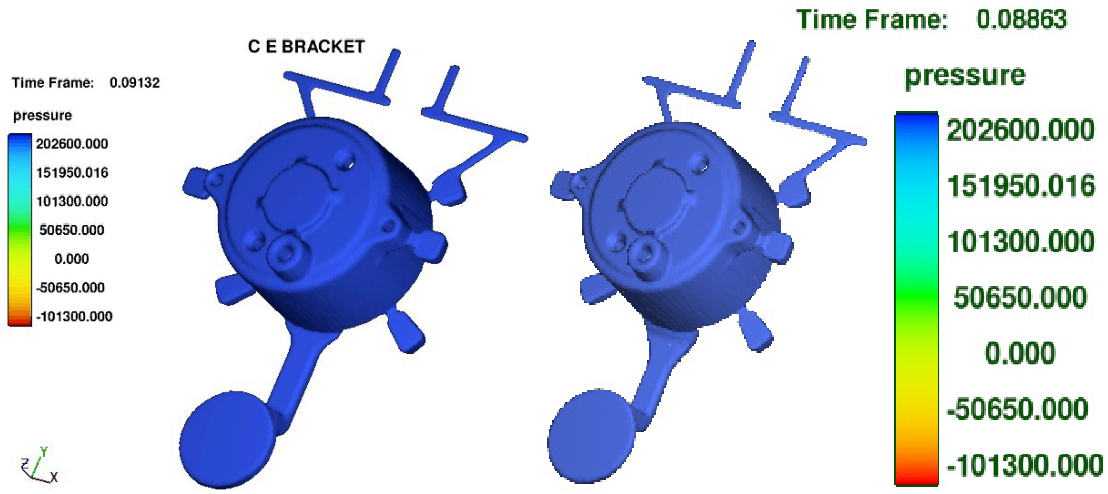

Figure 11: Pressure Simulations up to 100 % of cavity fill time

It can be seen from the simulation from figure 10 and 11 that, in the flat gate design; the metal is splashed all over the component and leads to turbulence of metal flow inside the mold. It can also be seen that in the flat gate near the place of metal flow inside the cavity, there is a region of negative pressure which also induces turbulence of metal flow. Occurrence of stream mixing requires addition of overflows which in turn increases the volume of metal poured into the sprue during the casting process. In the spoon gate design, the flow is steady and the metal is distributed uniformly into the mould cavity. The metal flows smoothly inside the cavity and there is no presence of turbulence inside the cavity. This in turn will produce better quality castings. Due to the absence of stream mixing, there is no need of extra overflows which in turn does not affect the volume of metal poured into the sprue during the casting process.

4.1.3 Velocity Distribution

The metal flow inside the casting with very high velocity leads to flash. Flash is a thin web or fin of metal on a casting which occurs at die partings, vents and around moveable cores. This excess metal is due to working and operating clearances in the die. The velocity simulation is very much useful in designing the overflows which need to present in component. As the filling velocity increases, the density of the casting increases up to a certain limit and decreases rapidly .High quality castings must have high density and thus higher velocity affects the quality of the castings.

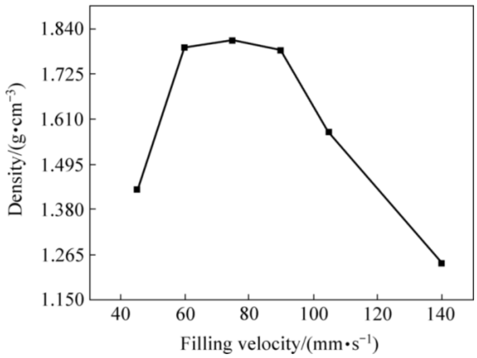

Figure 12: Density of casting Vs filling velocity

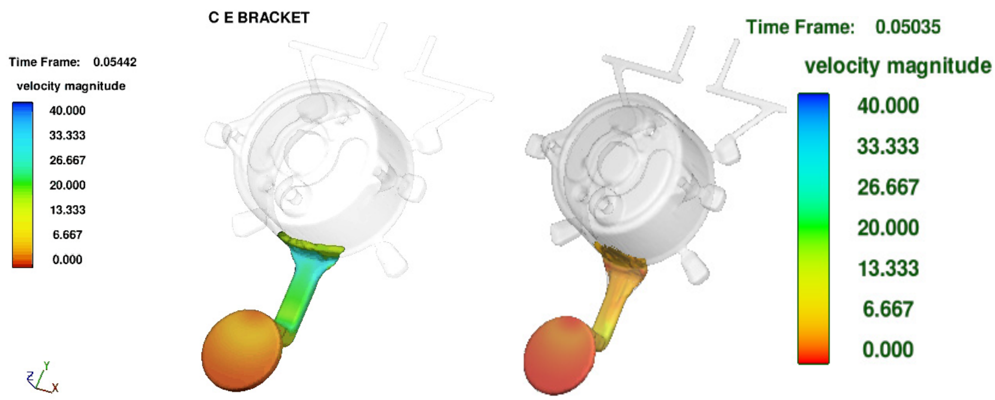

Figure 13: Velocity Simulations at Gate Entry

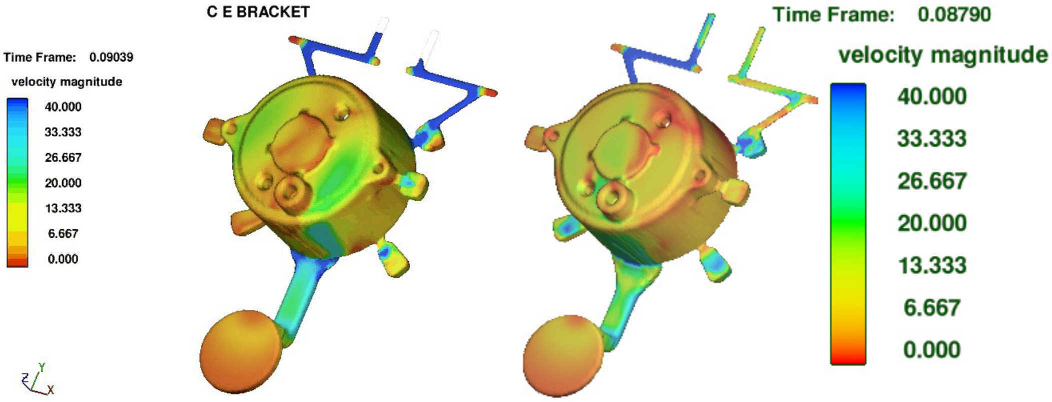

Figure 14: Velocity Simulations up to 100 % of cavity fill time

It can be seen from the figure 13 and 14 that in the flat gate design, at the gate entry section the metal enters with very high velocities which in turn would lead to flash. In spoon gate design, the velocity is too much reduced between 13.33 and 26.66 m/s from the previous 26.66 to 40.0 range. This shows the spoon gate is much safe and no flash might occur during the filling of the component.

4.1.4 Temperature Distribution

The metal which is poured from a ladle into a cold chamber die casting must have high temperatures in order to produce good quality castings. The temperature of the metal should be ideal and not too high as it influences the casting density. As the pouring temperature increases, the density of the casting increases up to a certain limit and decreases further .High quality castings must have high density and thus higher temperature affects the quality of the castings.

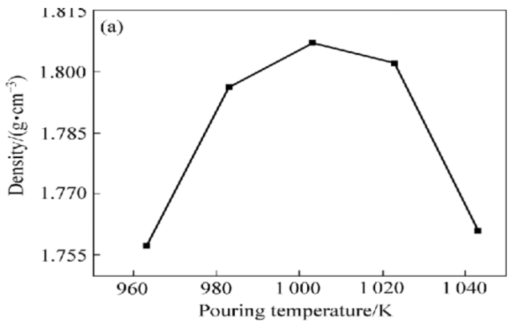

Figure 15: Density of casting Vs pouring temperature

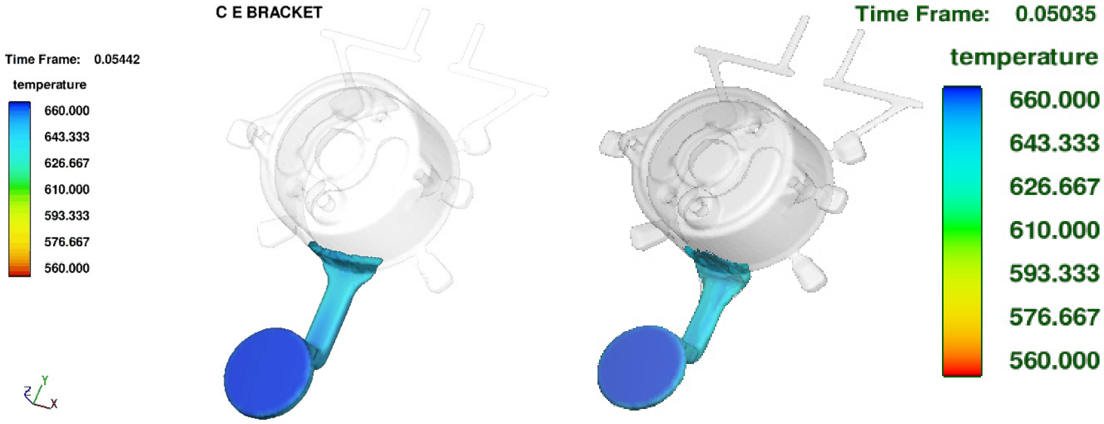

Figure 16: Temperature Simulations at Gate Entry

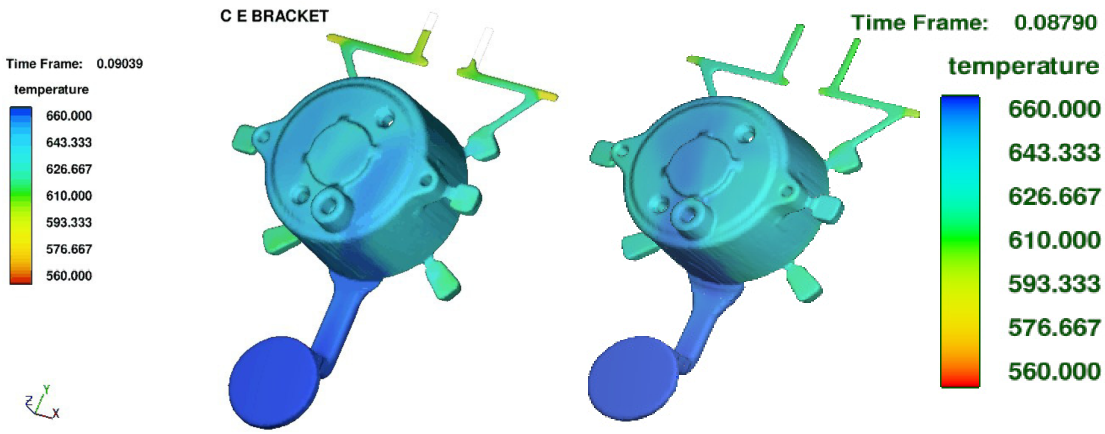

Figure 17: Temperature Simulations up to 100 % of cavity fill time

It can be seen from figure 16 and 17 that in the spoon fed gate system, the temperature remains ideal when compared with the flat gate component. It can also be seen that the temperature in the spoon gate gradually changes rather than a sudden change as seen in the flat gate. This in turn causes misruns and cold shuts in the component thereby reducing the quality of the casting. In the optimized gating system this is reduced considerably which in turn produced better quality castings and reduced rejections.

4.1.5 Porosity

Porosity may be the most persistent and common defect of castings. Forgings, machined parts and fabrications are able to avoid porosity with ingot cast feedstock, mechanical processing and automated inspection of simple shapes. Porosity in castings is due to bubbles being trapped during solidification. Porosity sources include entrapped air during filling, centreline shrinkage that occurs during the final solidification, blowholes from unvented cores, reactions at the mould wall, dissolved gases from melting and dross or slag containing gas porosity. One source of porosity in castings is a failure to eliminate all the air in the mould cavity. Most often this porosity appears to be a misrun or incomplete casting. In skin forming alloys when the filling event is chaotic, air bubbles can be entrapped in the casting. In order to check for the porosities inside the casting, the component is sliced during the time of maximum porosity and its plot is seen.

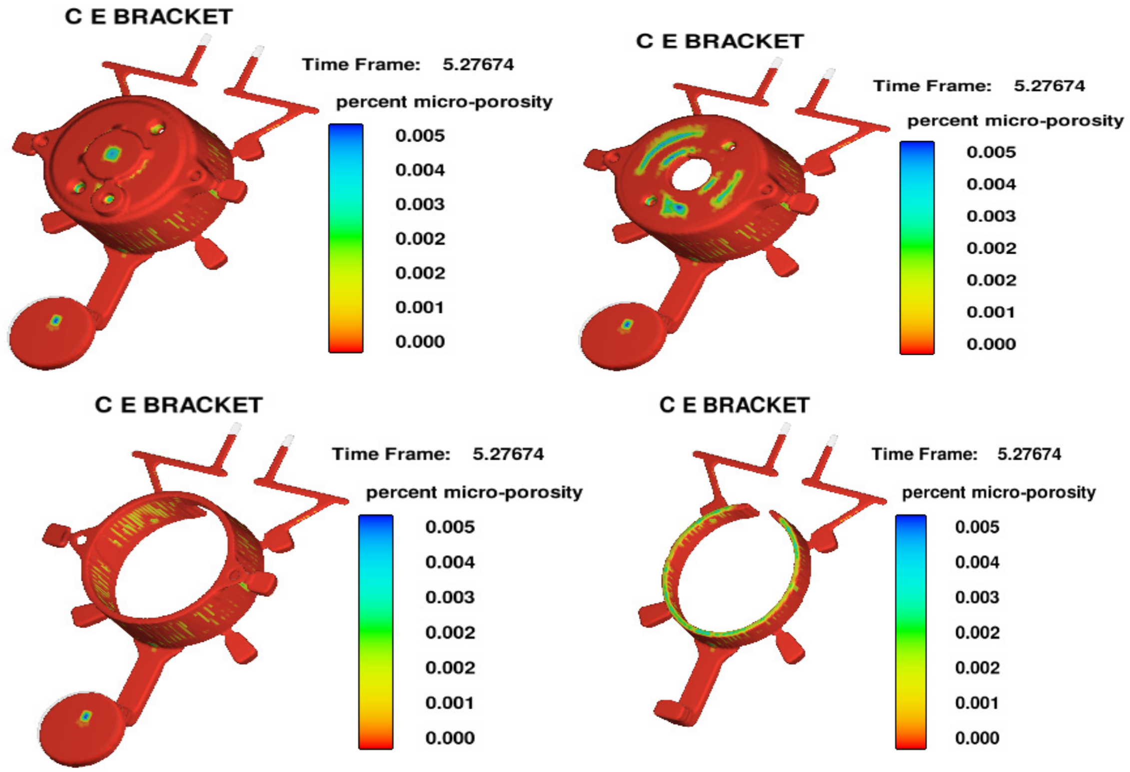

Figure 18: Sectional views of commutator end bracket using Porosity simulation

It can be seen from the figure 18 that at the top section of the component there seems to more percentage of micro porosity in the flat gate when compared with the spoon fed gate. Porosity in castings contributes directly to customer concerns about reliability and quality. Controlling porosity depends on understanding its sources and causes. Significant improvements in product quality, component performance, and design reliability can be achieved if porosity in castings can be controlled or eliminated.

4.1.6 Solid Fraction

When a liquid is cooled below its equilibrium solidification temperature the solidification takes place as growing dendrites of microscopic scale. An essential feature of the material formed this way is its solid fraction, which is less than unity due to liquid entrapped between the solid dendrites. The solid fraction must be unity at the end of the filling time as shown in figure 19. In the spoon fed system, the values of solid fraction are closer to unity which indicates higher quality castings than the flat gate design.

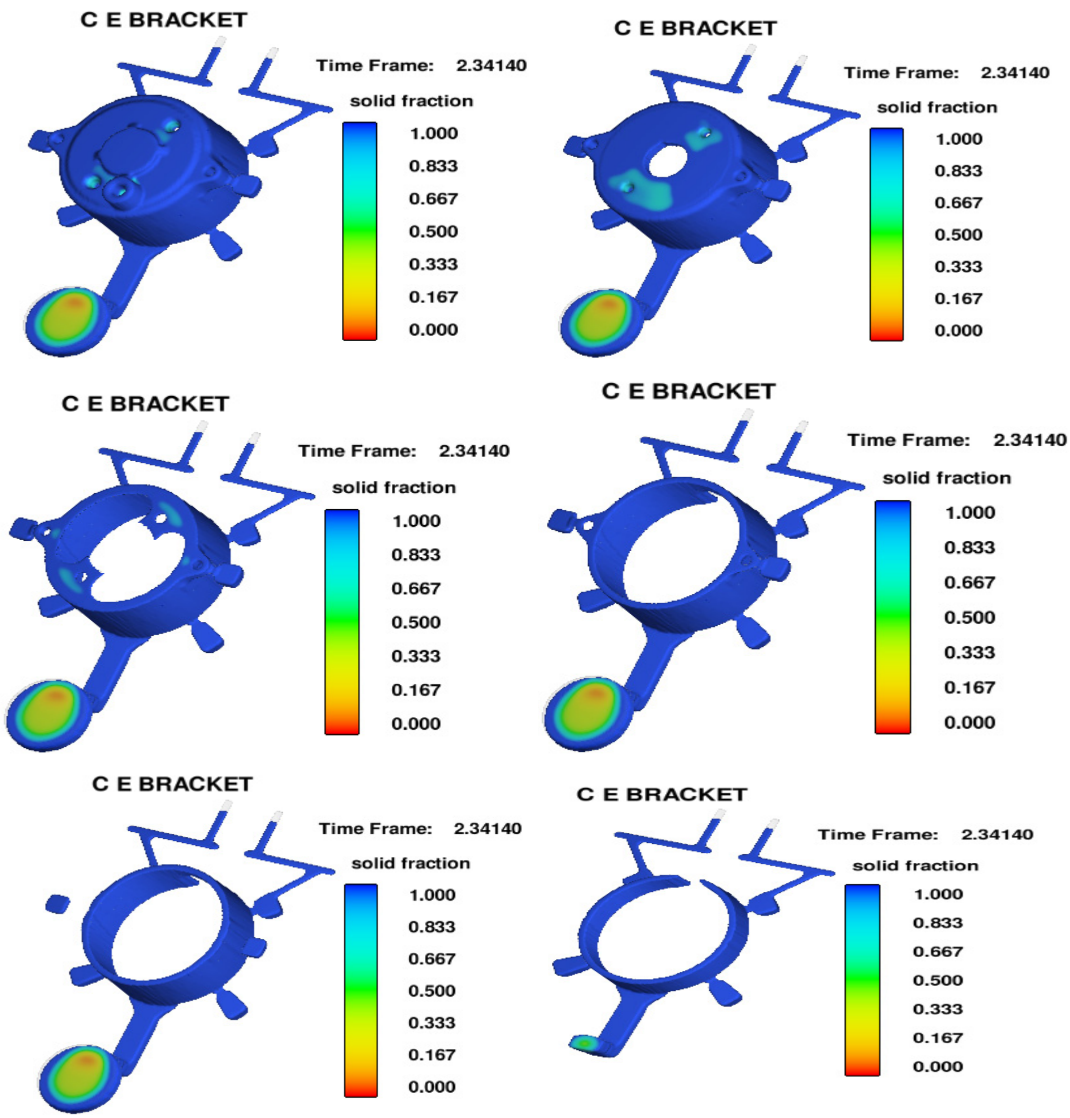

Figure 19: Sectional views of commutator end bracket using Solid fraction Simulation

4.2 Microstructure Validation

The microstructure shows typical chilled cast aluminium alloy microstructure using 100X magnification and H.F. etchant solution. The matrix on examination shows the reduction of shrinkage porosity in thick section from 300 microns in the existing design to 20 microns in the optimized design. The microstructure shows typical chilled cast aluminium alloy microstructure. The matrix on examination shown in figure 20 and 21 shows the reduction of shrinkage porosity in thin section from 250 microns in the existing design to 30 microns in the optimized design. The scanning also shows the presence of micro porosities. The micro structure shows fine inter-dendritic Al-Si eutectics in aluminium solid solutions. There is presence of some undissolved Cu-Al2 particles.

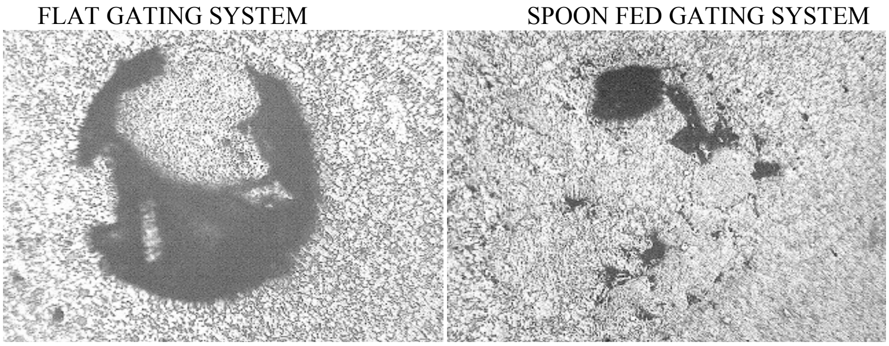

Figure 20: Microstructure image comparison of thick section

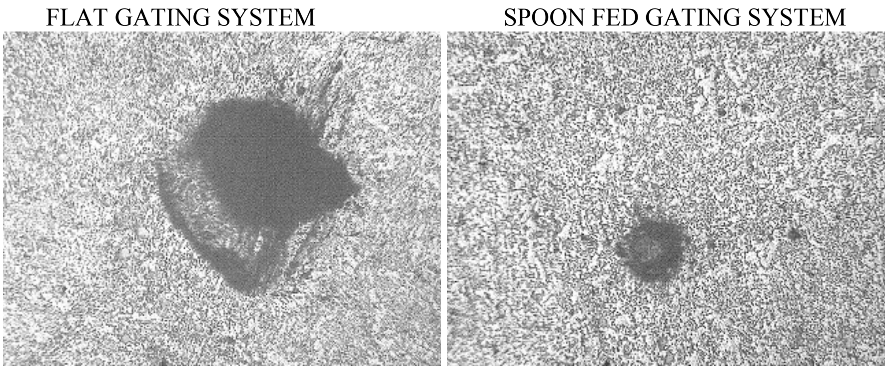

Figure 21: Microstructure image comparison of thin section

5. Conclusion

The paper dealt with the optimization of the gating system due to which various casting defects and the manufacturing lead time were significantly reduced. Initially, the component CE bracket was selected .The component was examined for defects by testing under an optical microscope and it found to contain hot tears, shrinkage porosities , gas porosities and flow marks on the surface of the component . This was due to improper gating system which had to be rectified and optimized .The previous gating system was a flat gating system .It led to turbulence, uneven, non uniform filling of the die cavity and due to these problems various defects were found to occur in the component. The quality of the casting was reduced as the density decreases proportionally to the amount of porosity leading to higher rejection rates. It was also found that there was non-uniform cooling of the component due to which the present design of the runner and gating system was studied thoroughly and the flow simulation results had also proven the above said defects. A new spoon fed gating system was designed so that the molten metal flows into the die cavity with uniform filling and lesser filling time. The negative pressure at the gate entry due to which turbulence was caused is also rectified. The flow analysis of the new optimized design was conducted and the results were validated using the microstructure examination of the components.

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