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Minimization of Defect in Aluminium Alloy Wheel Casting Using 7 QC Tools

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Abstract: With the increasing use of aluminum wheels in automotive industry, the aluminum foundry industry had to focus on the quality and reliability of the products. To produce good quality aluminum cast wheels, defects must be minimized.

Aim of the current study is to study defects of an aluminum alloy casting and to improve the quality of casting using quality control tools. This study shows the systematic approach to find the root cause of a major defects in aluminium castings using defect diagnostic approach as well as cause and effect diagram. Casting defect analysis is carried out using techniques like historical data analysis, cause-effect diagrams, design of experiments and root cause analysis. Data from X-ray inspection (Radiographic Inspection) have been collected along with the production parameter data. Using Pareto chart major defects in the aluminium castings were noted. The major defects for the rejections during production were identified as shrinkages, inclusions, porosity/gas holes and cracks. Each defect is studied thoroughly and the possible causes for the defects are shown in Fishbone Diagrams (Cause Effect Diagrams). As the shrinkages mainly occur due to lack of feedability during the fluid flow the stalk changing frequency is noted along with the shrinkages defects and a relation is drawn between them. As hydrogen forms gas holes and porosity in the aluminium castings the amount of hydrogen present in the molten metal is studied by finding specific gravity of the samples collected. The molten metal temperature effects the amount of the hydrogen absorbed by it. .So the effect of molten metal temperature on the specific gravity of the sample collected have been shown in a graph and the optimum value for molten metal temperature was found out.

1. Introduction

The use of aluminum castings in the automotive industry has increased incredibly over the past two decades. The driving force for this increased use is vehicle weight reduction for improved performance, particularly fuel efficiency. In many cases, the mechanical properties of the cast aluminum parts are superior to those of the cast iron or wrought steel parts being replaced. For the production of aluminum alloy wheel, Al-Si casting alloys are mostly used as the raw material. Because of their good casting properties, this type of alloys provides the alloy wheel to have good corrosion resistance and strength so that the vehicle can adapt to the road and weather conditions. The main alloying elements of Al-Si castings are silicon, magnesium, iron, manganese, beryllium, zinc, strontium and titanium. Each element gives some special features to the casting alloy so that the alloy can be produced with desired properties. The compositions of these elements affect the final properties.

Aluminum casting alloy wheels are generally produced using low-pressure die-casting. For the application of this casting method, Al-Si casting alloys should be chosen owing to their high adaptation capability to the permanent metal molds. By the help of alloying elements, it is possible to achieve effective and efficient aluminum alloy wheel production. Aluminum alloy wheels have important advantages compared to the steel wheels. advantages provide aluminum alloy wheel to be popular. However, in production of wheels, defects in the cast microstructure undermine performance characteristics.

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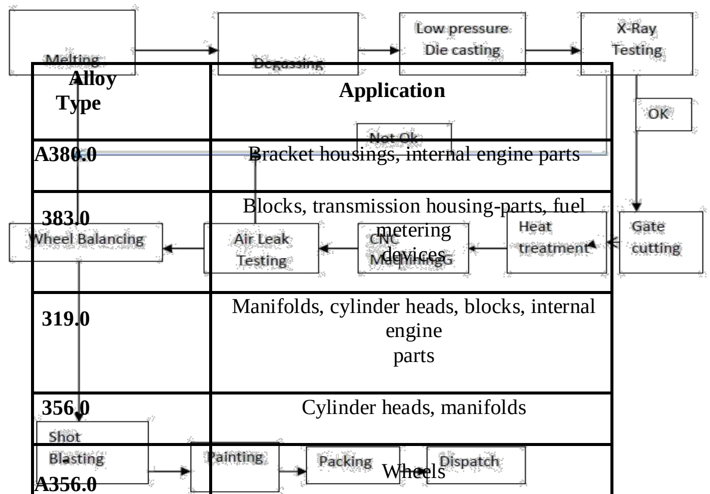
Quality improvement of aluminum alloy wheel production facilitates understanding the process parameters and their influences on the defect formation. To decrease the amount of scrap and rework, satisfactory quality of the production has to be achieved. This can be done using quality improvement tools. Controlling process parameters can decrease defects on aluminum alloy wheel and the amount of scrap produced. In this study, defects on aluminum alloy wheel were investigated by means of real time radioscopic method and minimize using quality control tools.

2. Theory and literature survey

2.1 Al-Si Casting Alloys

Aluminum cast alloys have been developed for casting qualities such as feeding ability and fluidity, as well as for mechanical properties such as strength, ductility, and corrosion resistance. Thus, their chemical compositions differ widely from those of the wrought aluminum alloys Because pure aluminum is a relatively poor casting material, aluminum casting is actually made of an aluminum alloy. The most important aluminum casting alloys are [1,3,4] aluminum-copper, aluminum-silicon, aluminum-zinc and aluminum-magnesium casting alloys.

Aluminum casting alloys with silicon as the major alloying element are the most important commercial casting alloys because of their superior casting characteristics. Aluminum-silicon alloys have comparatively high fluidity in the molten state, excellent feeding during solidification, and comparative freedom from hot shortness. Silicon does not reduce the good corrosion resistance of pure aluminum, and in some cases increases its corrosion resistance in mild acidic environment.



Alloy Type	Application
A380.0	Bracket housings, internal engine parts
383.0	Blocks, transmission housing-parts, fuel metering devices
319.0	Manifolds, cylinder heads, blocks, internal engine parts
356.0	Cylinder heads, manifolds
A356.0	Wheels
- B390.0	High wear applications such as ring gears and internal transmission parts

Table 1. Typical applications of the Al-Si alloy [6]

Element	319.0	333.0	354.0	356.0	A356.0	357.0
Silicon	5.5-6.5	8.0-10.0	8.6-9.4	6.5-7.5	6.5-7.5	6.5-7.5
Iron	1.0	1.0	0.2	0.6	0.2	0.15
Copper	3.0-4.0	3.0-4.0	1.6-2.0	0.25	0.2	0.05
Manganese	0.50	0.50	0.10	0.354	0.10	0.03
Magnesium	0.10	.50	.40-.60	.20	.25-.45	.45-.60
Chromium	0.00	0.00	0.00	0.00	0.00	0.00
Nickel	0.35	0.50	0.00	0.00	0.00	0.00
Zinc	1.00	1.00	0.10	0.35	0.10	0.05
Titanium	0.25	0.25	0.20	0.25	0.20	0.20
All others	0.50	0.50	0.20	0.20	0.20	0.20
Aluminum	Remainder	Remainder	Remainder	Remainder	Remainder	Remainder

Table 2. Chemical composition(limits of LPPM Al-Si casting alloys [22])

2.2 Types of alloys

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The types of Al alloy wheels are given below.

1. Forged Al Alloy Wheels
2. Single piece Al Alloy Wheels
3. Multi piece Al Alloy Wheels

Forged Al alloy wheels are generally used in medium and heavy trucks. A forged Al wheel is shown in Figure 1. Forged wheels are manufactured by using one piece of aluminum alloy that gives fuel savings, greater payloads and lower weight.

Most Al wheels are single-piece castings manufactured from a variety of casting processes (Fig.2.). The cast product provides an infinite number of styling iterations and optimized for minimum weight and cost. This type of wheels can be used in passenger cars, minivans, sport utility vehicles and etc. Multi piece wheels are actually manufactured from two or more components that are securely welded together. The process has the unique advantage of having a rolled-and-spun wrought aluminum rim combined with a cast disc, made of mold (Fig.3.). This cast disc can provide lower tooling cost.

Figure 1,2,3

2.3 Defects on Al Cast Wheels

There are different kinds of defects that can arise in casting processes. Often errors in design can be overcome by the adoption of the procedures involving careful control of the cast metal and of the casting procedure. In many cases, in order to facilitate production it is of greater practical and economic merit to modify the design of an object to be cast [2].

Casting defects occur during the time that passes for the last solidification becomes, after the pouring of the molten metal into the mould, due to the different influences. Generally, defects can appear in different shapes, dimensions and visions due to the type of material, molding design, dimension of the specimen and process control and so like variables.

A casting defect can be either the function of only one cause or the result of many causes. Moreover, with the influences of the many causes, only one defect can occur [9].

There are two groups of defects in Al-Si alloys based on Real-time Radioscopic Method:

1. Hole Type Defects

2.Crack Type Defects

Hole Type Defects

Blow Holes: In general, this type of defects can be easily inspected owing to having smooth surfaces with a spherical shape. Blow holes are round or elongated cavities, usually with smooth walls, found on or under the surface of the castings [9,10].
They can arise from a number of reasons:

1. Because of the entrapment of the air during the pouring of metal into the mould
2. Due to the reactions between molten metal with the mould or the core materials.

These cavities can be small, when they are known as "pinholes" or of quite large size known as "gas holes".[8]

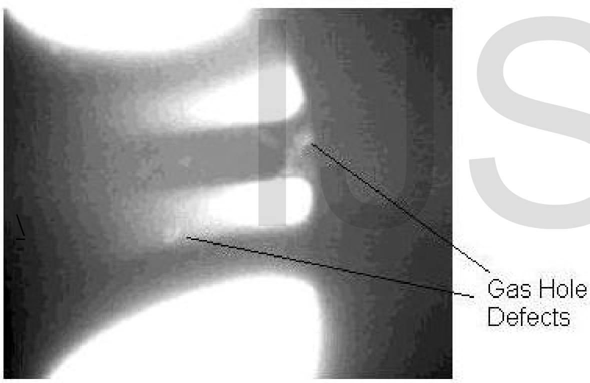


Figure 5 . Gas hole defect in Al alloy cast wheel [11]

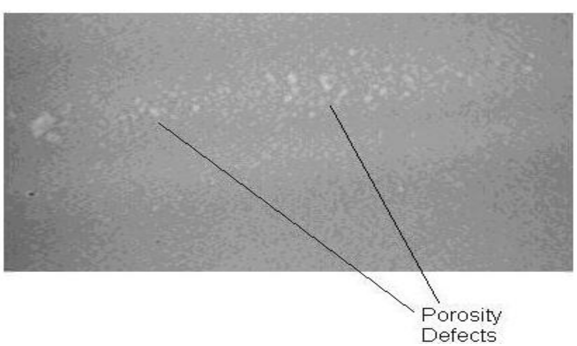


Figure 6 Porosity defect on Al alloy cast wheel [11]

3. The 7 QC Tools

The 7 QC Tools are simple statistical tools used for data analysis and problem solving .

The following are the 7 QC Tools[8]
1. Process Flow Diagram
2. Cause and Effect (Fishbone) Diagram
3. Control Charts
4. Check Sheet
5. Pareto Diagram
6. Scatter Plot
7. Histogram

Process Flow Diagram is a very useful tool to give brief information about the relationships between the process units. Process flow diagram expresses detailed knowledge of the process and identifies the process flow and interaction between the process steps. Potential control points can also be identified.[12]

Fishbone Diagram is a useful formal tool in unlayering potential causes. By using this diagram, all contributing factors and their relationship are displayed and it identifies problem areas where data can be collected and analyzed

Control Chart Analysis

Control chart analysis helps in the following ways

1. It helps in monitoring quality in the process
2. To detect nonrandom variability of the process To identify assignable causes.

The **chart contains three** horizontal lines

CL: Control limit (Mean Line)
UCL: Upper control limit
LCL: Lower control limit

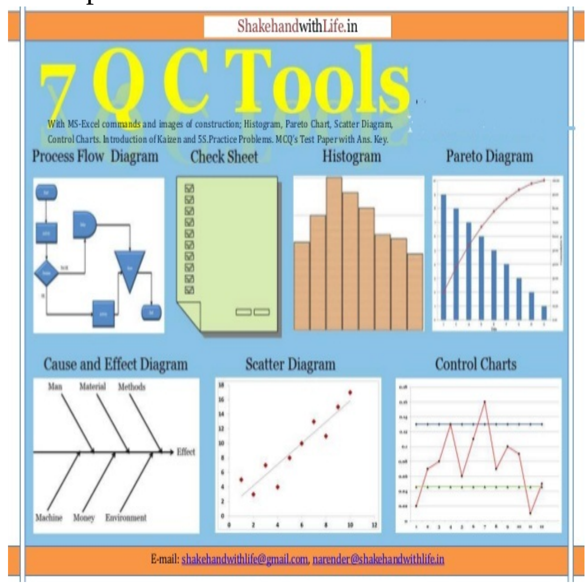
The process is assumed to be in-control as long as the points that are plotted are within control limits, and no need to take necessary action. If a point that plots outside of the control limits we assume that the process is out of control and to take corrective action to eliminate the assignable cause. Control charts provide reducing variability and monitoring performance over time. Trends and out of control conditions are immediately detected by using control charts.

Check Sheets will often become necessary to collect either historical or current operating data about the process under investigation. A check sheet can be useful in this data collection activity. Check sheet simplifies data collection and analysis and spots problem areas by frequency of location, type or cause.

The Pareto Diagram is simply a frequency distribution of attribute data arranged by category. It includes the number of defects in a wheel production. It shows the total frequency of occurrence of each defect type against the various defect types. Hence, the causes of these defect types should probably be identified and attacked first. Also, various types of Pareto diagrams can be arranged with different types of data arrangement. Pareto diagram identifies the most significant problems to be worked and shows the vital few problems and factors. Moreover, it explains as the %80 of the problems is due to 20% of the factors.

Scatter Plot is a useful tool for identifying a potential relationship between two variables. Data are collected in pairs on the two variables, as (y,x), for i=1, 2,...,n. Then y values are plotted against the corresponding x. The shape of the scatter plot often indicates what type of relationship may exist between the two variables. The scatter plot, indicates a positive correlation between temperature and pressure. By using this plot, a positive, negative or no relationship can be easily detected.

The Histogram represents a visual display of data. Observed frequencies versus the number of defects are given in this histogram. The height of the each bar is equal to the frequency occurrence of the defects. The shape of histogram shows the nature of the distribution of the data. On this display, the central tendency (average) and variability are seen. And also, specification limits can be used to display the capability of the process.



4. Analysis

Historical Data Analysis

To find the rejections in castings, data for occurrence of defects for one year was collected from one of leading Al alloy wheel casting industry. Using historical data analysis [8], check sheets have been prepared which helps to identify occurrence defects in aluminium alloy castings. Using check sheets data collection is simple and it also helps in spotting problem areas by frequency of location, cause and type of defect.

Pareto Diagram for Defects

Using the data collected for different casting defects pareto diagram have been drawn in figure 7. we can conclude that the major causes for the rejections in Al alloy wheel castings were due to 1) Shrinkages 2) Air leak 3) Crack 4) Inclusions etc

defect	rejected quantity	cum %	defect	rejected quantity	cum %
shrinkage	4080	39	mismatch	86	97
porosity	2612	64	grinding shade	67	98
crack	1413	77	half cycle	50	98
inclusion	985	86	below range	48	99
unfilling	415	90	ejector pin depression	43	99
profile damage	193	92	dents	36	100
distortion	183	94	above range	22	100
metal sticking	157	95	mesh	13	100
gas hole	129	97	without mesh	5	100

Table 3 Rejections in casting

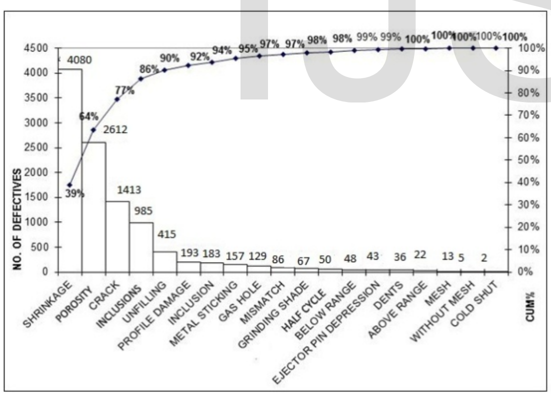


Figure 7 Pareto chart of rejections of Al alloy wheels for one year

The following are the results that are obtained from the graph shown in Figure 8.

- From sample number 1 to 20 and 45 to 60 change of the specific gravity is observed as being not in order. In these intervals, there become irregular trends for the specific gravity.
- However, between sample numbers 21and 45 the temperature from 700^{0}C to 720^{0}C, specific gravity regularly changes.
- Therefore, it can be said that the hydrogen content change is stable between 700^{0}C and 720^{0}C temperature of molten metal.

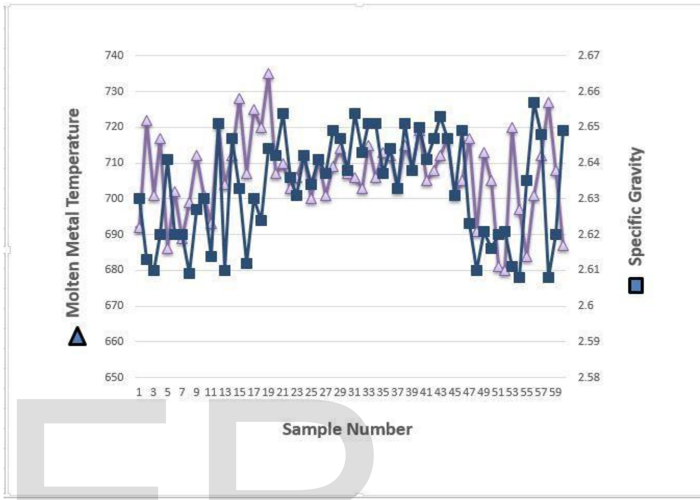


Figure 8

Between these temperature limits, the specific gravity values are in the range of change between 2.64 and 2.665. In this range, there is stability in the hydrogen content of molten metal.

The following are the methods to minimize porosity defect in Aluminium alloy castings [6].

Hydrogen content should be optimized between minimum and maximum values in order to obtain both effective feeding and low hydrogen values.

Optimizing hydrogen content can be achieved by controlling degassing.

Porosity can be minimized if Ti is added to the alloy as it improves grain refinement.

By increasing degassing time provides reducing the hydrogen content to the desired levels.

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Porosity can be taken into the inside zones by applying cooling during casting in the defect occurring area so that the porosity defect on the wheel can be minimized.

Casting temperature, casting time and casting pressure and solidification time have influences on the defects in aluminum cast wheels.[13]

To prevent micro porosity casting temperature has to be decreased.

Casting pressure is outstanding for confronting the gas pore formation. Increase in casting pressure will reduce porosity.

The solidification time affects the gas pore growth. With decreased solidification time, there becomes less time for hydrogen to diffuse from solidifying dendrite to the liquid. The formation of porosity is reduced with an increase in cooling rate.

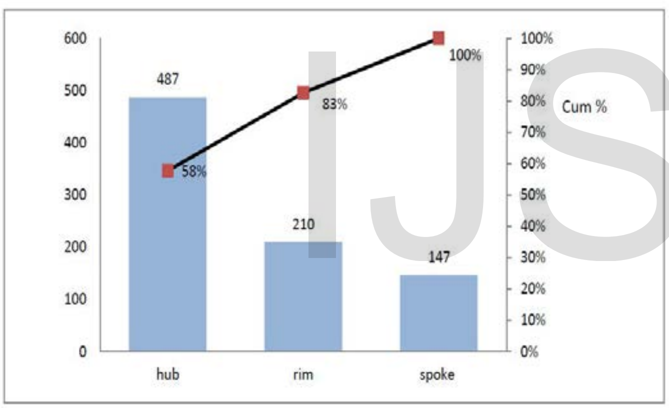

Figure 9 histogram for shrinkage defects

Hub part is the last solidified part of the wheel. Most of the shrinkages occur in the hub region due to the lack of feeding during the solidification.

Hub Shrinkage: It is because of in sufficient feeding of molten metal.

5. Conclusion

In this study, casting of an Al alloy was investigated. Aim was to minimization of casting defects using 7QC tools. This study shows the systematic approach to find the root cause of a major defects in aluminium castings using defect diagnostic approach as well as cause and effect diagram. To obtain more detailed and effective feedback control during casting of Al-alloy wheel, a process model for the production line was constructed. By help of this diagram the causes of defects and remedies can be pointed.

1.Pareto diagram for defects have been drawn and the major rejections are due to shrinkages, cracks, inclusions.

2. With the use of histograms it was noted that the shrinkage % decreases with the increase in stalk change frequency. A proper riser prevents shrinkage formation by maintaining a path for fluid flow. Therefore the feeding of the die is achieved by the effective riser.

3. Data has been collected using check sheets and the no of rejections due to various shrinkages have been noted. Using histogram it was noted that the hub shrinkages were more compared to rim and spoke shrinkages.

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