

# Manufacturing Process Defects of Automotive Brake Drums and Implementation of Poka-Yoke – A Case Study

Toon Daems<sup>1</sup>, Shashikantha Karinka<sup>2</sup>, Balakrishna Shetty A<sup>3</sup>, Eddy Versonnen<sup>4</sup>

Student, Professional Bachelor in Automotive Technology, Industrial Sciences Department, Karel de Grote University College, Antwerp, Belgium<sup>1</sup>

Professor, Mechanical Engineering & PG Coordinator, Mechanical Engineering Department, NMAM Institute of Technology, Nitte, India<sup>2</sup>

General Manager (Production), Lamina Foundries Limited, Nitte, India<sup>3</sup>

Faculty, member of Management & Technology, Industrial Sciences Department, Karel de Grote University College, Antwerp, Belgium<sup>4</sup>

**ABSTRACT:** Foundry or casting is an important manufacturing process. Many machine components and mechanisms are manufactured using the casting process. Several automobile and engine components are manufactured through the casting process. There are several types of casting processes and sand casting is one of the preferred methods. The defect free casting is very important in the present day competitive world for survival of industry, which also helps in conserving energy and in reducing the associated environmental pollution, health risks, global warming and climate change effects. In this paper, defects occurring in the manufacturing process of medium to large size automotive brake drums in a mid-size South-Indian foundry have been studied. The study involves segregation of all types of defects and discusses the causes for the variety of defects. It is planned to bring down the present rate of defects from 5% to a lower satisfactory level. Hence it is recommended to create Poka-Yoke for preventing the defects, which are occurring predominantly.

**KEYWORDS:** Manufacturing defects, foundry defects, machining defects, poka-yoke, rejection rate

## I. INTRODUCTION

The metallic components used in machines and mechanisms are manufactured through casting and metal forming processes [1-4]. Metal casting involves making metallic components from iron or other metals with a varying degree of alloying elements in liquid form. Metal forming involves working on solid metals by applying force to shape the metal using different techniques like forging, rolling, extrusion, drawing, shearing, bending and deep drawing. In components that undergo a lot of fluctuating or fatigue type of loads, metal forming is preferred because of its higher strength. Components where very high strength isn't an issue, casting is preferred because of its lower cost in comparison with metal forming. Different casting methods are used depending on complexity, volume and cost. These methods are: sand casting, permanent mould casting, injection moulding, shell moulding, lost wax casting and centrifugal casting [1]. For automotive components, sand casting is often used because of its ease to make a large variety of components and at low cost [2]. When sand casting is used, different defects can appear, some of them are specific for sand casting and some of them can happen in all casting processes. These defects are: leakages, short pours, cold metal, mould lift, sand drops, mould break, mould crush, blowholes, mismatch, swelling, shrinkage, rough surface, scabbing, sand inclusion, slag inclusion, damage, cracks, absent core, core crush, core shift, core breaking, core press, eccentricity, porosity, mould press, low hardness, and high hardness.

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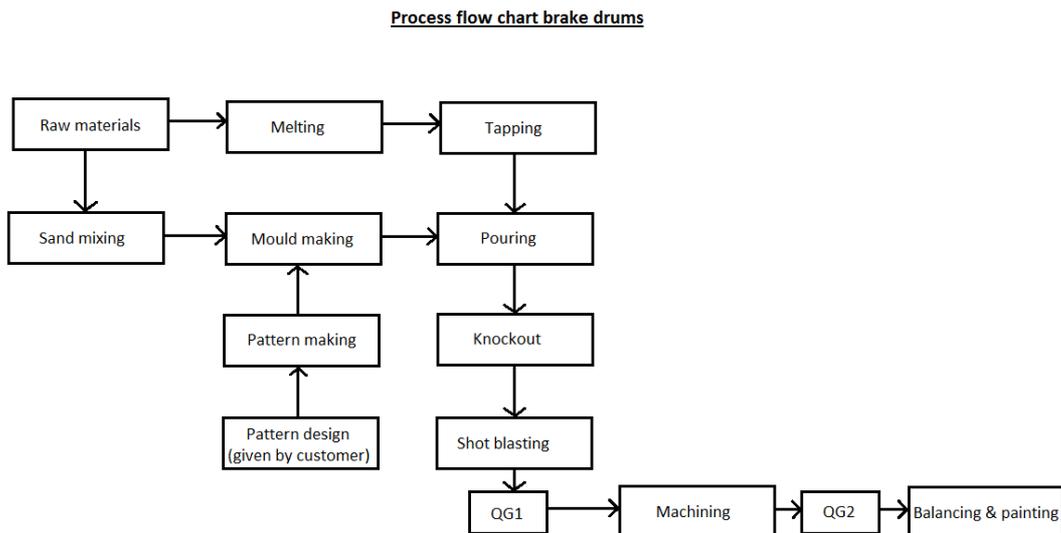
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In general, bringing down defects is a very important and continuous activity for any industry. In today's globalized world, competition is fierce so every advantage is welcome. The environmental impact is also a very important factor, every defect is a wastage of both raw materials (to some extent) and energy and therefore needs to be eliminated as much as possible. Around 70% of all primary energy in India comes from fossil sources and so saving energy means having a positive impact on people's health, reduced emission of greenhouse gasses and reduced general pollution. Hence bringing down defects is not just important for monetary gain. In the present work, defects were studied in a mid-size South Indian foundry where the sand casting technique is used for making automotive components. In this company, medium to large sized automotive brake drums are produced using the sand casting process. In order to identify and understand the different defects, the various sub-processes from raw material to the finished product required thorough understanding. The different types of defects need to be identified and segregated to know their share in the total rejections. The defects with the maximum number of occurrences need to be addressed first. These defects will be addressed using poka-yoke [5] techniques, the techniques will either prevent the defect from happening or warn the workers that they are about to produce a defect. Poka-yoke is a system that was first thought of by Shigeo Shingo and described in his book: Zero quality control. It contains two functions: carrying out 100% inspection and giving immediate feedback if abnormalities occur. Four different Poka-yoke techniques can be distinguished: the contact method, the fixed-value method, the motion-step method and the time method.

## II. METHODOLOGY OF WORK

The methodology involved complete process study of the brake drum manufacturing and then identifying and segregating the defects to decide on poka-yoke.

**2.1 Process study:** The study has been done in a mid-size South Indian foundry. The process flow chart of brake drum manufacture is given in Figure 1 and the processes are discussed in further sections.



**Figure1: Process flow chart of brake drum manufacture**

**2.1.1 Melting:** As shown in Figure 1, raw materials are delivered in the foundry; they are used in either the melting department or the sand mixing department. In the melting department, four induction furnaces are used. In these furnaces: pig iron, borings and scrap iron are heated up to 1430-1500° C depending on customer requirements. Carbon and other alloys are already present in the pig iron, in borings and in scrap, but if the amount is not correct, they can be added separately. Once the correct temperature is reached, the ladle is preheated and the metal is tapped into the ladle.

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During the tapping, inoculation is added. This inoculation is important for flow ability, machinability and to control the cool down period. Once tapping is completed, the metal can be poured into the moulds.

**2.1.2 Pouring:** The pouring needs to be done in a certain fixed time; the calculation of this time is given through an Equation as follows:

$$\text{Pouring time (s)} = K \cdot (0.95 + T/0.853) \cdot \sqrt[3]{W}$$

Where, K= Constant factor, T= Thickness in inch, W= Weight in pounds

The value of K depends on the CE (Carbon Equivalent) value as given in Table 1 below:

Table 1: Variation of Constant K versus Carbon Equivalent [6]

CE	4.20	4.00	3.80	3.40	3.20
K	1.00	0.85	0.75	0.65	0.6

If the pouring time is longer, there is a bigger chance of sand drops, scabbing, sand inclusion and blowholes [4].

**2.1.3 Solidification/cooling time:** After pouring, the metal needs to cool down. The cool down time depends on the weight of the casting; below 50 kg., cooldown time is 30 min., 50 to 70 kg., cooldown time is 45 min. and 70 to 100 kg., cooldown time is one hour. In general, 100 kg. is the heaviest casting produced in the foundry.

**2.1.4 Knock-out:** Once the cooldown period is over, the moulding box which contains the mould and the casting will be transported to the knockout facility. In the knockout facility, the moulding box is vibrated which will loosen the sand of the mould and remove it from the casting. The sand is automatically transported to the sand mixing facility along with 20% fresh sand and all excess material is removed from the casting. This excess material contains: the pouring cup where the metal is poured into the mould, the down spruce, the runner bar which connects the down spruce to the in-gates and the in-gates themselves are also removed, the in-gates provide the access to the actual shape which has to be cast.

**2.1.5 Shot-Blasting:** Once knockout is completed, the casting goes to shot blasting. Here the casting will be fired upon by a large amount of very small steel shots (1-2 mm), this process will remove all leftover moulding sand and other dirt and leave a clean casting. After shot blasting, the casting passes through a first “quality gate” where they are checked for any defects.

**2.1.6 Machining:** The next step is the machining process, where different operations are carried out based on the requirements of the customer. Both manual as well as completely automated machining is available at the foundry but automated machining will only be done on specific request of the customer. When machining is completed a second quality check is done, once again casting defects are checked because some defects will only emerge after machining, the castings are also checked for machining defects.

**2.1.7 Dynamic balancing, painting and packing:** After machining, the drums are balanced on a balancing machine, painted and finally packed for shipping.

**2.1.8 Sand preparation, mixing, mould making:** Raw materials are also used for sand mixing, the sand mixture contains: used sand, new sand, bentonite clay, bentokol (a petroleum product) and water. The new sand is added before knockout begins by putting it on the moulds after which it will be transported to the mixing facility along with the new sand, the other additives are put in afterwards in the sand mixing facility. The mixture is then transported to the mould making plant. In the moulding plant, the moulding boxes which come from the knockout facility are fixed onto the housing plate of the pattern. The sand mixture is poured in the box and pressed together by a pneumatic pressure of 7.6 bar. The mould is divided into two parts :a bottom part or drag and a top part or cope, these are put on top of each other as shown in Figure 2. Cope and drag are then fixed together as to prevent them from moving, after this pouring can commence.

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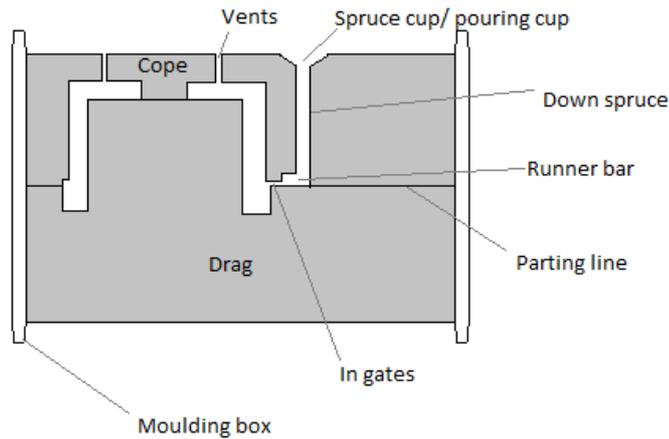


Figure2: Mould schematic

### III. RESULTS AND DISCUSSION

#### 3.1 Data collection of defects:

Defect statistics for the months of December 2015, January 2016 and February 2016 were acquired from the foundry. The drums based on these statistics were divided into three weight categories: type A is 30-50 kg, type B is 51-69 kg and type C is 70-90 kg.

After this, the share of each type of all defects was calculated (in percentage) on a monthly basis and plotted as graphs as shown in Figures 3 to 8. In Figure 9 and Figure10 an overview of the three months' defects is shown. The explanation for the abbreviations or nomenclature of defects is shown in Table 2.

Table 2: Nomenclature of Defects

Defects before machining		Defects after machining			
SD	Sand drop	BHBR	Blow hole brake surface	MB	Mould break
MB	Mould break	BHT	Blow hole top	SHR	Shrinkage
MC	Mould crush	BHF	Blow hole flange	SCB	Scabbing
BH	Blowhole	BHB	Blow hole bore	SI	Sand inclusion
MM	Mismatch	F/O	Flange oversize	SLG	Slag inclusion
SHR	Shrinkage	F/UC	Flange unclean	DM	Damage
RS	Rough surface	T/UC	Top unclean		
SCB	Scabbing	M/F	Machining fault		
DM	Damage	ECC	Eccentricity		
ECC	Eccentricity	SD	Sand drop		

It would be appropriate that the type of defects observed in the present work may be compared with the types of defects generally reported in literature from foundries. The type of defects commonly seen in foundry reported in literature is given in Table 3 below:

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Table 3: The different types of defects generally reported in literature [3,4]

Causes of Blowholes	
Moulding and sand causes	Low permeability, high moisture, excessive gassy ingredients, poor mixing (clay balls), improper venting, mould coatings not dried, improper pouring basin.
Pattern causes	Insufficient prints for venting, inadequate runner, gating sizes, inadequate flow-offs, risers.
Melting causes	Use of rusty materials, moist addition, presence of liquid slag.
Pouring causes	Use of wet ladles, interrupted or slow pouring, cold metal pouring, low pouring pressure.
Causes of Sand inclusion Defects	
Moulding and sand causes	Low green compression strength, improper mixing of sand, careless cutting of pouring cup, improper mould coating (bentokol), not providing filters.
Pattern causes	Rough pattern surface
Pouring causes	Too fast pouring, too slow pouring, excessive metal pressure due to large height of ladle, disturbing moulds while pouring
Causes of Shrinkage Defects	
Moulding causes	Soft ramming, Improper clamping
Sand causes	Low green compression strength, Improper binder
Melting causes	Incorrect composition, Not enough inoculation used, Excessive tapping temperature
Pouring causes	Insufficient metal poured, high pouring temperature, pouring interruptions

As mentioned earlier, the two sets of data for months of December -2015, January 2016 and February-2016 have been plotted in Figures 3-8, with Figure nos. 3, 5 and 7 representing the defects before machining in the respective three months and Figure nos. 4, 6 and 8 representing the defects for the same respective months for after-machining condition. The summary of findings of defect history for the three months is given in Table 4 below:

Table 4: Summary of severe defect types for the three months – Before Machining and after machining

Type of defects before machining in chronological order of severity	Type of defects after machining in chronological order of severity
<ol style="list-style-type: none"> <li>1. Shrinkage (SHR) is highest for category C and in lesser amounts for Category A and B.</li> <li>2. Scabbing (SCB) is a serious problem in category A &amp; B</li> <li>3. Eccentricity (ECC) in category B &amp; C.</li> <li>4. Mould crush (MC) in all three categories</li> <li>5. Blow Hole (BH) for category A</li> </ol>	<ol style="list-style-type: none"> <li>1. Blow Hole on Top (BHT) is a serious problem in category A &amp; B.</li> <li>2. Sand Inclusion (SI) for category C.</li> <li>3. Eccentricity (ECC) in category B &amp; C.</li> <li>4. Machining Fault (M/F) in categories A, B &amp; C.</li> </ol>

This list may be compared with the general defect list available in literature as shown in Table 3.

### 3.2 Explanation for defects before machining:

As seen in Table 4, the higher defects before machining are: Shrinkage, Scabbing, Eccentricity, Mould crush and Blow hole on top. The list of defects may be compared with the different types of defects reported in literature as shown in Table 3. The various types of defects, with high occurrences requiring corrective action are discussed in the following section.

**3.2.1 Shrinkage:** The sand height in the cope mould if not provided enough as per design, can lead to shrinkage as there would be insufficient metal after solidification due to shrinkage in the process of cooling. Moreover, the molten metal needs to be poured at a certain temperature range as also pouring time need to be maintained. Any deviation in pouring temperature higher than the allowed maximum temperature or deviation in pouring time can cause shrinkage problems. Moreover, shrinkage may also be caused due to use of sub-standard inoculation.

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**3.2.2 Eccentricity:** Before machining all parts are not checked, however, all parts are completely checked after machining. Some eccentric items are moved to machining with scope for acceptance.

**3.2.3 Scabbing:** The free-flow oil used for lubrication, if more in quantity, can get accumulated in the pattern, which in its turn gets absorbed by the sand and that portion of sand on the mould becomes weak. The remedy is to use facing sand with higher strength to control scabbing. Facing sand is prepared by adding extra bentonite.

**3.2.4 Mould crush:** This can happen due to improper closure of mould box. This has relation to eccentricity.

**3.2.5 Blow Holes:** Blow holes seen before machining are general in nature and are visual. Blow holes are mostly seen on the top of the casting because the top gets filled last. A central flow-off system connecting all vents on top can avoid the blow holes.

### 3.3 Explanation for defects after machining:

As seen in Table 4, the important defects after machining are: Blow-hole on top in category A & B, sand inclusion in category C, eccentricity in categories B & C and machining fault in all three categories.

**3.3.1 Blow Hole on Top:** There are many reasons for blow hole on top. One important point is temperature of metal pouring. The second important problem is gating and venting. Sufficient metal needs to be poured per unit time. If part size is bigger, bigger gating and venting will be required, however, in accordance with a mathematical formula explained earlier. Moreover, "Mould Permeability" should be maintained within range of 150-200. If permeability is less, gas cannot pass, and hence blow holes form. Additionally, if dead-clay (Dust of Mould) is more, the permeability becomes lower and does not allow gas to pass causing blow holes. If the mould proportion is increased from 1:4 (metal : sand) to 1:5 proportion, blow holes can occur. Sometimes some foreign particles may be there in sand. Hence removal step for foreign particles may be required. To reduce dead-clay, addition of around 20% fresh sand is a requirement. The requirement of fresh sand needs to be accurately measured and a Poka-Yoke in this regard may provide an error free solution.

**3.3.2 Sand Inclusion:** This may be due to more quantity of metal, which may force the sand in mould. The gate should not be at 90°. Also, if gates are positioned too close to each other, some sand may get carried away by the metal.

**3.3.3 Eccentricity:** Bigger size castings mean there are more problems. The bushes of the mould box and the closing pin need to be checked. The closing pin should not be bent because this might cause eccentricity. The bushes need to be properly aligned. The pattern might also have some eccentricity if its dowel pin is too loose, this will then lead to eccentricity problems in the casting.

**3.3.4 Machine Fault:** These problems are operator related such as operator setting, gauge problems etc.

### 3.4 Prevention of defects:

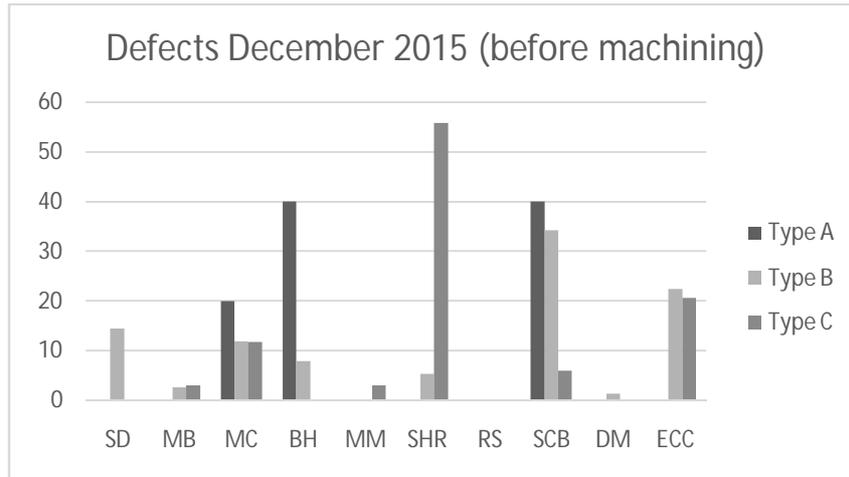
The present rejection rate is around 5%. It is proposed to bring down the rejection rate to lower satisfactory levels. The corrective action suggested is through provision of Poka-Yoke to prevent the defects from happening. All the defect causes are being studied in detail to incorporate the Poka-Yoke in the next phase of the study. It is proposed to have Poka-Yoke for some of the important defect causes such as ensuring correct quantity of fresh sand in mould preparation etc.

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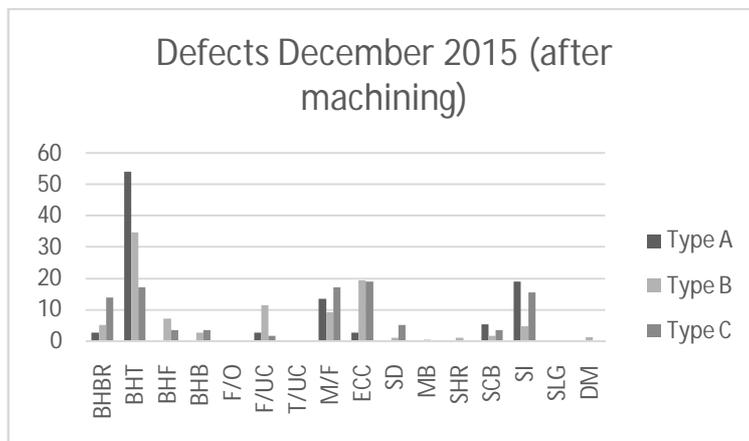
In Figure 3, the defects for the month of December 2015 are shown for the condition of before machining. These defects have been found in quality gate 1 (As seen in process flow chart, Figure: 1).



**Figure3: Defects December 2015 (before machining)**

On the horizontal axis, the different defects are given using the abbreviations or nomenclature shown in Table: 2. On the vertical axis, the share of each defect is shown in percentage of the total defects found in quality gate 1 in that month. This format has been used for all graphs. The most important defects are: shrinkage for type C, then blowholes and scabbing for type A and finally scabbing for type B.

In Figure 4, the defects for the month of December 2015 are shown for the condition of after machining. These defects have been found in quality gate 2 (see process flow chart Figure: 1). Most of the casting defects are found in quality gate 2 (75%) in comparison to quality gate 1 (25%). The most important defects are: top blowholes for types A and B, then eccentricity for types B and C, followed by sand inclusion for type A.



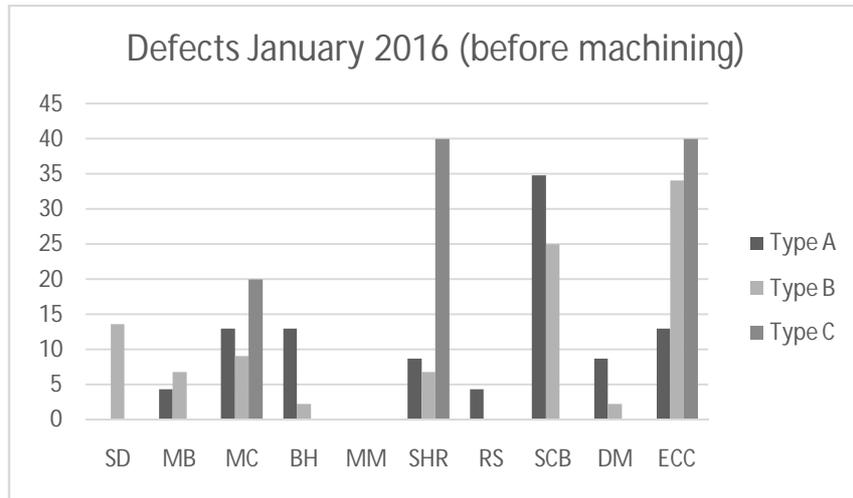
**Figure4: Defects December 2015 (after machining)**

In Figure 5, the defects for the month of January 2016 are shown for the condition of before-machining. These defects have been found in quality gate 1 (see process flow chart Figure: 1). The most important defects are: shrinkage and eccentricity for type C, then scabbing for type A, followed by eccentricity for type B.

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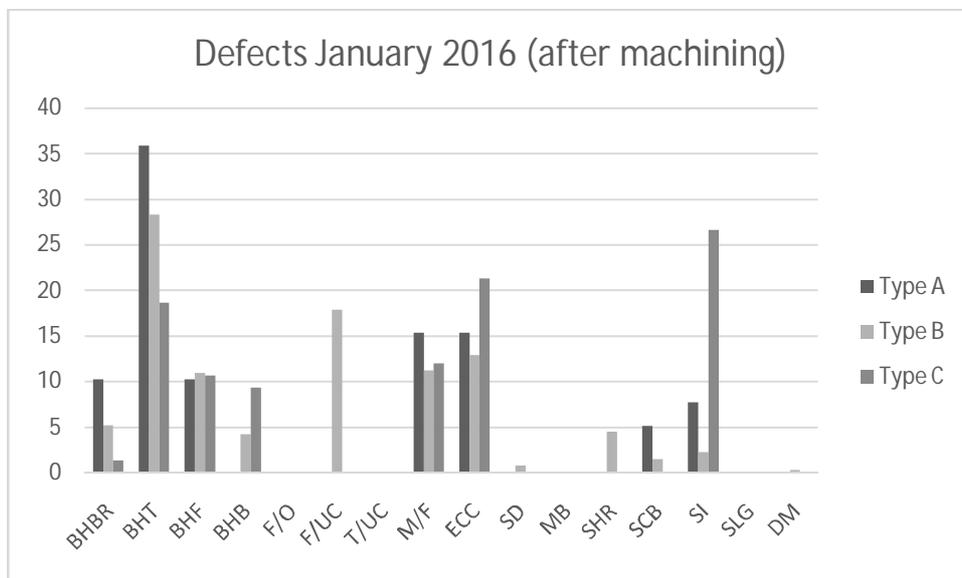
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**Figure 5: Defects January 2016 (before machining)**

In Figure 6, the defects for the month of January 2016 are shown for the condition of after-machining. These defects have been found in quality gate 2 (see process flow chart Figure: 1). The most important defects are: top blowholes for type A and B, then sand inclusion for type C, followed by eccentricity for type C.



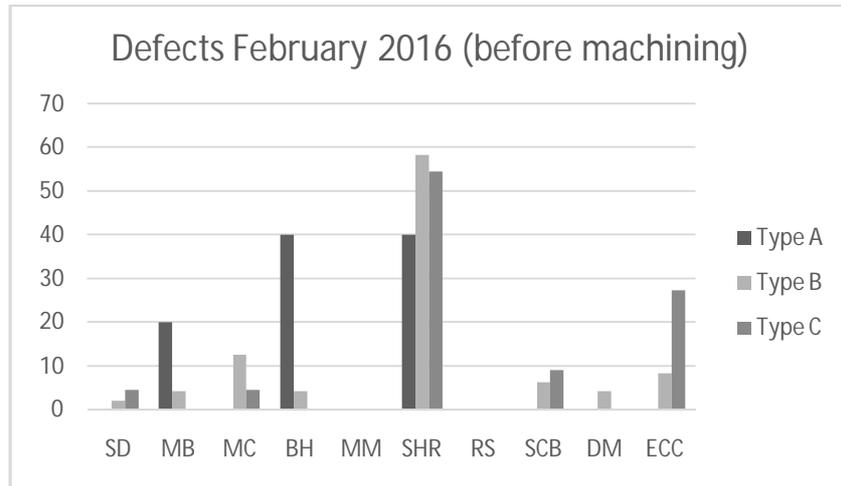
**Figure 6: Defects January 2016 (after machining)**

In Figure 7, the defects for the month of February 2016 are shown for the condition of before-machining. These defects have been found in quality gate 1 (see process flow chart Figure: 1). The most important defects are: shrinkage for types B and C, then blowholes and shrinkage for type A and finally eccentricity for type C.

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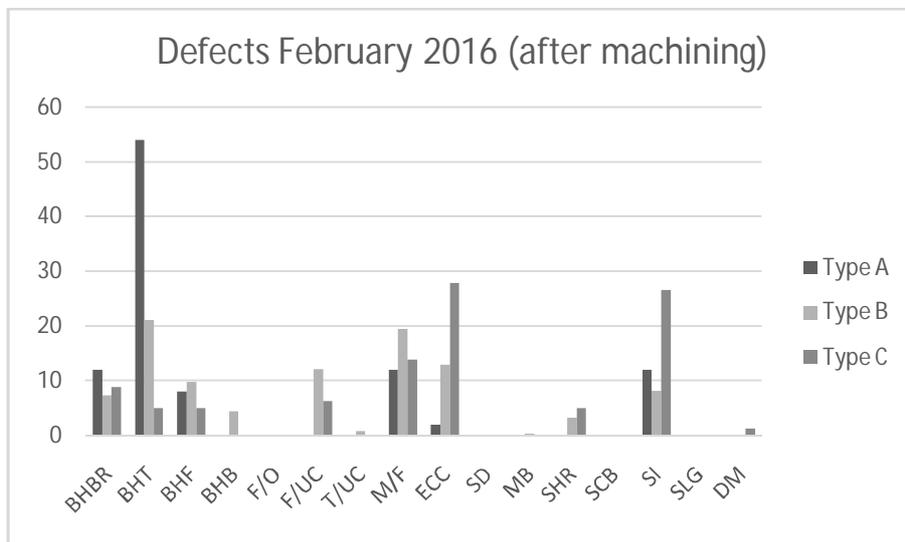
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**Figure 7: Defects February 2016 (before machining)**

In Figure 8, the defects for the month of February 2016 are shown for the condition of after-machining. These defects have been found in quality gate 2 (see process flow chart Figure: 1). The most important defects are: top blowholes for type A, then eccentricity and sand inclusion for type C and finally again top blowholes for type B.



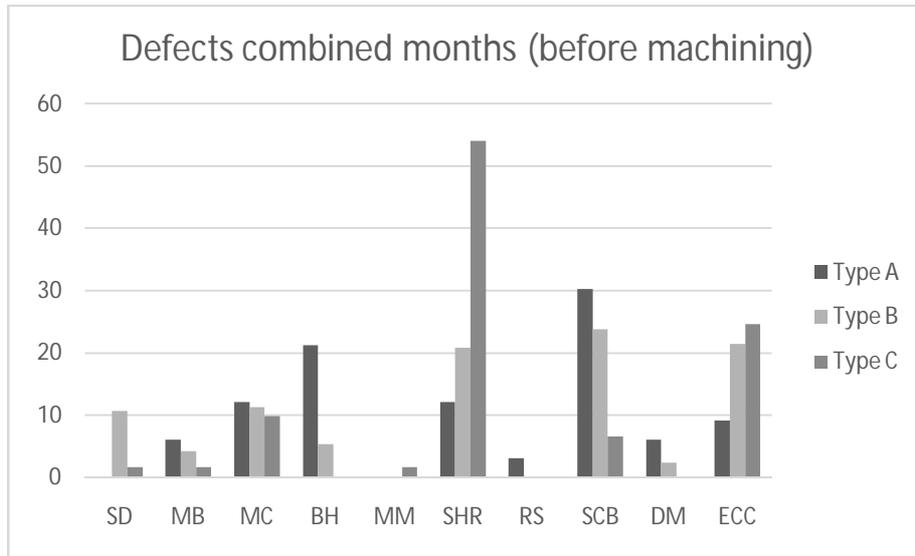
**Fig 8: Defects February 2016 (after machining)**

In Figure 9, the defects for the combined months of December 2015, January 2016 and February 2016 are shown for the condition of before-machining. These defects have been found in quality gate 1 (see process flow chart Figure: 1). The most important defects are: shrinkage for type C, then scabbing for type A and B, followed by eccentricity for types B and C.

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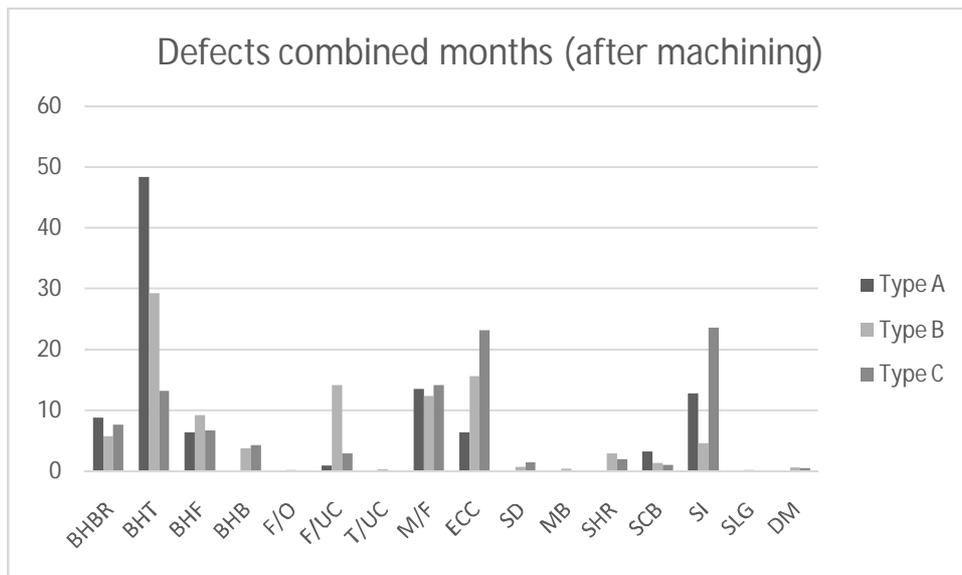
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**Figure 9: Defects combined for three months (before machining)**

In Figure 10, the defects for the combined months of December 2015, January 2016 and February 2016 are shown for the condition after-machining. These defects have been found in quality gate 2 (see process flow chart Figure: 1). The most important defects are: top blowholes for types A and C, then eccentricity and sand inclusion for type C, followed by eccentricity for type B. Since machining defects are around 13% of total for all types, it is also an important defect.



**Figure 10: Defects combined for three months (after machining)**

The results, observations and the discussions are concluded in the subsequent section.

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## IV. CONCLUSION

The conclusions of the study are as follows:

- i) The defects in Grey-Iron foundry process (before and after machining) have been studied for three categories of brake drums based on weight of casting with Category A upto 50 kg, Category B in the range of 50-70 kg and Category C in the range of 70 kg & above. The maximum weight handled in the foundry is 100 kg.
- ii) The defects are happening due to several causes, which are identified and segregated both before and after machining
- iii) Before machining, the most important defects are (in order of importance): shrinkage in Category C, scabbing in Categories A and B, eccentricity in Categories B and C, blowholes in Category A and mould crushes in all types.
- iv) Whereas after machining, the type of defects identified and segregated are: Blow-hole on top in category A & B, sand inclusion in Category C, eccentricity in Categories B & C and machining fault in all three categories.
- v) The finding of defect causes is more or less in agreement with the general trends for such industry found in literature and the total rejection rate is around 5%.
- vi) It is intended to reduce the rejection rate to a comfortable lower level in order to improve profit and also to save energy, which in turn will also bring environmental benefits.
- vii) It is possible to completely eliminate or reduce the number of occurrences of defects through systematic corrective action such as Poka-Yoke
- viii) It is recommended to initiate Poka-Yoke as a corrective measure to bring down the rejection rate in the next phase of study.
- ix) The key finding of this study is that the quality of sand and mould preparation are the key for eliminating substantial defects.
- x) The first corrective action through Poka-Yoke is expected to provide accurate proportions of sand components for mould preparation.

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