RESEARCH ARTICLE OPEN ACCESS

Defects, Root Causes in Casting Process and Their Remedies: Review

Vaibhav Ingle[1] Madhukar Sorte[2]
[1]*ME Mechanical Student, SCOE, Navi Mumbai, vhi4299@gmail.com*
[2]*Asso.Prof.in Mechanical Engg Department, SCOE, Navi Mumbai,madhukar.sorte@gmail.com*

ABSTRACT
Many industry aims to improve quality as well as productivity of manufacturing product. So need to number of process parameter to must controlled while casting process, so there are no of uncertainty and defects are face by organizations. In casting process industries are need to technical solution to minimize the uncertainty and defects. In this review paper to represent various casting defects and root causes for engine parts while casting process. Also provide preventive action to improve quality as well as productivity an industrial level.
Keywords: Casting defects and their root causes, remedies for casting defects.

I. INTRODUCTION

Casting is a manufacturing process, in which a hot molten metal is use to poured into a mold box, which contains a hollow cavity of the desired shape, and then allowed to solidify. That solidified part is known as a casting, Casting is most often used for making complex shapes that would be otherwise difficult or uneconomical to make by other methods. Casting is a process which carries risk of failure occurrence during all the process of accomplishment of the finished product. Hence necessary action should be taken while manufacturing of cast product so that defect free parts are obtained. During the process of casting, there is always a chance where defect will occur. Minor defect can be adjusted easily but high rejected rates could lead to significant change at high cost. Therefore it is essential for die caster to have knowledge on the type of defect and be able to identify the exact root cause, and their remedies. In this review paper an attempt has been made to provide all casting related defect with their causes and remedies.

In a casting process, the material is first heated to completely melt and then poured into a cavity of the mold. As soon as the molten metal is in the mold, it begins to cool. When the temperature drops below the freezing point (melting point) of the material, solidification starts. Solidification involves a change of phase of the material and differs depending on whether the material is a pure element or an alloy. A pure metal solidifies at a constant temperature, which is its melting point (freezing point).An attempt has been made to analyze the critical defects and possible remedial measures are suggested for cast masters to have a sound knowledge about such defects with an aim to minimize rejections rates.

II. MOTIVATION

Mostly casting defects are concerned with process parameters. Hence one has to control the process parameter to achieve zero defect parts. For controlling process parameter one must have knowledge about effect of process parameter on casting and their influence on defect. The correct identification of the casting defects at the initial stage is essential for taking remedial actions. Analysis of defects like shrinkage porosities computer aided casting simulation technique is the most efficient and accurate method. The quality and yield of the casting can be efficiently improved by modifying like SQC DOE Method simulation technique in shortest possible time and without carrying out the actual trials on foundry shop floor.

III. LITERATURE REVIEW

Rajesh Rajkolhe, J.G. Khan conclude that various defect are generated in casting process while manufacturing, defects may like as filling related, shape related, thermal related and other defects by appearance. While performing various number of process parameters as trial and error basis they find out various challenges and uncertainty in casting process. Such types of defects are developed poor quality and productivity. To obtain high quality they was found their remedies to minimize those challenges and uncertainty also rejections. This action may helps to improve quality as well as productivity in manufacturing industry.

Mr. Siddalingswami , S. Hiremath, dr, S.R. dulange stated that various casting defects and their causes. they go through a industry was kirloskar ferros industry ltd. Solapur, they identify a defects for 4R cylinder block which they found a rejection rate was more than 40%. They also conclude that , while production involve various parameter like pattern making, moulding, core making, and melting. A various defects like blowhole shrinkage, gas porosity, cold shot, sand inclusion etc. are generated while casting process. for improved their casting quality, they use product process search analysis, inspection method, design of experiment method to found out their remedies in casting process.

C. M. Choudhari, B. E. Narkhede, S. K. Mahajan, are state that various casting defects can be minimize by simulation software basis, software helps to improve quality of casting process and parameters. Utilization of methodology which involve four decision (1) orientation and parting line, (2) core print design, (3) feeder design, and (4) gating design. Experiment are perform for process by trial basis with help of simulation software which optimize faster and better result. It helps to minimize the bottleneck and non value added time in casting development as it reduce the number of trail for casting required on shop floor.

P. Shailesh, S.Sundarrajan and M.Komaraiah studied that optimization of process parameter in casting process for Al-Si alloy by using Design of Experiments (DOE) method. It helps to improve the mechanical properties of yield strength and density. The result is reducing the pouring temperature and increasing the speed of die lead of casted component. They also studied shrinkage characteristics and control the producing defects casting.

Dr. M. Arasu (Head department of foundry technology, PSG Polytechnic College) conclude that every casting process achieve to have cost effectiveness and high quality for customer point of view. They meant that cost effectiveness means a strategy of utilization of raw material and equipment to improve finish products with good quality for defect free casting in casting process. While in casting process of poorly maintained equipment used then they affect to die as well as casting parameters. So indirectly it fails to maintain quality, and defect developed on external as well as internal side on casting components.

T.R.Vijayaram, S.Sulaiman, A.M.S. Hamouda, and M.H.M. Ahmad (Metal casting industries) they was work on scrap rejection and rework in manufacturing and state that for avoid the defects by implementation of various modified technique which helps to eliminate the uncontrolled scrap and rejections. The modified technique such as statistical quality control (SQC) to adopted for developing metallurgical engineering foundry.

Guo-fa MI, Xiand-yu, Kuang-fei WANG, Heng-Zhi FU, are applied numerical value as a simulation for casting process. Types of defects like shrinkage, gas porosity, cold shut were analyze, also found the mold filling and solidification stage in casting parameters also found filling behavior, solidification sequence, thermal stress distribution in casting process for achieve high quality and productivity.

Alagarsamy are used trial and error method to solve casting related problem which helps find the defects and their root causes. Using a powerful technique to mapping defects and finding questionnaires such as design of experiments (DOE) for identify the defects and control the variables in casting process. They also conclude the various defects in casting and root cause so also they found their remedies to improve quality.

Malcolm Blair, Raymond Monroe, Christoph Beckermann, Rishard Hardin, Kent Carlson and Charles Monroe state that casting design are based on experience of designer who developed the design utilization factor of safety for casting process. Also, utilizes unquantified factor such as shrinkage, porosity, also consider in casting. They predict the occurrence and nature of defects and effect on performance of casting.

A.P.More, Dr.R.N.Baxi, Dr.S.B.Raju Mechanical Engineering Department, G.H.Raisoni College of Engineering, reviewed that casting defect analyze in initial improvement process to identify casting defects and their root cause. They minimize the various casting defects their critical component in casting process to improve quality. Identifying various defects and eliminates those defects by taking appropriate corrective action to achive higher productivity.

Elena Fiorese, Franco bollono and Gaiulio Timelli department of management and engineering, stated that various process are available for production of aluminium alloy, but significant role played by foundry process. they highlight on multilevel classification of structural defects and imperfection in aluminium alloy casting. The frist level of types of defects basis on their internal, external and geometric. Second level distingwish on their metallurgical origin and third level refer to the specific types of defects. In high pressure die casting required production rate up to 120 casting / hr. required high filling velocities of molten alloy up to 40 m/sec. (131 ft/sec)with significant turbulence in the flow. Solidification takes place in few seconds and die is first contact with a molten metal alloy temperature higher than 700* C, (1292* F) and after 30-40 seconds, spray with a die relies agent at room temperature. Solidification parameter is play main role to cooled the mold in casting so various defects can generated while differences in solidification time.

M. Avalle, G. Belingardi, M.P. cavatorta, R. Deglione Department of mechanical engineering politechno de Torino Italy, stated that the influence of casting defects are exist in Gs and shrinkage pores, as well as cold fill, dross and alumina skin. They also checked the specimen by experimentally and made observations in form of acceptable and non acceptable. High pressure die Casting used toobtaind complex shapes and geometry for high production rate. Their studied shows the temrature defects as well as effects on mechanical properties for material EN 46000 UNI EN 1706 which is mostly used in automotive field.

G. K.Sigworth concluded the concept of quality for improvement in aluminium casting which combination of strength and elongation possible in heat treated casting with the help of numerical value index. The concentration of casting defects was generating while molten material flow in mold. For getting defects free casting, the solidification rate is considered as important function, because it determine the size and amount of micro porosity (brittle phase) of component in casting. In solidification time molten material in die freeze quickly and concentrate high content of gas on different thickness which affects on tensile property.

J.B.Ferguson, Hugo F. Lopez, Kyu Cho,and Chang Soo Kim expert of material science and technology USA, stated that the mechanical property are influence by as thermodynamic stability of the participate in alloy, the concentration of impurity elements that evolve in alloy micro structure. Different heat treatments to control the quantity, size and composition of inter metallic form of alloy. The A-319 aluminium alloy material used for engine block for its good abressive property as well as mechanical strength. They also stated the account of temperature effects on youngs modulas, true yield stress, true failure stress and strain to failure for participation hardness alloy. Also shows strength coefficients, ductility parameter and strain hardening exponent for T-7 heat treatment condition.

J. Kajorncchairyakal, R. Sirichaivejakul, N moonrin, National metal and material technology center Bangkok are studied that the experimental finding concerning the effect of sulfur on A-356 aluminium alloy. It is better understanding regarding the influence of sulfur while solidification as well as mechanical property on alloy. They conduct experiment with of addition of sulfur and show the thermal analysis eutectic reaction of sulfuric alloy interval is quite longer. It is not more affect to tensile strength as well as bulk hardness between sulferise and normal alloy, which give greater ductility and lower yield strength with comparison with normal alloy.

Ildiko peter, Mario Rosso, Material science and chemical engineering department Italy, studied that mechanical performance hardly affected by internal surface and sub surface defects, porosity etc while casting. Aluminium based alloy with T-6 heat treatment fined the surface condition and inspection of micro and macro surface of metallic alloy. The most common defects found in Al-Si casting alloys while solidification by volume concentration, (Shrinkage) non correct feeding system, and gas (hydrogen) development. The defects like shrinkage pour inclusion crack initiate site, which mostly affect to all mechanical properties which indicate the mechanical failure.

IV. CASTING DEFECTS AND REMMEDIES

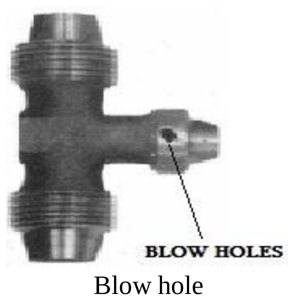
A properly designed casting, a properly prepared mould and correctly malted metal should result in a defect free casting. However, if proper control is not exercised in the foundry-sometimes it is too expensive [1].casting defect can be classified as follows-

4.1. Filling related defect
4.2. Shape related defect
4.3. Thermal related defect

4.1Filling related defect

4.1.1.Blowhole

During solidifying metal on surface of metal a rounded or ovel shape hole cavity on smooth or clean surface which is associated with oxides. It collects into a bubble at the high points of a mould cavity ad prevents the liquid metal from filling that space. Blowhole is a kind of cavities defect, which is also divided into pinhole and subsurface blowhole. Pinhole is very tiny hole. Subsurface blowhole only can be seen after machining. The defects are nearly always located in the cope part of the mould in poorly vented pockets and undercuts.



Blow hole

Possible causes

- poor venting core of mould
- Excessive release of gas permissibility
- Excessive moisture absorption by the cores
- Low pouring temperature while casting

Remedies

- Improve venting core of mould,
- provide venting channels,

- Reduce amounts of gas. Use slow-reacting binder
- Reduce quantity of binder.
- Use a coarser sand if necessary.
- Slowing down the heating rate and reducing gas pressure.
- Reducing absorption of water.

4.1.2. Sand inclusion

Sand inclusion is nothing but a sand hole or blacking scab, It looks like small or middle holes with sand grain in the internal or on the surface of castings. Inclusion defects looks like there are slag inside of metal castings. Sand inclusions are one of the most common casting defects. This casting defect is formed during abrasion of the mold surface by the metal flowing past and the associated thermomechanical stresses. The considerable compressive and shear stresses acting on the mold and core sections canlead to breakage of individual sand grains (erosions) or tearing off of larger mold sections (erosion scabs). This causes interruptions in smooth mold and core surfaces, thickening zones on individual casting sections and sand crusts (sand inclusions) in remote casting areas. Irregularly formed sand inclusions, It is often difficult to diagnose, as these defects generally occur at widely varying positions and are therefore very difficult to attribute to a local cause. Areas of sand are often torn away by the metal stream and then float to the surface of the casting because they cannot be wetted by the molten metal. Sand inclusions frequently appear in association with CO blowholes and slag particles. Sand inclusions can also be trapped under the casting surface in combination with metal oxides and slag's, and only become visible during machining.

Sand inclusion defects

Possible causes

- Core strength is less
- Excessive mismatching of core
- Rate of Pouring too high
- Impact against mould wall surface resulting in erosion
- Pouring time too long

Remedies

- Increase the strength of the cores. Use greater proportion of binder.
- Avoid core mismatching• inject gas more evenly
- Compact cores more evenly and effectively and if necessary

4.1.3. Cold lap or cold shut

A cold shut is caused when two streams while meeting in the mold cavity, do not fuse together properly thus forming a discontinuity in the casting. When the molten metal is poured into the mold cavity through more-than-one gate, multiple liquid fronts will have to flow together and become one solid. If the flowing metal fronts are too cool, they may not flow together, but will leave a seam in the part. Such a seam is called a cold shut, It is a crack with round edges. Cold lap is because of low melting temperature or poor gating system. When the metal is unable to fill the mould cavity completely and thus leaving unfilled portion called misrun. A cold shunt is called when two metal streams do not fuse together properly.

"Cold shut" defect on die cast part

Possible Causes

- Lack of fluidity in molten metal
- Faulty design
- Faulty gating

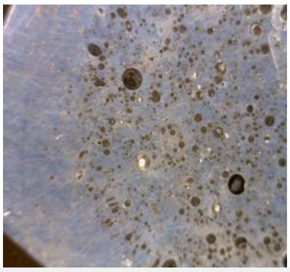
Remedies:

- Adjust proper pouring temperature
- Modify design
- Modify gating system

4.1.4. Gas porosity

Porosity in *castings* is due to bubbles being trapped during solidification. ... wall, dissolved *gases*from melting and dross or slag containing *gas porosity* The gas can be from trapped air, hydrogen dissolved in aluminum alloys, moisture from water based die lubricants or steam from cracked cooling lines.

usually internal, caused by trapped gases of various kinds in the die. Gas porosity comes from three main sources in die-casting, namely trapped air steam and burned lubricant. Air is present in the cavity before the shot. It can easily be trapped as the metal starts to fill the cavity. The air is then compressed as more and more metal streams into the cavity and the pressure rises. When the cavity is full it becomes dispersed as small spheres of high pressure air. The swirling flow can cause them to become elongated.



Defect Diagnosis: Gas Porosity

Possible Causes

- Metal pouring temperature too low.
- Insufficient metal fluidity
- Pouring too slow.
- Slag on the metal surface.
- Interruption to pouring during filling of the mould.
- Metal section too thin.

Remedies

- Increase metal pouring temperature.
- Modify metal composition to improve fluidity.
- Pour metal as rapidly as possible without interruption. Improve mould filling by modification to running and gating system. • Remove slag from metal surface.
- Reduce gas pressure in the mould by appropriate adjustment to moulding material propertie4s and ensuring.

4.2 Shape defects

4.2.1. Mismatch defect

Mismatch in mold defect is because of the shifting molding flashes. It will cause the dislocation at the parting line.

Mismatch defect

Possible causes

- A mismatch is caused by the cope and drag parts of the mould not remaining in their proper position. • This is caused by loose box pins, inaccurate pattern dowel pins or carelessness in placing the cope on the drag.

Remedies

- Check pattern mounting on match plate and Rectify, correct dowels. • Use proper molding box and closing pins.

4.2.2. Distortion or warp

Warped Casting—Distortion due to warp age is known as warp defect.

Distortion or warp

Possible causes

- Distortion due to warp age can occur over time in a casting that partially or completely liberates residual stresses.

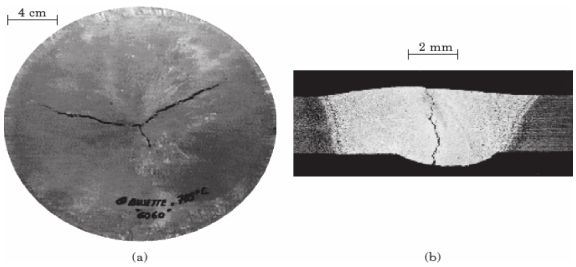
Remedies

- Common practice in iron casting is normalizing heat treatment to remove residual stress. In aluminum casting, a straightening between quench and aging might be required.

4.3 Thermal defects

4.3.1. Cracks or tears

Cracks can appear in die castings from a number of causes. Some cracks are very obvious and can easily be seen with the naked eye. Other cracks are very difficult to see without magnification.



Cracks or tears

Possible causes

- Shrinkage of the casting within the die
- Undercuts or damage in die cavities
- Uneven, or excessive, ejection forces

- Thermal imbalance in the die
- Insufficient draft in sections of the die
- Excessive porosity in critical regions of the Part
- Product design not matched to the process
- Inadequate die design

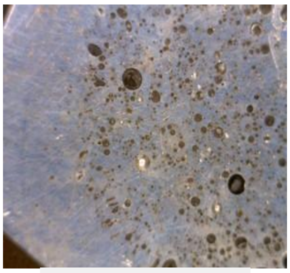
Remedies

- Reduce dry strength, add saw dust/ coal dust
- Reduce pouring temperature
- Avoid superheating of metal
- Use chills • Provide feeders
- Avoid early knockout. Give sufficient cooling time.
- Correct composition
- Reduce sharp corners

4.3.2. Shrinkage

Shrinkage defects occur when feed metal is not available to compensate for shrinkage as the metal solidifies. Shrinkage defects can be split into two different types: open shrinkage defects and closed shrinkage defects. Open shrinkage defects are open to the atmosphere, therefore as the shrinkage cavity forms air compensates. There are two types of open air defects: pipes and caved surfaces. Pipes form at the surface of the casting and burrow into the casting, while caved surfaces are shallow cavities that form across the surface of the casting.

Closed shrinkage defects, also known as shrinkage porosity, are defects that form within the casting. Isolated pools of liquid form inside solidified metal, which are called hot spots. The shrinkage defect usually forms at the top of the hot spots. They require a nucleation point, so impurities and dissolved gas can induce closed shrinkage defects. The defects are broken up into macroporosity and microporosity (or microshrinkage), where macroporosity can be seen by the naked eye and microporosity cannot.



Shrinkage Porosity.

Possible causes

- The density of a die casting alloy in the molten state is less than its density in the solid state. Therefore, when an alloy changes phase from the molten state to the solidstate, it always shrinks in size. This shrinkage takes place when the casting is solidifying inside a die casting die. At the centre of thick sections of a casting, this shrinkage can end up as many small voids known as ‘shrinkage porosity’. If the shrinkage porosity is small in diameter and confined to the very centre of thick sections it will usually cause no problems. However, if it is larger in size, or joined together, it can severely weaken a casting. It is also a particular problem for castings which need to be gas tight or water tight’.

Remedies

- The general technique for eliminating shrinkage porosity is to ensure that liquid metal under pressure continues to flow into the voids as they form.

V. CONCLUSION

In the present paper, a new classification of defects and imperfections or Al alloy castings has been presented. three categories of casting defect have been identified: filling-related defects, shrinkage defects, shape related defects, thermal-related defects, Briefly, Filling- related defects ,thermal-related defects result from the interaction between melt flows at different temperature, while undesired phases are non-metallic phases, such as oxides, pieces of refractory and dross, which come from the interaction between melt and environment. Finally, thermal contraction defects are cracks due to the casting contraction constrained by the die or already solidified material. In this research work different casting defects are studied. By referring different research papers causes and their remedies are listed. These will help to improve the quality in industries for analysis of casting defect. This study will definitely be helpful in improving the productivity. Rejections of the casting should be as minimized and get higher quality.

REFERANCES

[1]. Defects, Causes and Their Remedies in Casting Process: A Review Rajesh Rajkolhe1, J. G. Khan2 Asst Professor1, 2, Mechanical Engineering Department1, 2, Shri Sant Gajanan Maharaj College of Engineering,

[2]. “Review of Casting Defect Analysis to Initiate the Improvement Process”A.P.More, Dr.R.N.Baxi, Dr.S.B.Jaju Mechanical Engineering Department, G.H.Raisoni College of Engineering, Nagpur. 440016 (India)

[3]. Defect formation in cast iron Lennart Elmquist School of Engineering Jönköping

University, Sweden Tammerfors, Finland, November 8, 2012

[4]. Analysis of Casting Defects and Identification of Remedial Measures – A Diagnostic Study Dr D.N. Shivappa1, Mr Rohit2, Mr. Abhijit Bhattacharya3 International Journal of Engineering Inventions ISSN: 2278-7461, www.ijeijournal.com Volume 1, Issue 6 (October2012) PP: 01-05

[5]. Casting Defect Analysis using Design of Experiments (DoE) and Computer Aided Casting Simulation Technique Uday A. Dabade* and Rahul C. Bhedasgaonkar,(2013)

[6]. Reduction of defects in grey cast iron castings by six sigma approach Raguramsingh., Syath Abuthakeer. ME Lean Manufacturing, PSG College of Technology Department of Mechanical Engineering, PSG College of Technology, Coimbatore, India.

[7]. Process optimization as a tool in the analysis of steel casting defects By Dr.Hathibelagal Roshan, Chief Metallurgist Maynard Steel Casting Company Milwaukee

[8]. Silver anniversary paper,div5 Porosity defects in iron casting from mold metal interface reaction. R.l.naro.aci international,inc,cleveland,ohio.

[9]. Advanced techniques in casting defects and rejection analysis: a study in an industry Mr. Siddalingswami. S. Hiremath, Dr. S. R. Dulange Professor, Mechanical Engg. Solapur University, [IJIERT] ISSN: 2394-3696 volume 2, issue 9, sep.-2015

[10]. Modeling and simulation with experimental validation of Temperature distribution during solidification process in sand cast By C. M. Choudhari, , B. E. Narkhede, S. K. Mahajan

[11]. Analysis of Casting Defect Through Diagnostic Study Approach Method, B.Chokkalingam & S.S.Mohamed Nazirudeen, Department of Foundry Technology, Coimbatore, India.

[12]. New Approach to Casting Defects Classification and Analysis Supported by Simulation, V.V.Mane, Amlt Sata and Y.R. vire.

[13]. Casting Defect Hand Book, American Foundry Society (AFS), Des Plaines II, 1972.

[14]. Casting Defect analysis using Design of Experiments (DOE) and Computer aided Casting Simulation Technique, Uday A.Dabade and Rahul.C, Bhedasaonkar, Department of Mechanical Engineering, Walchand College of Engineering Sangli, India.

[15]. Metal Casting Principal and Practice, T.V.Ramana Rao, India.

[16]. Principal of Methoding and Casting Design, Professor Goutam Sutradhar

[17]. B.ravi, "Casting Simulation and Optimization: Benefits, Bottlenecks", Indian foundry journal, 2008, pp.3-5.

[18]. Dr.M.Arasu (Head, Department of Foundry Technology, PSG Polytechnic College)

[19]. Guo-fa MI, Xiand-yu, Kuang-fei WANG, Heng-Zhi FU Malcolm Blair, Raymond Monroe, Christoph Beckermann, Rishard Hardin, Kent Carlson and Charles Monroe

[20]. A.Alagarsamy, Citation Corporation, Birmingham, Alabama

[21]. "Review of Casting Defect Analysis to Initiate the Improvement Process"A.P.More, Dr.R.N.Baxi, Dr.S.B.Jaju Mechanical Engineering Department, G.H.Raisoni College of Engineering, Nagpur. 440016 (India)

[22]. Defect formation in cast iron Lennart Elmquist School of Engineering Jönköping University, Sweden Tammerfors, Finland, November 8, 2012

[23]. Analysis of Casting Defects and Identification of Remedial Measures – A Diagnostic Study Dr D.N. Shivappa1, Mr Rohit2, Mr. Abhijit Bhattacharya3 International Journal of Engineering Inventions ISSN: 2278-7461, www.ijeijournal.com Volume 1, Issue 6 (October2012) PP: 01-05

[24]. Casting Defect Analysis using Design of Experiments (DoE) and Computer Aided Casting Simulation Technique Uday A. Dabade* and Rahul C. Bhedasaonkar,(2013)

[25]. Reduction of defects in grey cast iron castings by six sigma approach Raguramsingh.M#1, Syath Abuthakeer.S*2 #ME Lean Manufacturing, PSG College of Technology, Coimbatore, India. Assistant Professor, Department of Mechanical Engineering, PSG College of Technology, Coimbatore, India. 2syathpsgtech@gmail.com

[26]. Process optimization as a tool in the analysis of steel casting defects By Dr.Hathibelagal Roshan, Chief Metallurgist Maynard Steel Casting Company Milwaukee, WI 53217

[27]. Silver anniversary paper, div5 Porosity defects in iron casting from mold metal interface reaction. R.l.naro. aci international,inc, Cleveland, ohio

[28]. Modeling of shrinkage defects during solidification of long and short freezing

materials A. eisa,, Y. Houbaertc, Zhian Xub, Rob Van Tol b, A.D. Santosa, J.F. Duartea, A.B. Magalha˜ esa a FEUP – Faculdade de Engenharia da Universidade do Porto, Porto, Portugal b WTCM Foundry Center, Research Center of Belgium Metalworking Industry, 9052 Zwijnaarde, Gent, Belgium c UGent – University of Ghent, Technologiepark Zwijnaarde 903, Gent, Belgium.

[29]. New classification of defects and imperfection for aluminium alloy casting Elena Fiorese, Franco bollono and Gaiulio Timelli department of management and engineering international journal of metal casting vol.9 issue 1, 2015

[30]. Casting defects and fatigue strength of die cast aluninium alloy M. Avalle, G. Belingardi, M.P. cavatorta, R. Deglione Department of mechanical engineering politechno de Torino Italy international journal of fatigue 24 2002

[31]. Understanding the quality in aluminium casting G. K.Sigworth USAAmerican foundary society 2011

[32]. temperature effect on tensile properties of precipation hardend alloy J.B.Ferguson, Hugo F. Lopez, Kyu Cho,and Chang Soo Kim expert of material science and technology USA

[33]. Solidification charectristics and mechanical properties of aluminium silicon alloy containing sulfur J. Kajorncchairyakal, R. Sirichaivejakul, N moonrin, National metal and material technology center Bangkok

[34]. The effect of microstructural charectristics and casting defects on the mechanical failure of Al based alloy Ildiko peter, Mario Rosso, Material science and chemical engineering department Italy