Minimization of Casting Defects in Aluminium Alloy Oil Tank Casting through Quality Control and Design

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ABSTRACT
Casting process contains complex interactions with various parameters and operations related to molding, melting, degassing, metal composition, hardening, cooling and machining. In Gravity die casting process the metals enters the mold under gravity. Gravity die casting method is used for manufacturing of aluminium alloy oil tank. Aluminium alloy replaced many metal to maintain quality of performance. Aim of the project is to reduce minimize the defect in aluminium alloy (LM6) oil tank casting and improving the productivity of organization using statistical process control approach. Casting defects analysis is done by Cause and Effect diagram or Ishikawa diagram and Pareto chart. Rejection of castings is due to blow holes, pin holes, porosity and shrinkage finally casting defect is reduced by improving degasification step and by checking the temperature of molten metal and mold and new design proposal is given.
KEYWORDS - Ishikawa diagram, Pareto chart,Degasification, LM6 Aluminum alloy

1. INTRODUCTION

Casting is defined as a process in which molten metal is poured into a mold that consists of hollow cavity of the required shape. The metal and mold are cooled, and then metal part (casting part) is extracted.The die casting process in which forces molten metal under high pressure into mold cavities. Most die castings are made from nonferrous metals, specifically Zinc (Zn), copper (Cu) and aluminium-based alloys, but ferrous metal die castings are also possible. The die casting method is suited for applications from which varies small to medium-sized parts are needed with good detail, a fine surface quality and dimensional consistency.

Generally in aluminum alloys, Aluminum is the important metal. The typical alloying elements are copper (Cu), Magnesium (Mg), Manganese (Mn), Silicon (Si), Tin (Sn) and Zinc (Zn). Mainly aluminium alloys are classified into two types namely casting alloys and wrought alloys and further sub divided into the categories heat treatable and non-heat treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions.

Aluminium alloy Characteristics - Operating temperatures are high, Corrosion resistance is excellent, lightweight, Good strength and hardness, Good stiffness and strength, Thermal conductivity is outstanding, Electrical conductivity is high.The important and most cast aluminium alloy used is Aluminium-Silicon (Al-Si), in which it consists of 4% - 13% of silicon which is high level gives good casting characteristics. In engineering structures and components aluminium alloys are used because those alloys are light weight, corrosion resistance etc. which is very much required. Density of Aluminium is 2.7g/cm3 which is approximately one by third (1/3rd) as compared to steel.The aluminium surface which is exposed is mixed with oxygen to form inert Aluminium oxide film in which ten-millionths of an inch thick, which blocks further oxidation.

Another important thing is if there is any scratches on protective layer on aluminium it will instantly reseal itself.Aluminium – Silicon (Al-Si) alloy - The most and the main alloying element of aluminium silicon (Al-Si) cast alloy is Silicon. In hypoeutectic aluminium Silicon (Al-Si) alloy the Silicon content ranges from 5% to 12% weight. For getting good castability product silicon is primary responsible; i.e., it has the capability to readily fill dies and to solidify castings with no hot tearing or hot cracking issues. If more silicon is present in alloy, the lower is its thermal expansion coefficient. Since silicon is a veryhard phase it significantly contributes to alloy wear resistance. To improve Al-Si alloy strength it combines with other elements and to make alloys heat treatable [1].

Solidification of Aluminium alloy - In solidification of aluminium alloy undercooling depends on the percentage concentration of the alloying element in the melt, rate of cooling and type of allowing element is used. It is seen that by increasing cooling rate and percentage contribution of alloying element, undercooling can be increased [2].

General steps involved in Aluminium alloy oil tank production are

- Melting the ingots (Aluminium alloy)
- Degassing process
- Pouring molten metal to die which is attached to Gravity die casting machine
- Solidification of Aluminium alloy
- Checking hardness

Mainly there are two variants die casting

1. Pore free die casting
2. Direct injection die casting

In pore free die casting gas porosity defects is eliminated and direct injection die casting used to reduce scrap and yield can be increased with zinc castings. Aluminium alloy classified into commercially pure aluminium, heat treatable alloy and non-heat treatable alloys.

Statistical Process Control - Statistical process control is also called SPC analytical tool, which is also decision making tool which allows us to see proper process whether it is working correctly not, if it is not working properly, study the process and implement correct actions and take necessary actions. This is key to quality control.

Steps involved in statistical process are Plan, Do, Studyand Act. The starting phases of statistical process control contain different tools. There are seven quality control tools, they are Check Sheet, Cause-and-Effect diagram, Flow Chart, Pareto Chart, Scatter Diagram, Histogram and Control Charts.

2. LITERATURE REVIEW

Chennakesava Reddy.et. al. [3], uses Aluminium (Al), Silicon (Si) and Magnesium (Mg) to identify the mechanical properties and casting properties with the help of gravity die casting process. The areas the listed below are taken into consideration and analysis is done for aluminium silicon magnesium: The time required for solidification in gravity die casting process mold increases with the pouring temperature of melt, decreases when mold preheat temperature increases. It is seen that freezing range will reduce due to silicon content which is present in the alloy whereas magnesium content which is present in the alloy widens it. Solidification process can be increased by doing required degasification of molten metal.

Vivekkumar R. Mishra.et. al. [4] explained about Mechanical Vibration on die casting of Aluminium alloys. Here it is shown that effect of Mechanical Vibration on inner defect, grain size and some related properties of aluminium alloys. As a result during Mechanical Vibration on Gravity die casting process shows the improvement in grain structure properties of alloys. The mechanical properties like Hardness and Ultimate tensile strength are increased at a particular frequency of vibration.

Vasdev Malhotra.et. al. [5] studied the change in process parameters and their effects in castings. They thought that reducing casting defects using simulation software will become critical, finally came to conclusion that producing defect free castings is difficult but can minimize casting defects by varying the process parameters.

S. Ferhathulla Hussainy.et .al. [6] their main aim is to identify the defects in casting and improving the casting using computer aided simulation software. The defects seen in components are shrinkage, incomplete mold cavity and cracks, this is improper design of gating and risering, improper degasification and improper selection of process parameters. Solid cast simulation software is used. Using this software defects are reduced by visualizing solidification, cooling and mold filling.

Kenneth N. Obiekea.et.al. [7], showed microstructure and Mechanical properties of aluminium die cast A380 alloy by producing and experimentally by varying pressure. The experiment is conducted on five samples. The results shows good nickel properties, as increasing the pressure, hardness value is increased, number of grains increased, gave good yield strength and tensile strength and impact strength also increased. And also by increasing the pressure, fine microstructure is obtained.

Dr. D R Prajapati [8]explained how to implement SPC techniques in industry to improve the productivity of industry and efficiency of the product. Here the two main techniques they have used are control charts and cause and effect diagram out of 7 statistical process control techniques. Here industry manufactured product is shocker seals which is having 9.1% defective products. Using the above two techniques they reduced defective percentage of products from 9.1% to 5%.

Vivek Patil. Et.al. [9] explained the various techniques used to reduce the casting defects. Here foundry named Ashta liners Ltd, Maharashtra was taken for research. The techniques involved are statistical techniques and quality control techniques like Cause and effect diagrams, Historical data analysis, Just-in-time (JIT), Design of experiments (DOE) etc. and satisfactory results were obtained.

Siva.T.et.al [10] explained about designing of optimum riser dimensions to produce defect free casting. Here LM6 aluminium alloy is used and experiment is conducted on double plate casting of size 240*150*25mm is considered. Here it consists of three models, first model is about riser without chill and sleeve, second model is about riser with sleeve and third model is about riser without sleeve and chill. It gives that optimum riser dimensions give better results. Third model gave better results compared to other two models.

3. PROCESS FLOW DIAGRAM

This diagram provides brief information which is related to process of the Aluminium alloy oil tank product (used in vacuum pumps) and it also categorizes the flow of process. Process flow diagram for Aluminium alloy oil tank is shown in figure 1.

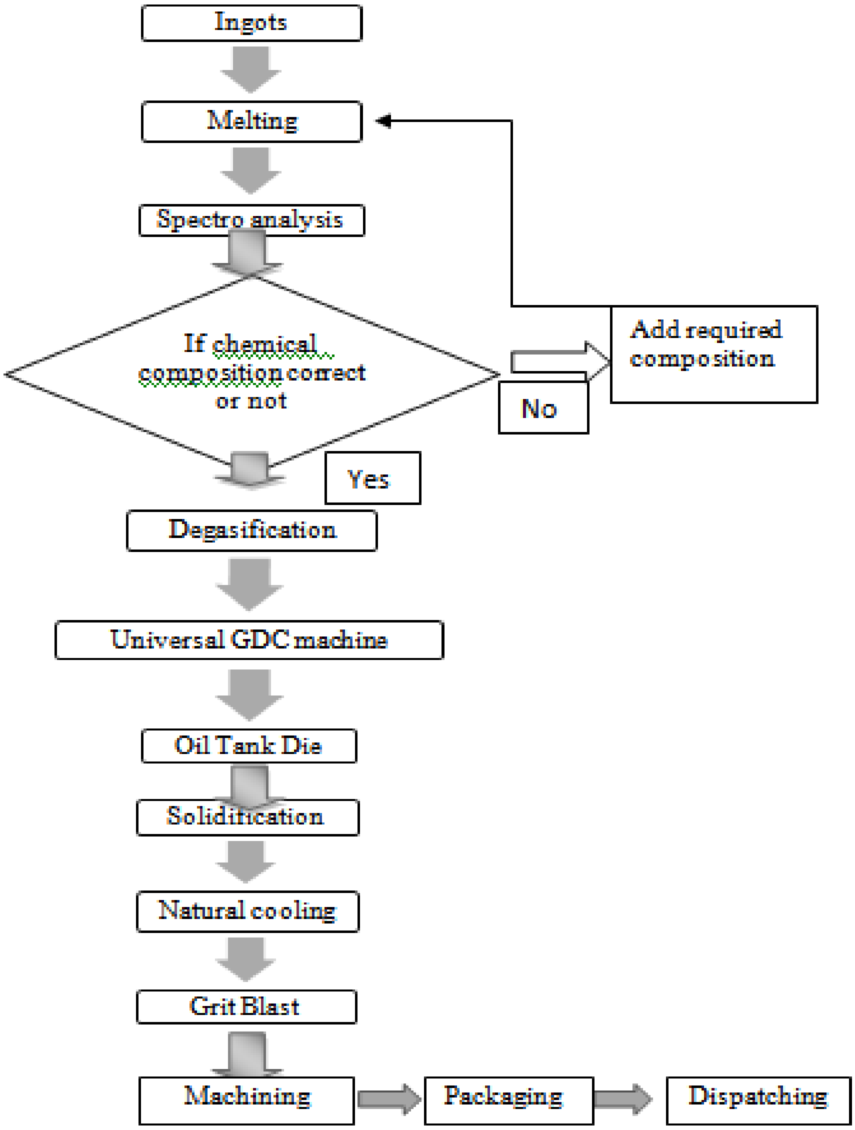

Figure 1 - Process flow diagram for Aluminium alloy oil tank

Material used here is LM6 Aluminium alloy. This alloy conforms to British Standards 1490 LM6.The machines used here is Universal Gravity Die Casting (GDC) machine and Resistance furnace in which aluminum alloy (LM6) is melted around 7600c.

4. PROBLEM BACKGROUND

Problem definition – During manufacturing of aluminium alloy oil tank, the rejections of castings is 15.75% i.e. 23 defective products, due to blow holes, pin holes, porosity and shrinkage.

Objective – The objective of this project is to minimize the defect in aluminium alloy oil tank casting and improving the productivity of organization.

Considering the month of April 2017 to November 2017 aluminium castings oil tank rejections.

$$\text{Overall defective percentage} = \frac{\text{Total number of defective products}}{\text{Total number of products}} = 23/146 = 15.75\%$$

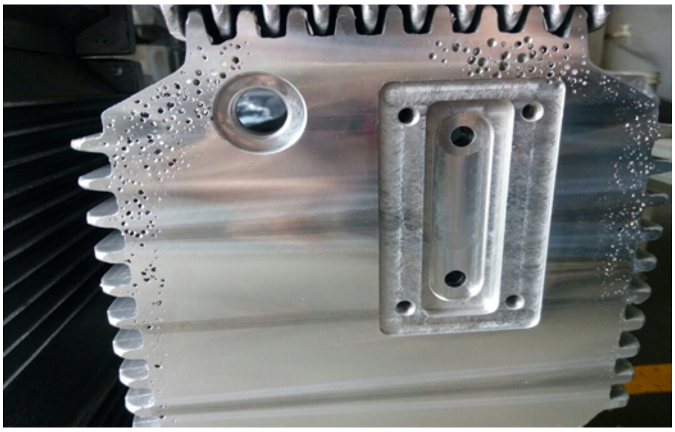

Figure 2- Defective product

The chemical composition of LM6 aluminium alloy casting and density of that casting is checked before pouring molten metal into the mold using spectroanalysis and density index machine. Two days were taken for collecting values. Elements contribution percentage in alloy is shown in table 4.

Table 1 - Elements contribution percentage in alloy

	1st day		2nd day	
Elements	Morning	Afternoon	Morning	Afternoon
Silicon	10.37	10.39	10.60	10.15
Iron	0.436	0.430	0.32	0.419
Copper	0.077	0.081	0.064	0.052
Manganese	0.012	0.012	0.047	0.0087
Magnesium	0.139	0.145	0.149	0.141
Zinc	0.053	0.057	0.036	0.038
Led	<0.05	<0.05	<0.05	<0.05
Tin	<0.005	<0.005	<0.005	<0.005
Titanium	0.035	0.032	0.030	0.028
Nickel	<0.005	<0.005	<0.005	<0.005
Chromium	0.0053	0.0064	0.0035	0.0048
Aluminium	88.84	88.81	88.64	89.13

4.1 Cause and Effect diagram

The Fishbone diagram or Cause and Effect diagram or Ishikawa diagram gives all possible causes that are responsible for defective product. Different causes for defective aluminium alloy tank are shown below. Fishbone diagram for defective casting isshown in figure 3.

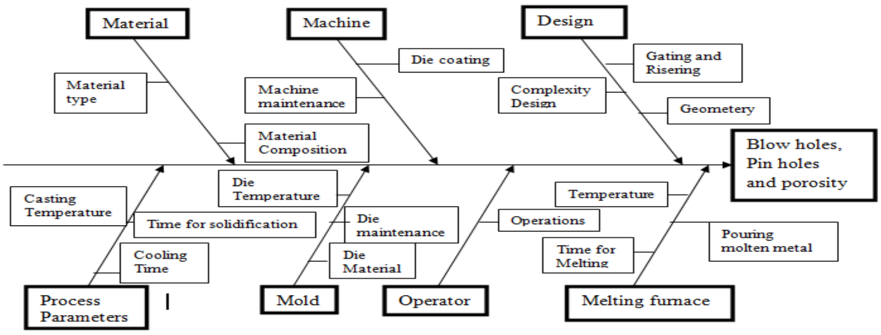

Figure 3 - Fishbone diagram for defective casting

4.2 Pareto chart

The purpose of the Pareto chart is to highlight the most important among a set of factors.Pareto chart for rejected alloy casting. Pareto chart for rejected alloy casting is shown in figure 4.

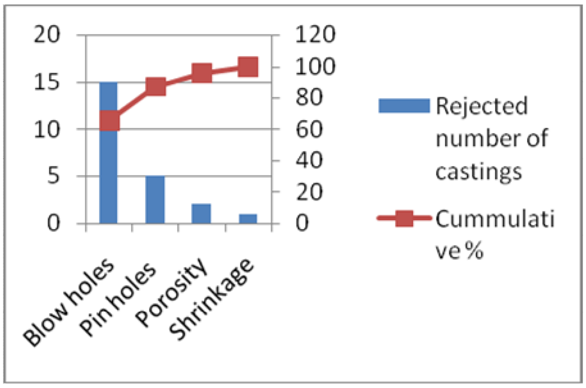

Figure 4 -Pareto chart for rejected alloy casting

5. METHODOLOGY

The methodology used here is "Defect Diagnostic Approach". The detailed procedure of this approach is given below with the figure 8.

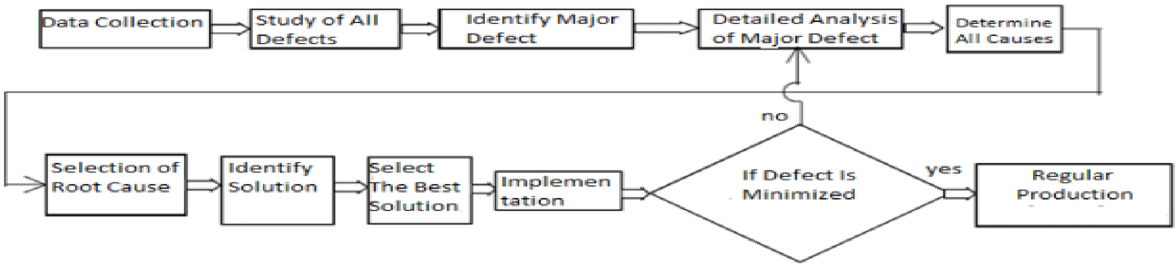

Figure 5 - Defect diagnostic approach

6. DESIGN OF DIE (Mold)

A new Die (mold) design is done using CREO software for the casting and ANSYS software is used for analysis and design is shown below in figure 6.

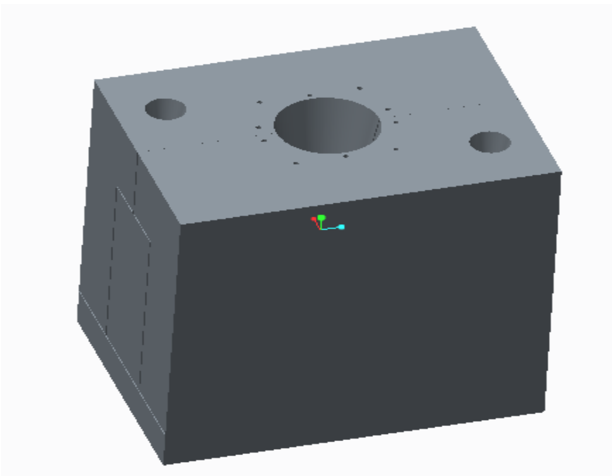

Figure 6 - Assembly of Die (Mold)

6.1 Calculation

- RISER
  - Shape factor=2.18
  - Vr/Vc = 0.8
  - Casting volume (Vc)= 1080.912cm^3
  - Volume of riser (Vr) = 0.8 Vc = 864.72cm^3
  - Vr = ∏ D^3 /4
  - D = 10.32 cm
  - Height of riser (Hr) = 10.5cm
  - Length of neck (Ln) = D/2 = 5.16 cm
  - Diameter of neck (Dn) = Ln+0.2Dr = 7.224 cm
  - Area of Sprue inlet (Asi) = $Ase \times \frac{\sqrt{Hse}}{\sqrt{Hsi}}$ = 574.07mm^3
  - Radius of Sprue inlet (Rsi) = $\sqrt{\frac{Asi}{\pi}}$ = 13.5mm
  - Diameter of Sprue inlet = 27mm

- SPRUE
  - As ≥ Ac √H/h
  - Total poured weight = 4.75+3.25 = 8kg
  - Fr = 0.4 (frictional loss factor)
  - t=5s (from graph 5.3)
  - Height of Sprue (H) = 36.2cm
  - Area of choke (Ac) = 1.44 cm
  - Height of Sprue inlet (Hsi) = 50mm
  - Height of Sprue exit (Hse) = 50+362 = 412mm
  - Area of Sprue exit (Ase) = 199.99 mm^3
  - Radius of Sprue exit (Rse) = $\sqrt{\frac{Ase}{\pi}}$ = 7.97mm≈8mm
  - Diameter of Sprue exit = 16 mm

7. ANALYSIS OF DIE (MOLD)

Consider a pressure of 35 MPa to identify safe working load of mold.Equivalent stress and Maximum principal stress are shown in figure 7a and 7brespectively.

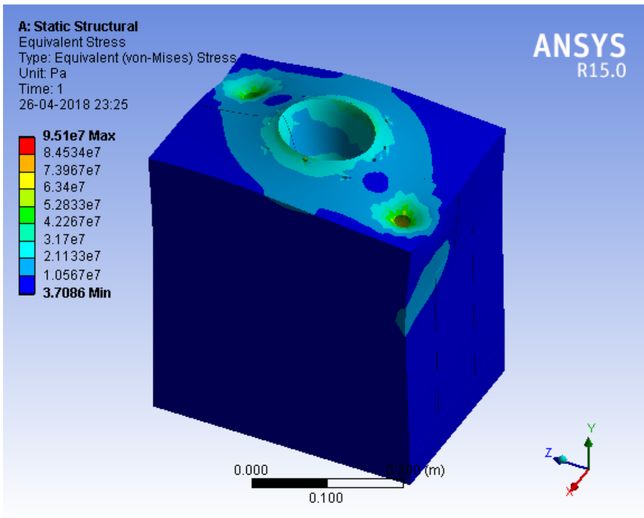

Figure 7a - Equivalent stress

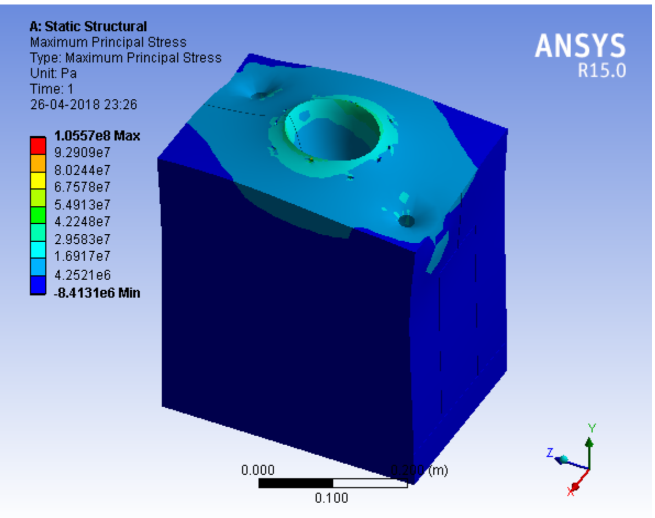

Figure 7b - Maximum principal stress

Table 2- below shows for Equivalent stress Table 8 - below shows Maximum Principal Stress

	Stress (MPa)
Maximum	95.1
Minimum	0

	Stress (MPa)
Maximum	105.57
Minimum	0

8. RESULTS

The temperature of molten metal when pouring to mold, Degasification of molten metal, chemical composition of molten metal and mold temperature before pouring molten metal are identified. To identify the defects in oil tank casting entire process of casting should be properly analyzed.

In order to minimize the blow holes, pin holes, porosity and shrinkage of casting we have taken care with degasification processi.e. itis done once for every 4-5 parts, the temperature of the molten metal and mold before each and every oil tank casting preparation is checked by pyrometer and composition of alloy is checked by spectroanalysis and we have reduced the defects by controlling process parameters.When it comes to design part of mold, sufficient vent holes were not provided. Design of mold is done by providing sufficient vent holes and stress analysis is done, all values obtained are within the limits.

9. CONCLUSION

The quality control tools were used to solve the problem. Objective of the project is to minimize the casting defects and improve the productivity of organization and this is done by controlling process parameters. The using of various tools like check sheet, Pareto diagram, fishbone diagram etc. helps to solve the problem, hence we identified the exact problem and we have solved that. The new Die (mold) design (new design) is done using CREO software and stress analysis is done using ANSYS software and values obtained are within the limits.

REFERENCES

1] H. Fredriksson, U. Åkerlind, Solidification and Crystallization Processing in Metals and Alloys, John Wiley & Sons Ltd., Chichester, 2012.
2] D.M. Stefanescu, Science and Engineering of Casting Solidification, Kluwer Academic/Plenum Publishers, New York, 2002
3] Chennakesava Reddy and Ch. Rajanna, Design of Gravity Die Casting Process parameters of Al-Si-Mg alloys, Journal of Machining and Forming Technologies ISSN: 1947-4369 Volume 1 Issue ½.
4] Vivekkumar R. Mishra, Gourav PurohitA, Chetan Jaiswal, Nishant Vyas, Review Paper on Effects of Mechanical Vibration on Gravity Die Casting of Aluminium alloys, International Journal for Innovative Research in Science & Technology| Volume 3 | Issue 09 | February 2017 ISSN: 2349-6010.
5] Vasdev Malhotra, Yogesh kumar, Study of Process Parameters of Gravity Dies Casting Defects, International Journal of Mechanical Engineering and Technology (IJMET)Volume 7, Issue 2, March-April 2016, pp. 208–211, Article ID: IJMET_07_02_023.
6] S. Ferhathullah Hussainy, M. Viquar Mohiuddin, P. Laxminarayana, A. Krishnaiah, S. Sundarrajan ,A Practical Approach to Eliminate Defects in Gravity Die Cast Al-alloy casting using simulation software, International Journal of Research in Engineering and Technology eISSN: 2319-1163 | pISSN: 2321-7308
7] Kenneth N. Obiekea, Shekarau Y. Aku, Danjuma S. Yawas, Effects of Pressure on the Mechanical Properties and Microstructure of Die Cast Aluminium A380 Alloy, Journal of Minerals and Materials Characterization and Engineering, 2014, 2, 248-258.
8] Dr. D. R. Prajapati, Implementation of SPC Techniques in Automotive Industry: A Case Study, International Journal of Emerging Technology and Advanced Engineering (ISSN 2250-2459, Volume 2, Issue 3, March 2012).
9] Vivek Patil , Mahesh Sutar, Quality control and Statistical Techniques used to improve Productivity and to reduce Rejections due to Casting Defects: A Review, International Journal of Research in Advent Technology, Vol.3, No 4, April 2015 E-ISSN: 2321-9637.
10] Siva.T, Yugendra Rajan.D, Melkin.M.S, Experimental analysis of cylindrical riser design for LM6 aluminium alloy castings, International Journal of Latest Engineering Research and Applications (IJLERA) ISSN: 2455-7137 Volume – 01, Issue – 03, June – 2016, PP – 54-63.