

Study of Porosity Defect in Aluminum Die Castings and its Evaluation and Control for Automotive Applications

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ABSTRACT : *The growing requirement of competitive products in Automotive Market is in race and winner is always with high quality product built with defect free components. Certain Defects are unavoidable but yes can be limited by implementing certain controls in design and process. Die cast components are highly in use into Automotive applications such as Heatsinks or casings and so is the existence of Porosity in them analyzed and verified as OK up to certain levels. So, yes Porosity is a big concern in die casting as a defect but also the good news is that porosity doesn't always mean a casting is defective and that changes need to be made. A full inspection may show that it meets your stability and structural integrity requirements. This paper explains the detailed study of Porosity defect especially in Aluminum Die Castings used in Automotive Industry and focus on various Analysis and Verification methods used to identify the presence of Porosity based on common Standards.*

KEYWORDS – *Aluminum, Computed tomography, Non-Destructive Testing, Porosity & Radiographic Testing*

1. INTRODUCTION

The ability to reduce overall physical weight of the product without compromising on durability has been a key driver behind increased demand for aluminum and other light alloy parts like zinc in recent years – properties including electrical and thermal conductivity, mechanical strength, corrosion resistance is also attracting the attention of automotive manufacturers in various industries. Due to this unique range of characteristics, light metal can be used to cast complex, safety-critical components in automotive, electronics and aerospace. It also offers a cost-effective and high-volume production option for simple to complex parts.

Over time, aluminum has been progressively incorporated into automotive doors, trunks, hoods, and engines. Today, aluminum makes up a much more significant percentage of the vehicle. One of the biggest advantages apart from Aluminum Alloy being lightweight, good durable and corrosion resistant also lies with better thermal properties to make it be used as heatsinks in automotive electronics which generate power. For example, Power MOSFETs assembled in Picture Circuit Board often are assembled onto Aluminum heatsinks to effectively dissipate the heat generated to the ambient environment. Aluminum remains “the fastest growing automotive material over competing materials and is entering its most unprecedented growth phase since we’ve been tracking the shifting mix of automotive materials,” the latest survey of automakers by Ducker Worldwide (U.S. leading consultancy) showed.¹ The WardsAuto and DuPont Automotive survey also confirms aluminum is the first preferred material of choice among engineers and designers to help meet the expected fuel economy and emissions standards by 2025.²

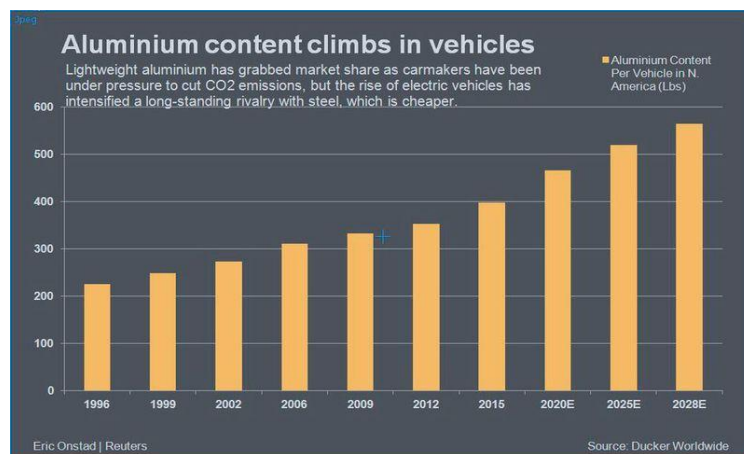


Fig 1: Growing demand of Aluminum into the Automotive World



Fig 2: Aluminum Die Casting components generally used for Automotive Applications

Pressure die casting is simply a quick, reliable and cost-effective manufacturing process for production of high-volume metal components with complex features and tight tolerances. To produce light alloy castings, the most common technologies are: high pressure die casting, and low pressure die casting. Selection of the process strongly depends on the component complexity, the number of parts and the manufacturing budget.

Refer below chart to understand the overview of both Die Cast Processes: -

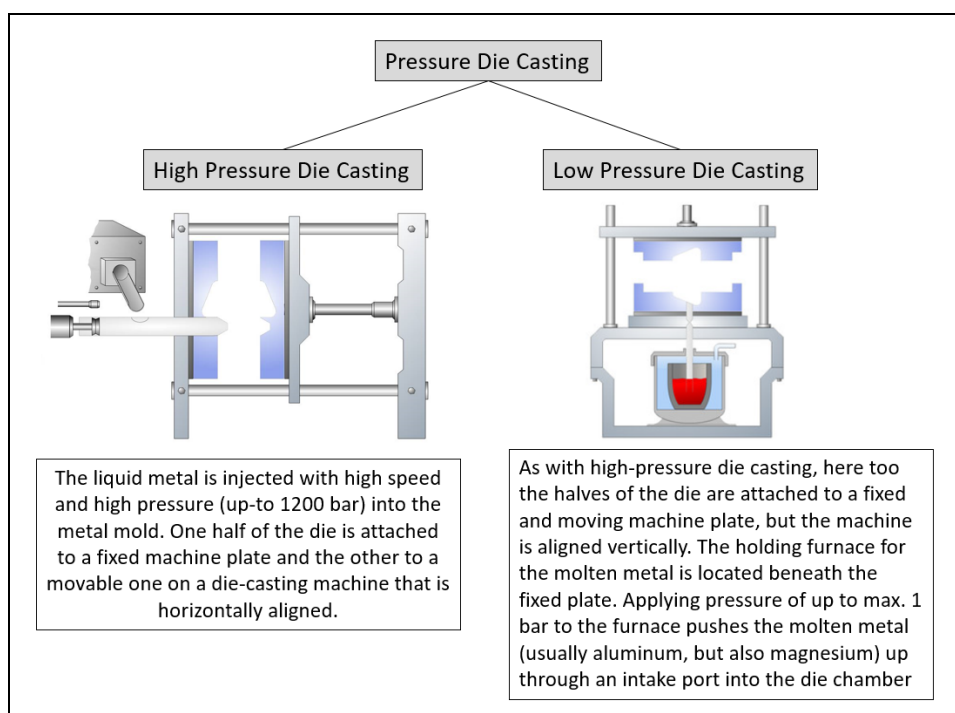


Fig 3: Types of Pressure Die Casting Process

High Pressure Die Casting Process are further divided into two types. The only difference between the two processes is the method being used to inject molten metal into the die.

Refer below chart to understand the overview of both the Processes: -

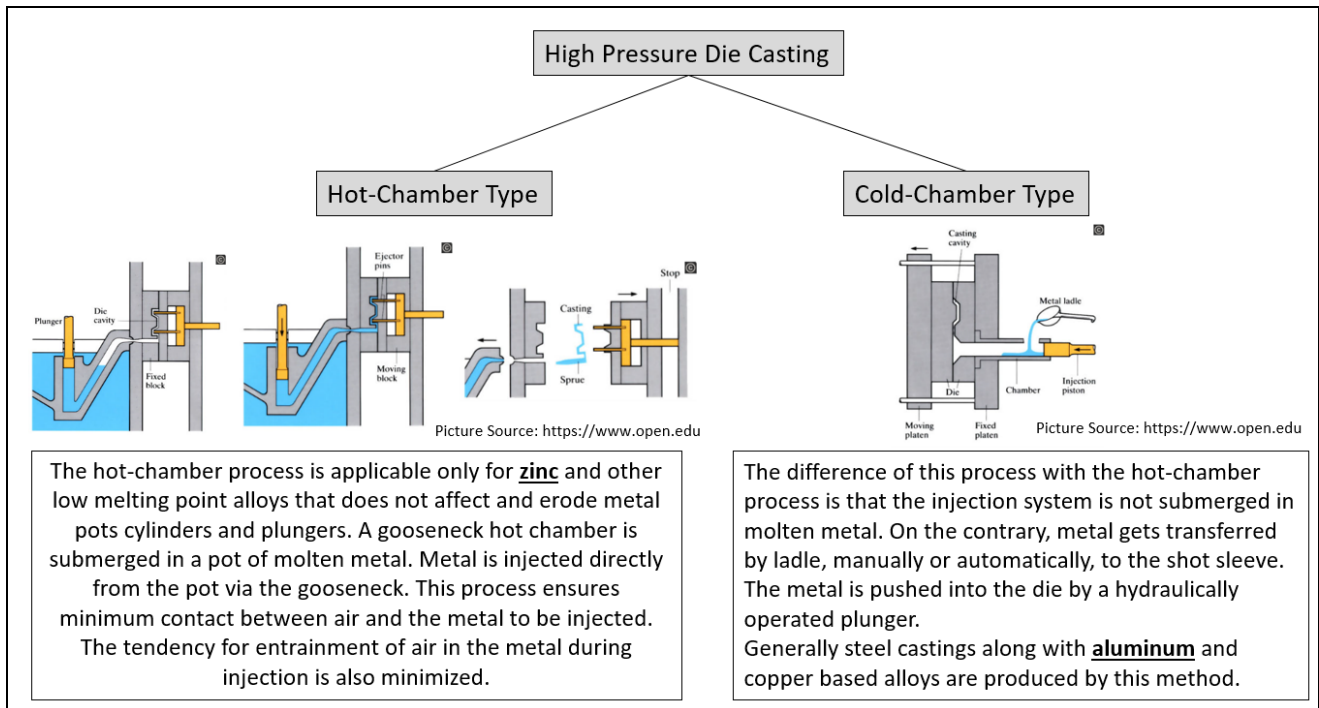


Fig 4: Types of High Pressure Die Casting Process

While high pressure die casting has wider application encompassing nearly 50% of all light alloy casting production. Currently low pressure-die casting accounts for about 20% of the total production but its use is increasing. High pressure castings are must for castings requiring tight tolerance and complex or detailed geometry. Low pressure die casting is commonly used for larger and non-critical parts. Here in our study we will focus on the High Pressure Die Casting Process involving the usage of Aluminum Alloy.

2. POROSITY IN CASTING COMPONENTS

Porosity simply refers to any holes or voids in a pressure die cast part either on the surface in the form of surface porosity or the inner porosity which is common area of interest for the designers. While die castings have a good surface finish, and are dimensionally accurate, porosity inside the part is cannot be ignored but most importantly can control in terms of careful Part Design, Process Controls, Post Processes and through Drawing Controls.

Porosity if on higher levels can directly affect the structural integrity and can impact the functionality of the part, creating a weak point. For example, if you are concerned with pressure tightness or ingress protection, porosity can lead to leakage. Refer Fig.5 below in which we can see porosity critically structure inside a part and as you can understand this may lead to failures related to leakage and environmental exposures in future during its service. In some cases, porosity can also have an indirect impact on customers' finishing requirements. So, it is very important to characterize the porosity in the castings for estimating their fatigue strength over service lifetime.

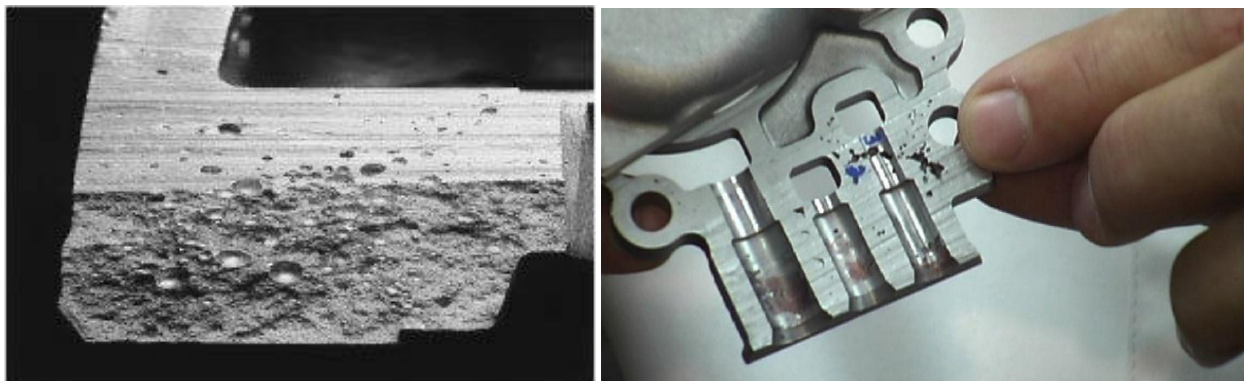


Fig.5: Porosity in the Die cast components

To understand more deeply on the problems the porosity can lead into we need to refer below Figure 6: -

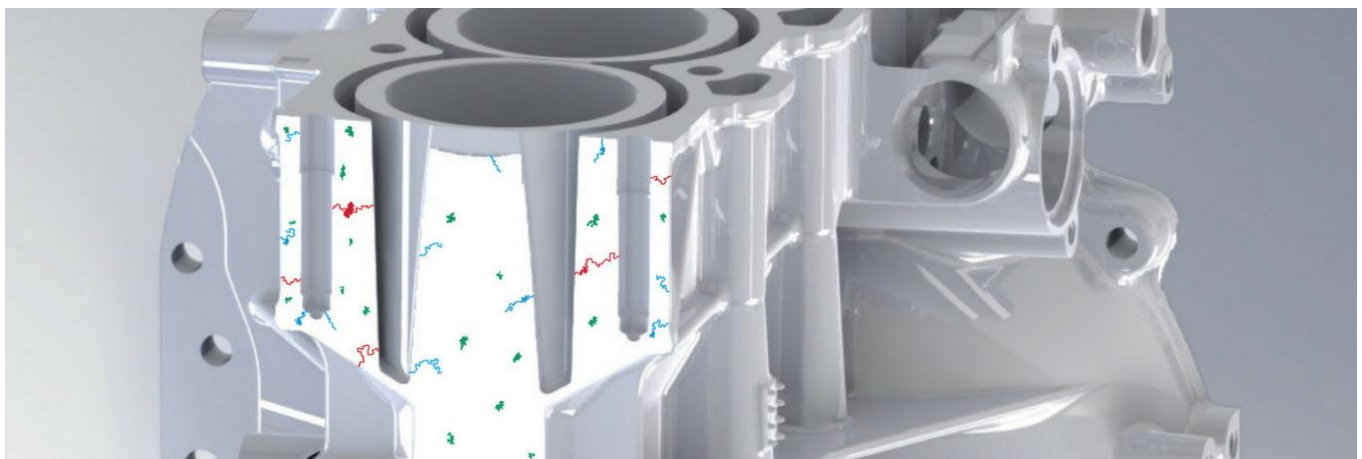


Fig.6: Problems associated with Porosity

Here are the porosity defects at component areas highlighted in Blue, Red and Green.

1. Blind Porosity (highlighted in blue): From one surface only and therefore not forming a continuous passage for liquid.
2. Through Porosity (highlighted in red): Stretching from one side of a casting to another thereby causing a leak path.
3. Fully Enclosed Porosity (highlighted in green): Enclosed within the casting and has no passage to the surface.

Blind and Through porosity cause immediate casting problems. Blind porosity can cause internal corrosion. Blind porosity can cause defects on the part surface when secondary treatments, like powder coating or anodizing, are done. This is because solutions used to clean the castings prior to the treatment will leech out of the voids after the surface finish process.

Through porosity will affect the part's structural integrity, creating a failure point. Through porosity will prevent the part from being pressure tight. This will impact performance if the part is designed to hold gases or fluids.

Fully enclosed porosity is not a problem unless secondary machining uncovers this porosity. Machining can break fully enclosed porosity, which will then turn it to either Blind or Through porosity. ³

3. TYPES OF POROSITY

The two most common types of casting porosity types are:

Gas porosity and shrinkage porosity.

Gas-Related Porosity:

Gas-related porosity is caused by trapped mold or core gases in the liquid metal. Gas porosity is round and generally smooth, although it can be flattened to some extent by pressure.

There are three major and general sources of gas porosity for die castings:

- Air that is pressed into the mold cavity during the first and second phase (Shot phase, Changeover point)
- Gas from lubricant
- High level of hydrogen gas (H₂) dissolved in the aluminum at liquid phase.

Gas porosity is always buoyant and will be near the top of the casting.



Fig.7: Gas Porosity

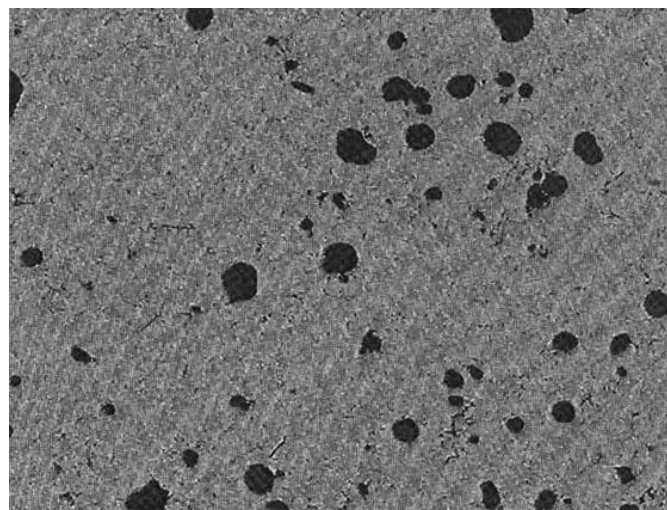


Figure 8: Gas porosity is round with smooth walls (sometimes shiny) and often grouped together (but not always). It is not sharp, jagged or crack-like in appearance.

Shrinkage-Related Porosity:

When a casting solidifies inside the tool, it always shrinks in size. Shrinkage porosity defects are cavities inside components which can cause material weakening and, if positioned on surface, can worsen aesthetic quality and corrosion resistance. Unlike Gas Porosity Shrinkage porosity will have a rough, irregular, jagged or linear appearance.

Shrinkage porosity appears during material solidification phase, which begins with mold filling phase and ends when every part of the material is completely solidified. The cause of its creation is material shrink and, for this reason, porosity is as intense as shrink rate is high. At the center 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 center 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 problem for castings which has water ingress requirements or need to be pressure tight.

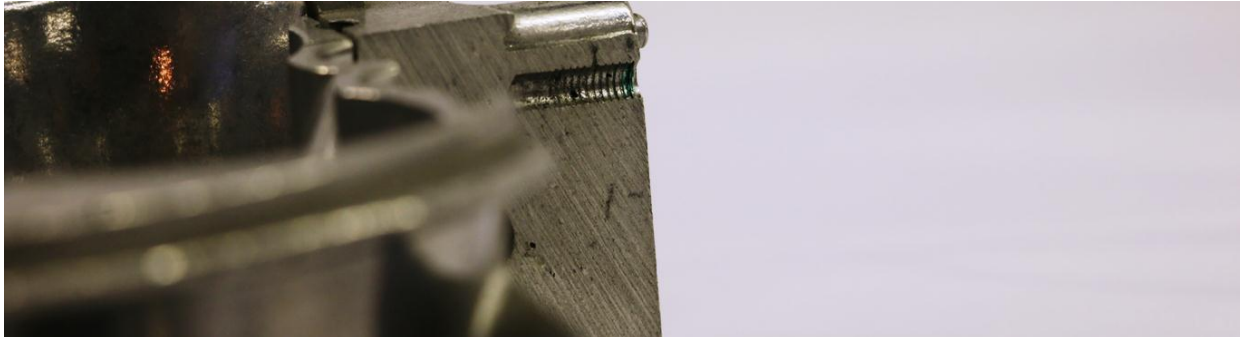


Fig.9: Shrinkage Porosity



Fig.10: Shrinkage Porosity closed view

4. POROSITY ANALYSIS THROUGH NON-DESTRUCTIVE TECHNIQUES

As of now it is clear the type and problem associated with Porosity. It is also important as next step to evaluate or analyze the Porosity in a casting component. Determining the type and location of defects in the material is essential not only for quality control but also because it allows to establish the source of their presence.

Hidden defects inside the casting that occur during manufacturing need to be diagnosed correctly, otherwise new defects may be introduced. Unfortunately, this is no easy task, because the defects are notoriously difficult to detect.

In the last decades, industrial interest in the development of advanced non-destructive testing (NDT) techniques for qualification of materials and products has been increased noticeably. ⁴

Radiographic Testing (RT) is a non-destructive testing (NDT) method which uses either x-rays or gamma rays to examine the internal structure or volume of manufactured components identifying any flaws or defects. Dense material withstands the radiation penetration, giving these areas a darker appearance. Less dense materials, such as porosity, allow more penetration and are shown as a lighter appearance.

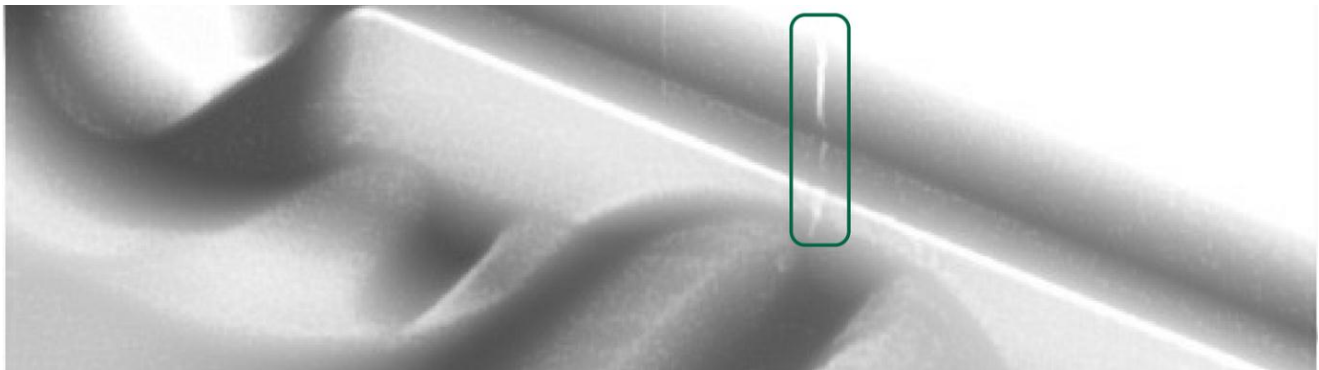


Figure 11: The porosity (highlighted in green) is shown in a lighter appearance, while the rest of the casting has a darker appearance.

This Radiographic X-Ray Inspection can be a simple 2D or a special 3D verification of the component.

The most common Radiographic techniques using X-Ray for Porosity Analysis in an Automotive Industry are: -

- 2D Radiographic Inspection (X-Ray) Inspection
- 3D Computed tomography (CT) Scan

In general, X-ray machines use the light or radio waves to produce the image by scanning the affected component and result in a **2D image**; CT scan is the advanced type of X-ray image producer which provides **3D image** and scanned the body with 360 degrees and produces multiple X-ray which can view on the computer screen.

Digital X-ray imaging can identify the existence of porosity but cannot provide volumetric data about the condition. Computed tomography (CT) not only can provide a quantitative analysis of porosity in the casting, it can also be used to provide dimensions on both external and internal features.

Thus, we can say in a summarized form that: -

- 2D Radiographic (X-Ray) Inspection: Mostly used for Qualitative Analysis centered verification
- 3D Computed tomography (CT) Scan: Mostly used for Quantitative Analysis centered verification

It is also important to understand that how to characterize the specific porosity type with the help of Radiographic inspection. The below chart mentioned in Figure 12 will make this clear.

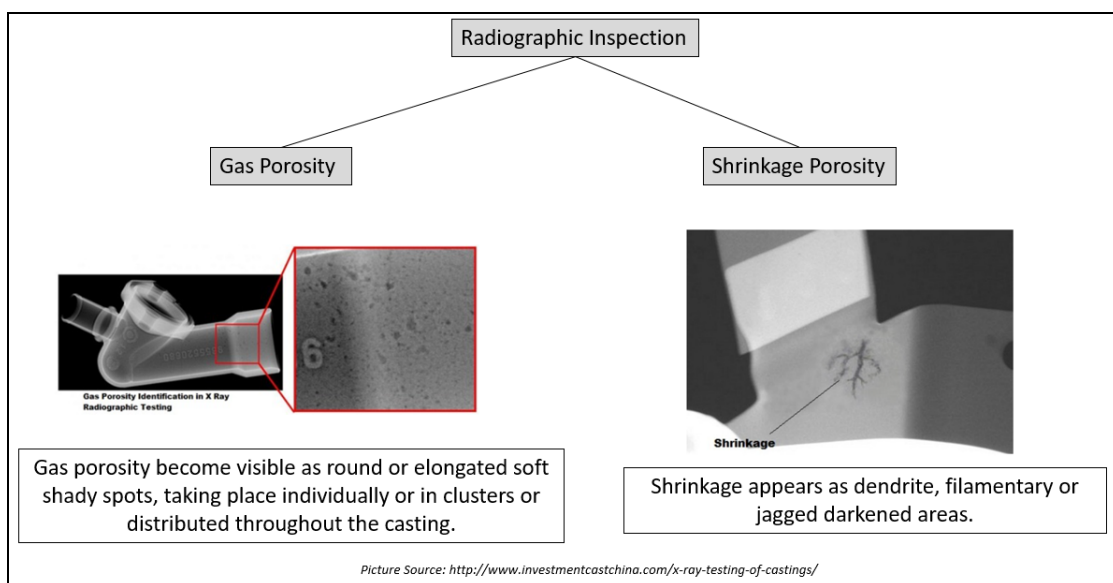


Figure 12: Characterization of Porosity Types through Radiographic Inspection

2D Radiographic (X-Ray) Inspection:

Radiographic Inspection is most common used 2D Radiographic Inspection method by suppliers which is economical, quick and can be installed in-house. Most of the Indian die cast manufacturer already have this inspection setup in-house.

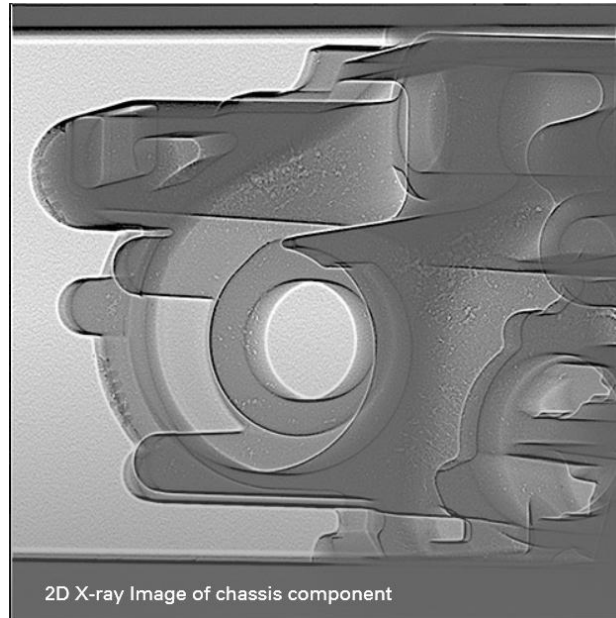


Figure 13: Characterization of Porosity through simple 2D Radiographic Inspection

3D Computed tomography (CT) Scan:

The commonly used 2-D x-ray testing method is not suitable to provide rapidly enough a enough quantity of information about the complete casting. Computed tomography (CT) is an imaging tool that combines x-rays with computer technology in non-destructive material testing and mostly used where we need a Quantitative Analysis of the Diecast Porosity. Suppose we have more detailed requirement to evaluate the Pore Diameter or Pore to Pore Distance, so this 3D CT Scan is really an efficient Global solution.

A CT scan, or computed tomography scan is an imaging procedure that uses computer-processed combinations of many X-ray measurements taken from different angles to produce cross-sectional (tomographic) images (virtual "slices") of specific areas of a scanned object, allowing the user to see inside the object without cutting.

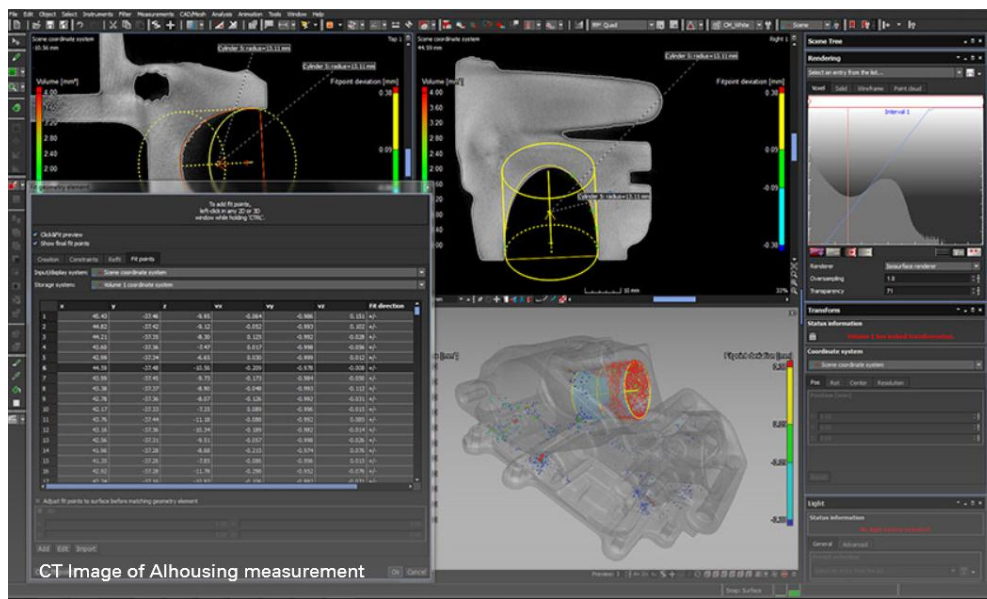


Figure 14: Analysis through CT Image of a diecast component

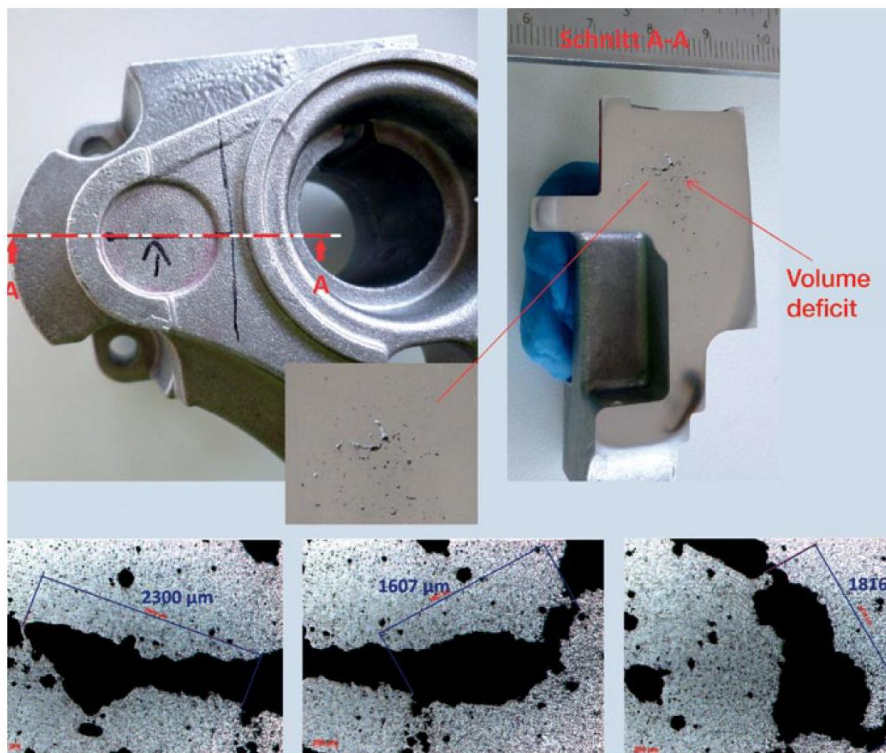


Figure 15: Shows the result of the metallographic examination of the part with the largest content of porosities detected by the tomographic scan.

In below figure you can see the Overview of test methods/measured variables for determining porosity.

Determination method / Quantity to be measured	Visual inspection (on machined functional surfaces)	2-D radiographic test (X-ray)	3-D radiographic test (CT X-ray)
Global porosity content [%]	-	-	X
Porosity content in the reference area [%]	0	0	X
Pore diameter/length [Ø]	0	0	X
Disregarded pores [U]	X	0	X
Number of permitted pores [Z]	X	0	X
Distance of adjacent pores [A]	0	-	0
Pore accumulation [H]	0	-	0
Localised porosity [N]	0	0	0
Density of the casting	-	-	-
Minimum pore size that can be evaluated	≥ 0,5 mm	5-6% of the X-rayed wall thickness	3-5% of the X-rayed wall thickness
Type of test	Random sample/100% test	Random sample/100% test	Random sample
Expenditure	Medium/high	Medium/high	High

Quantitative measured values	X
Qualitative measured values	0
No measured values	-

Figure 16: Overview of test methods/measured variables for determining porosity

5. POROSITY STANDARDS USED IN AUTOMOTIVE INDUSTRY

There is a big variety of standards and specifications in the industry related to the porosity defects and in the automotive industry generally refer to the following standards and specifications:

1. **ASTM E505** which is the American Standard Reference Radiographs for Inspection of Aluminum and Magnesium Die Casting;
2. **VDG Specification P 201**- the German Standard for Volume Deficits of Non-Ferrous Metal Castings.

NOTE: Companies as Ford, Renault group, Indian OEMs use the ASTM E505 for porosity specification.

Volkswagen Group for porosity specification use the VDG Specification P 201.

Standard Name: ASTM E505

Standard Reference: Standard Reference Radiographs for Inspection of Aluminum and Magnesium Die Castings

Standard Definition: This standard basically defines reference Radiographic images based on the severity levels of porosity. These reference images are then compared to component radiographic image to define the Porosity level based on image comparison.

This standard will be referred for internal porosity which is inspected by 2D Radiographic Test (X-ray). There are four levels of porosity as per ASTM. [Level 1 (Best) to Level 4 (Worst)]

NOTE: As compared to VDG Standard, verification done as per ASTM standard is a 2D Radiographic inspection and provides qualitative analysis. Also, less cost and could be done mostly with in-house facilities.

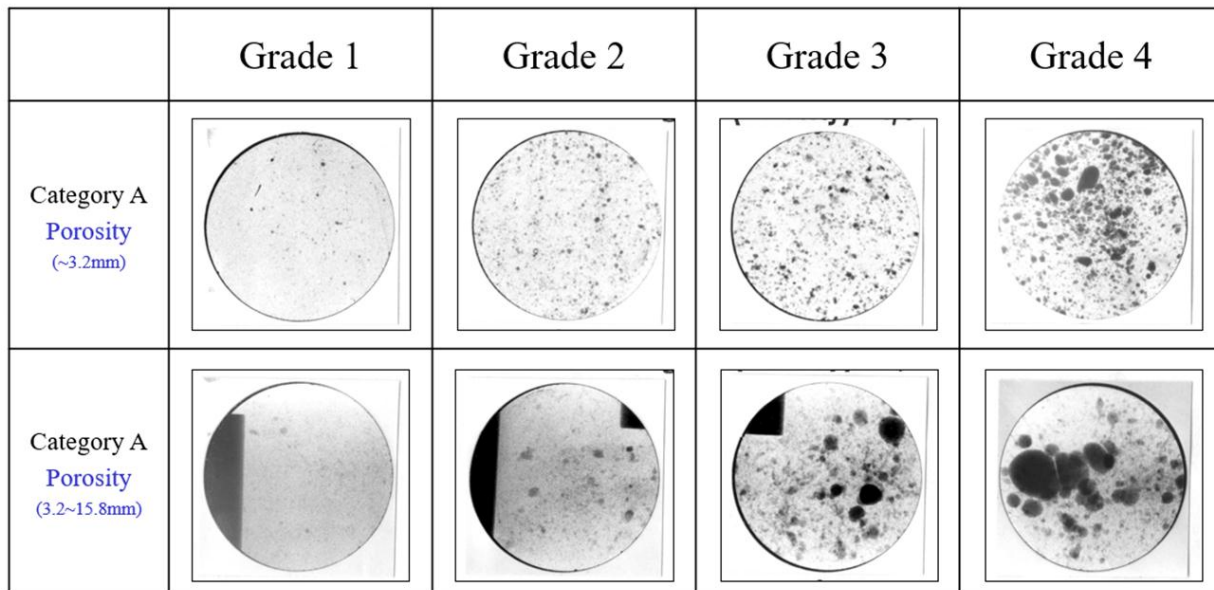


Figure 17: ASTM E 505: Reference Radiographs for Inspection of Aluminum Die Castings

Definition as Requirements: To define the porosity requirement based on the ASTM standard we need to first identify the Functional interfaces of the component which is critical to Function like electronic interfaces, ingress gap, cooling surface for Picture Circuit Board, Screw interfaces etc. Based on this we can put the requirement for the component and mention in the Drawing.

The castings / casting area can be divided into the following function classes:

- Function class 1: Castings with safety requirements
- Function class 2: Castings, statically and dynamically loaded castings and/or surfaces with special functional requirements
- Function class 3: Castings not included in classes 1 or 2 without specific functional requirements

For internal Faults, transmission/fluoroscopy test (X-ray test, see EN 12681) The quality classes are specified based on X-ray sample exposures in the following standards:

- ASTM E 155 for castings made of aluminum alloys, as well as magnesium alloys produced with the gravity casting process
- ASTM E 505 for die castings made of aluminum allows as well as magnesium alloys produced with the die casting process (*this is the case we considered in this paper*)

Below you can see some general acceptable limits: -

Acceptance limits for tests of internal faults according to ASTM E 505						
Function class 1		Function class 2			Function class 3	
Critical areas	Other areas	Critical areas	Other areas	Critical areas	Other areas	
		Tightness*	Load			
Grade A or better	Grade B or better	Grade A or better	Grade B or better	Grade C or better	Grade C or better	Grade D or better

Figure 18: Acceptance Limit example

NOTE: * If tightness and load areas are not differentiated on the cast part drawing, the requirements of the load area apply to all critical areas.

Below you see acceptance pattern reference for Category and Grade: -

You can see Porosity will come in Reference Category A and corresponding to that we have 4 Grades to verify the acceptable limit.

Acceptance limits for aluminium die castings produced with the die casting process (acceptance reference patterns to ASTM E 505)								
Type of fault	Quality grade A		Quality grade A		Quality grade C		Quality grade D	
	Wall thickness in mm							
	≤ 3	> 3	≤ 3	> 3	≤ 3	> 3	≤ 3	> 3
Discontinuity code A Porosity	1	1	2	2	3	3	4	4
Discontinuity code B Cold fill	1		2		3		4	
Discontinuity code C Shrinkage	1	1	2	2	3	3	4	4
Discontinuity code D Foreign materials	1	1	1	1	1	1	1	1

Figure 19: Category and Grade Requirement

Evaluation example: -

In below reference example you can see Representative radiosity pictures of a component.

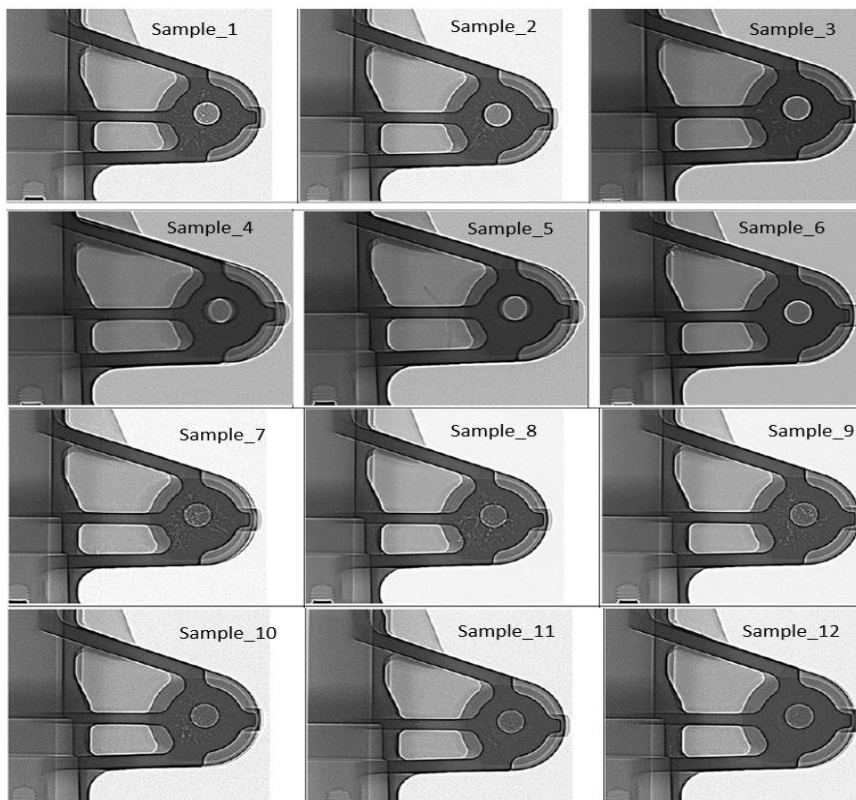


Figure 20: Representative radiosity pictures captures

Acceptance criteria for above samples is:

Shrinkage level Target ASTM E505 Level 1 on the area of interest which is the functional area around hole.

Here we will consider Category C Shrinkage and Grade 1 to Grade 4.

Based on the evaluation result is shown as below: -

Shrinkage level Target ASTM E505 Level 1	
NOK	Sample_1
NOK	Sample_2
NOK	Sample_3
OK	Sample_4
OK	Sample_5
OK	Sample_6
NOK	Sample_7
NOK	Sample_8
NOK	Sample_9
NOK	Sample_10
NOK	Sample_11
NOK	Sample_12

Figure 21: Results as depicted from representative radioscropy pictures

Standard Name: VDG Specification P 201

Standard Reference: This Standard defines the requirements for the porosity of castings regardless of the casting process used.

Standard Definition: This Standard supersedes Volkswagen Standard VW 50097 "Porosity of metal castings (VDG P201)" (VDG = Association of German Foundry Experts – German abbreviation)

Parameters of Considerations: -

The designation system of the porosities is composed of the following parameters as per the VDG specification VDG P202:

[Rz] – Roughness of the reference surface:

[Rz] is specified in μm . If the roughness information is missing, [Rz] = 0 applies automatically.

This corresponds to a metallographically polished microsection.

[%] – Pore content:

The pore content is defined as the maximum permissible pore volume in percent for the agreed reference surfaces.

[\varnothing] – Pore diameter/pore length:

The maximum permissible pore diameter is specified in mm.

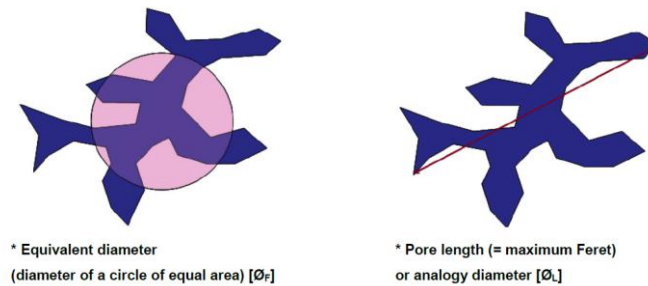


Figure 22: Representation of Pore Diameter / Pore Length

[A] – Distance between adjacent pores:

The minimum distance to be adhered to between two adjacent pores is described with this parameter.

The distance specification [A] is an integer factor with which the diameter of the smaller of two adjacent pores is multiplied and the minimum distance is calculated.

[U] – Disregarded pores:

The value [U] indicates up to which diameter pores are disregarded in the reference surface evaluation.

[Z] – Number of pores:

This parameter indicates the maximum permissible number of individual pores per reference surface as an integer value. Pore accumulations are treated as individual pores here.

[H], [HR], or [HK] – Pore accumulations:

A pore accumulation is present where the distance between two adjacent pores is less than the diameter of the smaller pore.

The value for [H], [HR] and [HK] can have the following binary values:

- 0 = pore accumulations impermissible
- 1 = pore accumulations permissible

[N], [NR], or [NK] – Localized porosities:

A localized porosity is present whenever the diameter of a pore accumulation exceeds the maximum permissible diameter for individual pores.

[N], [NR], or [NK] can have the following binary values:

- 0 = localized porosity impermissible
- 1 = localized porosity permissible⁵

Requirement Representation: -

This is porosity requirement standard which need to be followed on the highlighted Regions in drawing.

A permissible porosity is specified in the form of a key. This key is composed of several parameters. The type and quantity of parameters can be freely agreed upon, and the parameters can be indicated in any sequence. The designation of the reference sheet is indicated in the first position in the porosity key, followed by a hyphen. The individual parameters follow. A numerical value is placed after each individual parameter. The parameters and the associated values are placed in square brackets. The various parameters are separated from each other by slashes.

Example of a porosity key:

VDG-P202- [Parameter 1][Value]/ [Parameter 2] [Value]/ [Parameter 3] [Value]/ ... /[Parameter n] [Value]

E.g.

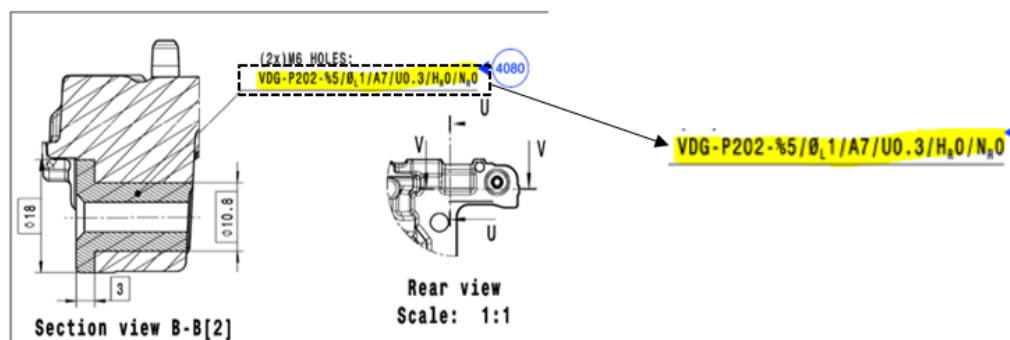


Figure 23: Representation of Porosity Key in drawings

From the Porosity key in Figure 23 we can now easily make out that: -

VDG-P202: Standard name

%5: A porosity of 5% is permitted for the agreed reference areas. (Maximum pore content)

ϕL1$: A pore length of 1 mm must not be exceeded.$

A7: The distance between two adjacent pores must be at least the diameter of the smallest of the two pores multiplied by the factor 7.

U0.3: Pores up to and including a diameter of 0.3 mm are disregarded.

HR0: Pore accumulations are not allowed.

NR0: Localized aggregated porosity impermissible

Evaluation example: -

The Porosity as per VDG Standard is analyzed best with 3D CT Scan and Image Analysis. In the example we will see Porosity quantitative analysis done by CT scan on Cut section of mentioned area of a Die cast component.

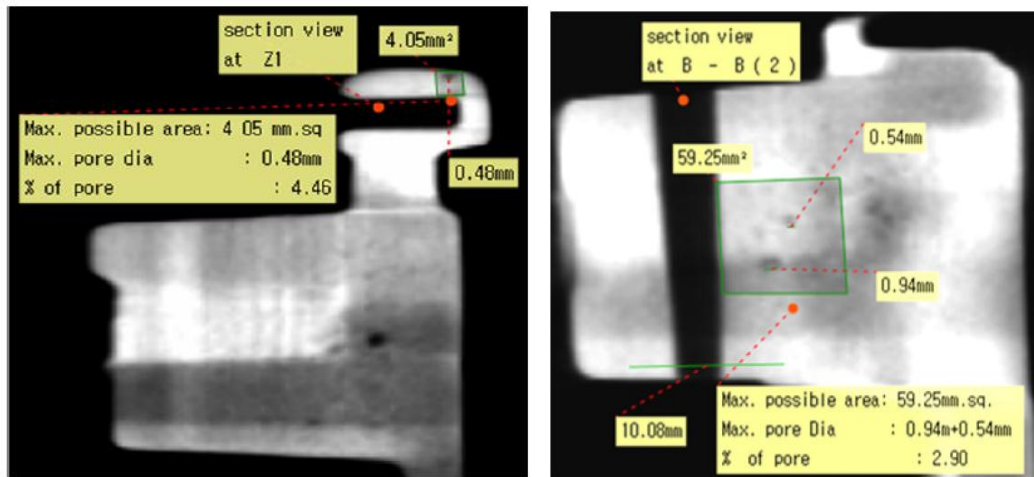


Figure 24: Component 1 and 2 – Section views at different areas

Acceptance criteria for above evaluation is:

Component 1 - Section View: VDG-P202-%5/ $\phi_L0.5/U0.2/H_{R0}/N_{R0}$

Component 2 – Section View: VDG-P202-%5/ $\phi_L1/A7/U0.3/H_{R0}/N_{R0}$

Result Summary based on CT Scan Evaluation in Figure 24:

Component 1:

Max Pore Día: 0.48 mm

% of Pore: 4.46

Result: OK

Component 2:

Max Pore Día: 0.94 mm

% of Pore: 2.9

Result: OK

Examples of microstructures with different pore contents:

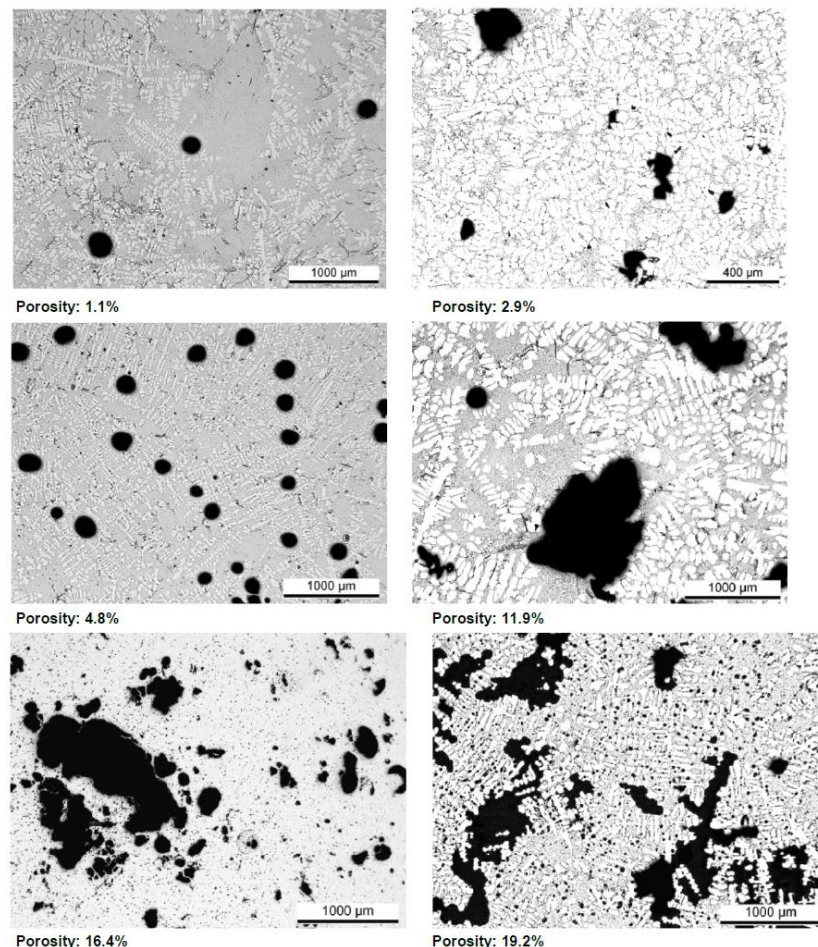


Figure 25

6. MINIMIZING POROSITY

We know that by injecting the molten metal into the die you create an economical, high-speed process; however, it creates porosity, which is generally the inevitable outcome of one or more of the following:

- Gasification of impurities at high temperatures
- Shrinkage that takes place as the metal solidifies
- Unexpected or uncontrolled changes in temperature
- Variations in wall thickness
- Die cast machine shot speed
- Part and/or tool design

There are various methods through which the porosity can be minimized: -

1. Design Stage

This is initial stage which plays a major role and could be crucial in terms of minimizing casting defects before going to the die cast part manufacturer. We can adhere to certain design guidelines for the part design at initial level itself. A

Designer should always align with die cast expert to have a type of checklist to review his design features in term of manufacturability. Important attributes to check include: -

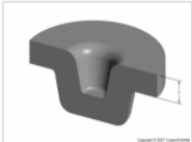

- Parting Lines for Die Cast Components and Products
- Flash Formation and Location
- Proper Draft for Die Casting Parts
- Radii & Fillet
- Wall Thicknesses
- Ribs, External Corners & Metal Savers
- Die Casting Lettering, Symbols & Ornamentations
- Incorporating Bosses Into Die Cast Design
- Cast Surface Finish on Die Cast Parts
- CAD Feature Order
- Focus on These Principles for Successful Die Casting Design

Example of some basic design rules are below: -

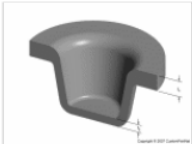
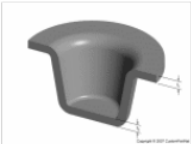
Design Rules

Maximum wall thickness

- Decrease the [maximum wall thickness](#) of a part to shorten the [cycle time](#) (injection time and cooling time specifically) and reduce the part volume

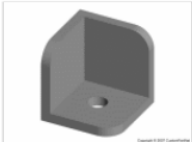
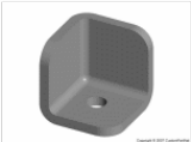
INCORRECT	CORRECT
	
Part with thick walls	Part redesigned with thin walls

- Uniform wall thickness will ensure uniform cooling and reduce defects

INCORRECT	CORRECT
	
Non-uniform wall thickness ($t_1 \neq t_2$)	Uniform wall thickness ($t_1 = t_2$)

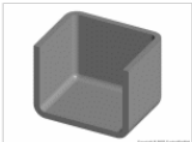
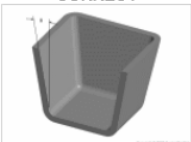
Corners

- Round corners to reduce stress concentrations and fracture
- Inner radius should be at least the thickness of the walls

INCORRECT	CORRECT
	
Sharp corner	Rounded corner

Draft

- Apply a [draft](#) angle to all walls parallel to the parting direction to facilitate removing the part from the die.
 - Aluminum: 1° for walls, 2° for inside cores
 - Magnesium: 0.75° for walls, 1.5° for inside cores
 - Zinc: 0.5° for walls, 1° for inside cores

INCORRECT	CORRECT
	
No draft angle	Draft angle (θ)

Below you can see an example of Checklist prepared to adhere your design in terms of manufacturability

Sl.No	Die-Casting Part Design Checkpoints	Status/Colour "Yes" - Green "No" - Red	Comments if any
1	Wallthickness		
1.1	General casting wall thickness has been considered as per guideline value ?		
1.2	Least/minimum casting wall thickness has been considered as per guideline value ?		
1.3	At all cross sections, uniform wall thickness is maintained by avoiding thick sections ?		
1.4	Thick sections are nearer to ingate or ingate provision has been considered near to thick section ?		
1.5	Whether homogenous wall thickness is maintained ?		
1.6	Sufficient Gap between two walls has been ensured to avoid weak profile in tool inserts?		
1.7	For Aluminium diecast, general wall thickness is < 5mm maintained?		
1.8	For Aluminium diecast, section thickness is < 12mm maintained?		
2	Draft		
2.1	All surfaces provided with draft respect to parting plane?		
2.2	Recommended minimum draft values are provided on all surfaces as per guideline values?		
2.3	Whether function of part doesn't affects even if unspecified draft value is applied by supplier on its own?		
2.4	Whether increased draft is provided in critical areas that affect ejection (demolding)?		
2.5	For Aluminum diecast part, general draft are as per guideline values ?		
2.6	Draft in rivet domes are provided as per guidelines?		
3	Radius/Fillets		
3.1	Whether part design is without sharp corners (except in parting lines)?		
3.2	Whether minimum fillet dimension is equal to wall thickness?		
3.3	Whether minimum radius is provided in all edges		
3.4	Whether fillets/radius are provided as per guideline value mentioned for various sections (L, T, X, Y)		

Figure 26: Die cast checklist example

2. Design for Manufacturing Stage

After above alignment in terms of part CAD design we now take up the design with the manufacturer. This step to minimizing porosity is finding an engineering team that can provide design for manufacturing (DFM) insight on the front end of the project. Suppliers can use software like MAGMA to simulate the casting process to optimize the die beforehand. To reduce porosity, sometimes engineers strategically place runner gates, water lines, vents, overflows, and cooling channels to protect areas of concern in the component. In some cases, there is a process called as **vacuum Impregnation** which assists to the injection process to further improve the casting. When the molten alloy is injected into the die at high speeds, the air in the die cavity creates pressure and resistance, which in turn creates porosity. Adding vacuum vents to pull the air as the metal is being injected allows the air to escape the cavity faster, therefore reducing the amount of porosity in the part and potentially eliminating the need for secondary impregnation. Vacuum casting also has the benefit of removing a portion of the residue materials (i.e. die lubrication droplets) prior to the metal entering the cavity. This will minimize the chance of gas porosity forming during solidification.



Figure 27: Without vacuum casting (left) With vacuum casting (right)

Here also we can implement a Checklist to have a better alignment in terms of Die Design. An example you can see below: -

13 Checklist for Die Casting Die Specifications (To be used in consultation with your Die Caster)		NADCA T-2-1-15 Checklist	
Part 1 – New Die Casting Dies: Items to be Addressed			
In the case of new die casting dies, all of the items in Part 1, below, should be reviewed. Note, in the case of tooling to be transferred to, or "inherited" by a die caster, the items asterisked (*) in Part 1 should be addressed, plus the items noted in Part 2 on the next page.			
Type of New Die	<input type="checkbox"/> Prototype Die Casting Die <input type="checkbox"/> Production Die Casting Die	<small>This two-part specification checklist is intended for use in consultation with your die caster prior to estimation of new die design and construction, or prior to die casting production using "inherited" tooling. It should be used in combination with checklists C-8-1 and C-8-2 in Commercial Practices, Section 8.</small>	
Cavity Steel*	<input type="checkbox"/> H13 <input type="checkbox"/> Premium Grade H13 <input type="checkbox"/> Superior Grade H13 <input type="checkbox"/> Other Tool Steel: _____ NADCA No. 229 Certification Required: <input type="checkbox"/> Yes <input type="checkbox"/> No Grade _____ Class _____		
Cavity Steel Heat Treat*	<input type="checkbox"/> Hardness Required: _____ <input type="checkbox"/> Toughness Required: _____ ft.-lbs NADCA No. 229 Certification Required: <input type="checkbox"/> Yes <input type="checkbox"/> No		
Cored Holes*	<input type="checkbox"/> All Holes Cored <input type="checkbox"/> Cored Holes As Noted On Print <input type="checkbox"/> No Cored Holes		
Die Operation for Part Features*	<input type="checkbox"/> Mechanical Movement <input type="checkbox"/> Hydraulic Movement <input type="checkbox"/> Features To Be Achieved By Secondary Operations		
Estimated Part Volume	Monthly: _____ Annual: _____ Expected Product Life: _____		
Castling Alloy*	Alloy _____ <input type="checkbox"/> Aluminum _____ <input type="checkbox"/> Copper _____ <input type="checkbox"/> Magnesium _____ <input type="checkbox"/> Zinc _____ <input type="checkbox"/> ZA _____		
Castling Weight	Estimated Casting Weight: _____		
As-cast Part Finish*	<input type="checkbox"/> Mechanical Grade (Functional Finish) (Ref. 125 Ra) <input type="checkbox"/> Painting Grade (Ref 63 Ra) <input type="checkbox"/> Highest Quality (Cosmetic Finish) For Plating, Etc. (Ref. 32 Ra) <small>*Die wear can offset surface finish over the life of the die.</small>		
Class of Die	<input type="checkbox"/> Unit Die <input type="checkbox"/> Single Cavity <input type="checkbox"/> Conventional Die <input type="checkbox"/> Multiple Cavity <input type="checkbox"/> Multiple Cavity - Family Die		
Cast-In Date Insert*	<input type="checkbox"/> In Die Cavity <input type="checkbox"/> Other Requirements: _____ <input type="checkbox"/> Not Required		
Cast-In Part Number*	<input type="checkbox"/> In Die Cavity <input type="checkbox"/> Other Requirements: _____ <input type="checkbox"/> Not Required		
Other	Write in any other special requirements (ie. tolerances, leak testing, x-rays): _____		
Part 2 – New Die Casting Dies: Items to be Addressed (Continued)			
Cast-In Logo, Lettering*	<input type="checkbox"/> In Die Cavity <input type="checkbox"/> Other _____ Include: <input type="checkbox"/> Customer Logo <input type="checkbox"/> Supplier Logo <input type="checkbox"/> Recycling Logo	<input type="checkbox"/> Cavity No. <input type="checkbox"/> Revision No. <input type="checkbox"/> Part Number	
Die Layout	<input type="checkbox"/> Customer to Approve Layout <input type="checkbox"/> Approval by Die Caster		
First-Piece Approval	<input type="checkbox"/> Customer Approval Before Production Run Required <input type="checkbox"/> Run on Die Caster Approval <input type="checkbox"/> PPAP		
Gages*	<input type="checkbox"/> Customer to Supply Special Gages <input type="checkbox"/> Die Caster to Supply Special Gages		
Trim Die	<input type="checkbox"/> Mechanical Movement <input type="checkbox"/> Hydraulic Movement <input type="checkbox"/> Features To Be Achieved By Secondary Operations		
Machining Fixtures	<input type="checkbox"/> No Secondary machining required <input type="checkbox"/> Machining required, no special fixtures <input type="checkbox"/> Special machining fixtures required, customer to supply <input type="checkbox"/> Special machining fixtures required, die caster to supply		
Special Items	Special Items to be included in the tooling package: _____		
Part 3 – Inherited Die Casting Dies: Additional Items to be Addressed			
In the case of inherited tooling, not the asterisked items (*) in Part 1, plus the items below. Note that with transferred, or "inherited," tooling for die casting production the existing die casting die, the trim die, and, if required, the secondary machining fixtures, must be available for review and evaluation to determine whether the dies and fixtures are capable of producing to specifications and the extent of maintenance and/or rework required before the onset of production. This would include any adaptations of the die caster's equipment to accommodate production using the inherited dies. Final production estimates will be based on this review.			
Inherited Die	<input type="checkbox"/> Die Casting Die Available for Evaluation <input type="checkbox"/> Die to be Available for Evaluation (date): _____		
Inherited Trim Die	<input type="checkbox"/> Trim Die Not Required <input type="checkbox"/> Trim Die Available for Evaluation <input type="checkbox"/> Trim Die to be Available for Evaluation (date): _____		
Inherited Machining Fixtures	<input type="checkbox"/> Special Machining Fixtures Not Required <input type="checkbox"/> Machining Fixtures Available for Evaluation <input type="checkbox"/> Machining Fixtures to be Available for Evaluation (date): _____		
Actual Casting Weight	Weight of Actual Casting: _____		
Size of Die	Size of Casting Die (for equipment limitations): _____		
Weight of Die	Weight of Casting Die (for crane limitations): _____		
Availability of Die Design	<input type="checkbox"/> Yes <input type="checkbox"/> No		

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2-1: Publisher grants permission to reproduce this checklist as part of a die casting Request for Quotation or Production Specification.

Figure 28: Example checklist Part 1,2&3

3. Porosity concerns in Secondary Operations

If the part requires machining or other secondary operations after casting, porosity can be a major concern where we can experience issues with porosity when their part was cosmetically plated during the trial run. Sometimes suppliers quickly adjusted the gating method, overflow locations, and applied vacuum casting to solve the problem. When machining is to be performed on a die casting, a minimum amount of material should be removed to avoid penetrating the less dense portion below the "skin". The best post-casting (secondary) machining results are attained if the die casting is located from datum points that are in the same die half as the feature to be machined.

It is important to discuss any and all secondary machining requirements with the manufacturer prior to die design. If consultation occurs early in the design of the part itself, the engineers can often minimize the effect of tolerance accumulation and unnecessary machining. Most important, with a combination of minor part design revisions and special considerations in the design of the die, higher-density areas can be assured in regions of critical secondary machining.

7. CONCLUSION

From the above analysis and detailed representation, Porosity plays a vital role in the Products critical to Function and Safety. Also, we saw standards used in Automotive industry to evaluate the Porosity through different NDT methods. This is quite clear that if we follow a technical path from Design stage to manufacturing stage, we can at very high extent reduce the casting defects at pre-stages to avoid taking deviations and complexity at later stage.

References

[1] [2]: www.spotlightmetal.com

[3]: <https://www.godfreywing.com/blog>

[4]: Zhao, X., He, Z., Zhang, S., Liang, D.: A sparse representation based robust inspection system for hidden defects classification in casting components. *Neurocomputing* 153, 1–10 (2015)

[5]: VW 50093: Issue 2012-07

Fig [2]: www.investmentcastchina.com

Fig [5]: <https://www.hillandgriffith.com/die-casting-news/die-casting-porosity-2> and

<http://www.mapeng.net/Files/Remoteupfile/2015-1/24/01-gas-porosity-in-castings.jpg>

Fig [6] [7] [9]: <https://www.godfreywing.com/blog/how-to-fix-die-casting-porosity>

Fig [8] [10]: <https://www.hillandgriffith.com/die-casting-news/diecasting-gas-porosity-problem-solving>

Fig [11]: <https://www.godfreywing.com>

Fig [13] [14]: <https://www.yxlon.com/en/applications/foundries>

Fig [15]: http://www.papco.cz/ke_stazeni/soubor2_62.pdf

Fig [16]: P202 Version: September 2010 BDG-Layout August 2015

Fig [18] [19]: http://www.voith.com/corp-en/VN_3068_en.pdf

Fig [22] [25]: BDG, Hansaallee 203, 40549 Düsseldorf, for download: www.bdguss.de

Fig [27]: <https://www.dynacast.com/en/knowledge-center/multiple-design-solutions/die-cast-design/part-improvement/porosity>

Fig [28]: NADCA Product Specification Standards for Die Castings / 2015