HOW TO SOLVE CASTING DEFECTS IN THE ALUMINUM GRAVITY DIE CASTINGS IN THE SHOP FLOOR?

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Abstract

The main objective of this paper is to share the practical knowledge gained in solving the casting defects ,in an Aluminum Gravity die castings, in the two foundry shop floors. In this paper the problems faced and solved in a typical alum casting namely "Body casting " is explained This casting is meant for USA export . This is a very critical casting with respect to quality . It has an 'encast' steel insert, and a resin bonded shell core. Heat treatment T6 , Pressure tightness shot blasting & painting are asked for by the customer.

Generally speaking, with respect to casting defects, lot of theoretical knowledge is available in the books. But it is difficult to apply that knowledge in the foundry shop directly.

In this paper some theoretical aspects of the casting defects are explained. Then, how to find out solutions? by applying "Tree diagrams " which are derived from 7 QC & M7 tools.

Why? Why? analysis was used to find solutions for the defects. Magma simulation was used when tthe new die was designed.

PART - 1

Classification of casting defects & their basic mechanisms are explained. Without knowing the basic mechanism of a defect, it will be very difficult to find solutions through "Tree diagrams
Main focus is given for some defects

1. **Shrinkages ,**
2. **Air blow holes,**
3. **Hydrogen porosity &**
4. **Resin gas porosity.**

Because the four defects are very common in alum castings. Resin gas porosity is due to excess % of resin & insufficient venting & wrong gating. Air blow holes are due to turbulent filling of molten metal in the die. Hydrogen porosity is causedby precipitation of Hydrogen from the molten metal which is released just before the end of solidification. Shrinkages are due to lack of feed metal & also higher inclusion level in the molten metal. A combination of " shrinkage with gas blow hole" is also possible. This is called "Ginkage". But the shop floor foundry man should know how to differentiate & diagnose the defect correctly.

In the Part - 2,

A case study ,regarding an "actual problem solving" is explained. Lot of changes in the die & processes.

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Conclusions :

By using "**Tree diagrams " & Why? Why**? analysis , casting rejection had come down to 5% from 95%. (2) One must be very careful in diagnosing & defining the problem " **What?** with facts and figures,. Otherwise, it can go wrong.

Key words: Turbulence , pouring of metal, shrinkage, interdendritic porosity, feeding, resin sand , casting orientation in a GDC die , shell sand core .

PART - 1

Aluminum casting defects may be classified as below:-

1. visible defect and 2.Invisiable defects:

Again this may be further classified as below, for better clarity and a broader picture. From this, one can see how many kinds of defects are to be taken care of in the foundry while producing a casting.

TREE DIAGRAM FOR ALUM CASTING DEFECTS ANALYSIS IN GDC

3 **4**

WHAT? WHAT?

WHAT? VISIBLES DEFECTS → **1) FOUNDRY DEFECTS** →

1 GREYING EXTERNAL

2 SHRINKAGE

3 COLD SHUT

4 DRAG

5 CRACK

6 SAND DROP

7 MECHANICAL CRACKS

8 RESIN GAS BLOW UP

9 ROUGH FINISH ON CAST SURFACE

10 ROUND OFF

11 EJECTOR PIN PROTRODING IN

12 EJECTON PIN GONE BACK IN THE DIE

13 HOT TEAR

14 DATE MARKING INSERTS NOT PROVIDED.

15 MATL CHIP OFF

WHAT?	**2) FETTLING**	**1 EXCESS SAWING**
GDC CASTING	**DEFECTS**	**2 PARTING LINE FLASHES NOT REMOVED**
DEFECTS		**3 EJECTOR PIN FLASHES NOT REMOVED.**
	3)SHOT	**1 DULL COLOUR**
	BLASTING	**2 ROUGH FINISH**
	DEFECTS	**3 BLACK PATCHES AFTER MACHINING**
		4 SHOT BALLS CARRIED WITH CASTING
	→ IN VISIBLES	**1 PIN HOLES**
	DEFECTS	**2 BLOW HOLES**
		3 INTERNAL SHRINKAGE
		4 FLUTTER EFFECT
		5 INCLUSIONS
		6 TENSILE STRENGTH IS LESS
		7 HARDNESS IS LOW
		8 MICRO STRUCTURE IS COURSE
		9 PIPING
		10 HARD SPOTS
		11 INCREASING OF IRON %

Out of the many defects listed, above , more details will be given for:-

1) Shrinkage porosity, **2) Blow holes**

In a casting, shrinkages areas are " low pr regions" & gas bubbles are " high pr regions"

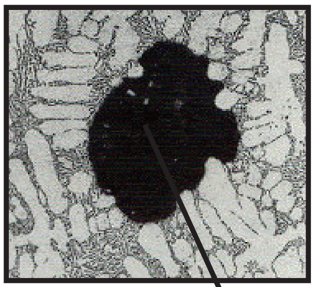
1. 1) TYPES OF SHRINKAGES POROSITIES

1) Macro shrinkages 2) Micro shrinkages 3) Intermediate type, 4) Ginkage.

1.2) Appearances of shrinkages:—

1) Macro shrinkages

2) Micro shrinkage



Interdendritic shrinkage

3) Ginkage

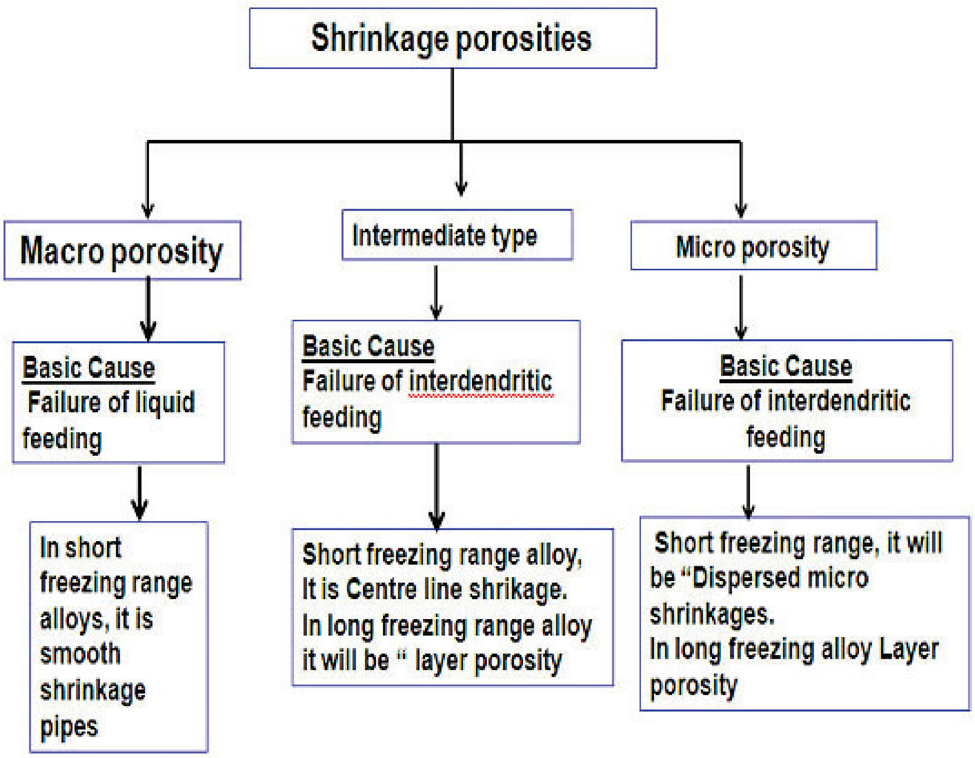
It is a combination of gas and Shrinkage.

1.3) Causes for the shrinkages

1) Macro shrinkages are straight forward i.e lack of supply of feed metal to the shrinking areas of the casting.

2) Micro shrinkages are due lack of interdendritic feeding.

3) "Ginkage" is a newly coined word to indicate the" combination of both gas & shrinkage".

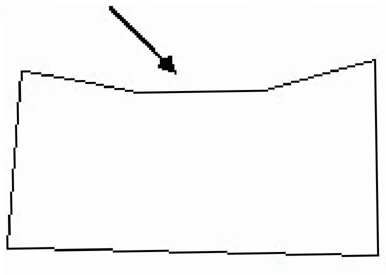


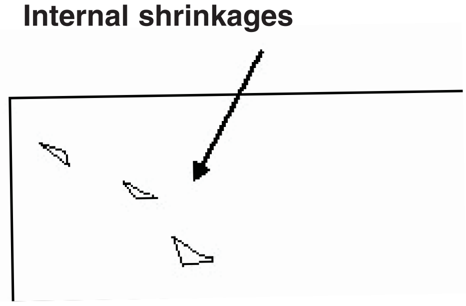
<u>General location where the shrinkage occurs:</u>

1 By a concave defect on the **<u>'as cast surface"</u>Internal shrinkages**

2 Inside of the heavy section which are suffering from lack of feeding

1.4) External by a dip on the as cast surface **Internal shrinkages**

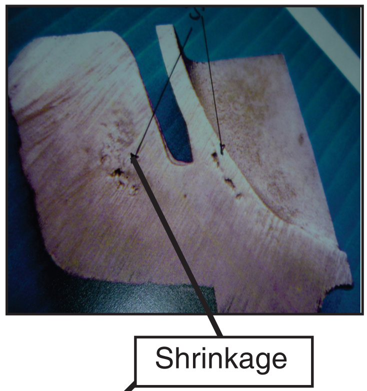




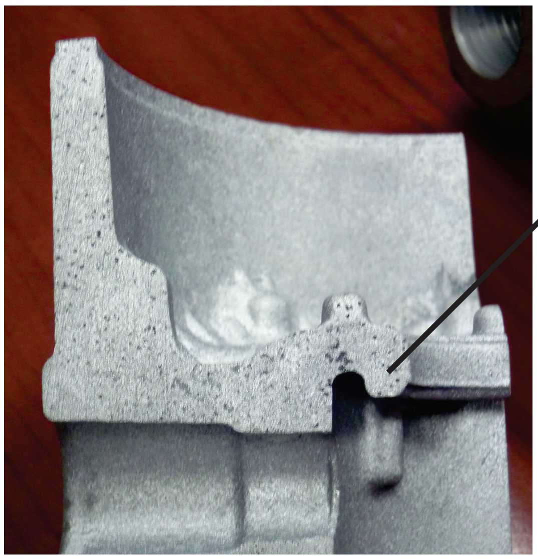
1.5) Where and at what stage shrinkages can be seen?

1) At the " visual inspection stage" as external shrinkages on the castings

2) On the machined surfaces & Cut sections



By etching the casting cut sections:-



3) While pressure testing, the castings may leak if there inter connected shrinkages.

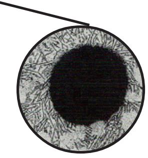
2) Blow holes:-

2.1 Types of Blow holes:-

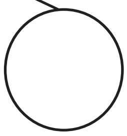
1) **Air blow holes,**
2) **Resin gas blow holes**
3) **Hydrogen gas blow holes**

2.2) Appearance of blow holes:-

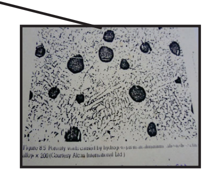
Air blow holes are spherical shaped, with dark grayish color & the shape will be dendritic



Resin gas blow holes are also near spherical shaped with the shiny surface and some time look like : Polished surface"



Hydrogen blow holes, very small in size, generally occur in the form of " clusters", round shaped with sharp edges



2.3) Distribution and typical general sizes are given below:-

Air blow holes are spherical shaped, with dark grayish color & the shape will be dendritic

Defect	Distribution	Size
1. Hydrogen gas precipitation	#. Uniform # Apart from 1 to 2 mm	0.05 to 0.5 mm
2. Air entrainment	#above gates, in general # very close to the surface, Only revealed after shot blasting	1 to 5 mm
3. Core gas	# At uniform distance under top of the casting	3 or 4 or even 1o mm plus

2.4) Causes for different blow holes:-

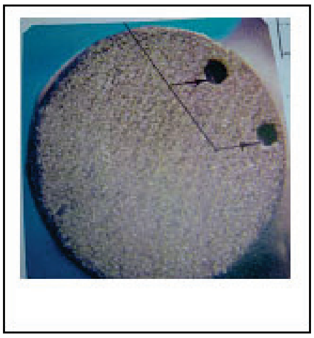
\# **Air blow holes** :- Due to turbulence while pouring or due air inclusion due " vortex formation while Pouring. and also due to lack of venting.

\# **Resin gas blow holes**:- Due to resin % exceeding 3.2% and lack of venting in the die etc.

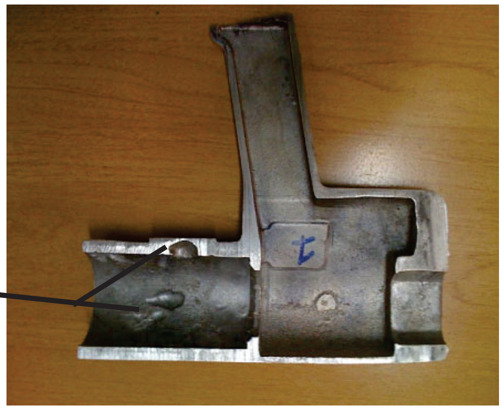
\# **Hydrogen blow holes** :- Due to Hydrogen gas content exceeding 0.12 cc / 100 grams in the molten aluminum alloy.

2.5) Location of blow holes:-

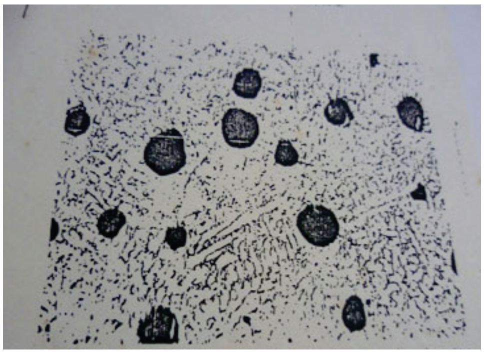
 # Air blow hole :- Mostly near the surface area, just below the skin of the casting & the ingate areas.



This is a typical air blow hole, seen after shot blasting



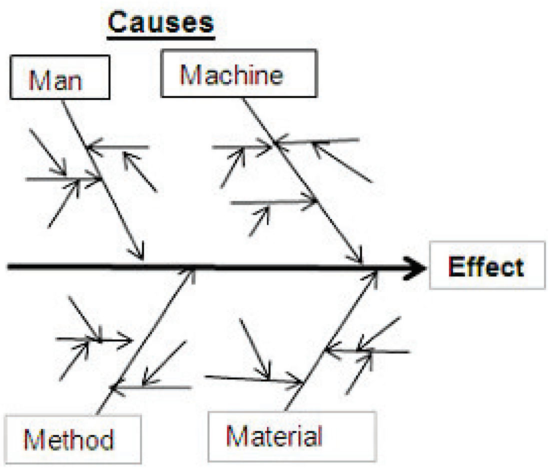
 # Resin Blow hole :-Seen at as cast & also on the machined surfaces inside the casting, mostly at the top sides of the casting



 # Hydrogen blow holes:- **Some times noticed, after machining the areas below the riser and also in the heavy sections inside of the casting**

<u>Solution development for casting defects</u>:-

Alum castings are produced by the combined activities of Molten aluminum, Die caster, Die, and the Process. They are called as process parameters. **Abnormal variations** of these parameters from the set Values, are the causes for the defects. These several causes results in a bad effect , which can be called as " casting defect" in this context. To understand the all the causes more clearly a " cause and Effect diagram was introduced by the Japanese Prof. Dr.Ishikawa, as one of his 7 QC tools.



For the easier the shop floor investigations the cause and effect diagram is **re written** as "Tree diagrams. In this paper " Tree diagrams" are given for 1.shrinkage 2.Blow holes 3. Hydrogen pin holes By using these diagrams ,the " non- causes " can be ticked out and the **most probable causes** can be indentified. Then, deeper investigations can be proceeded & solutions can be developed accordingly.

Tree diagram for Shrinkage investigation (General)

What? Shrinkage

Basic causes
1) Lack of feeding
2. very high temp of die & metal,
3) Gas & solid inclusions
4) Excess calcium content

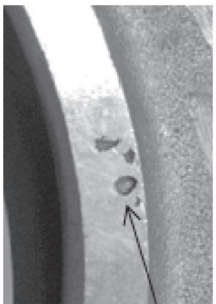
Process parameters

- **Alum Alloy**
  - 1) Why? 1) Too high / low a metal temp. → 2) Why? Pyro meter faulty → 3) Why? Thermocouple welding gave way → 4) How? Stop & correct → 5) How? Establish periodical checking.
  - 2) Silicon content in the alloy
    - Why? → Lesser than the spec. → How? Check & correct if needed.
    - → The alloy selection is such, Si is less for this configuration of the casting. → How? Explore the possiblity for high Si alloy
  - 3) Calcium content is high → Check the composition → How? Control it with in 0.00008 to 0.0015 % → How? Communicate alloy supplier the spec
  - 4) Inclusion content is high in the molten alum.
    - Why? 1. Poor condition of furnace lining → How? Correct the furnaces
    - 2. Poor burner instalation → Why? Flame is in direct contact with the charges → How? Take correc -tive action
    - 3. Poor quality of Charge material. → How? Avoid 100% scrap matl. use 60: 40 ,Ingot : scrap
    - 4. Improper degassing practices → Use rotary degassing with dry Nitrogen.
- **Die**
  - Why? 1) Insufficient riser volume → How? Watch for abnormal shrinking of riser. → How? Increase riser volume.
  - 2) No riser is possible due to casting configuration or die parting constrains. → How? Investigate cooling metoods
  - 3) Sharp edges & corners in the die → How? 1) Round of the sharp edges 2) Increase radious in the corners.
  - 4) Die temp is too low? → 1) Check for mechanical problems in the die 2) Check for excessive die mass.
- **Die coating**
  - Why? 1) In sufficient riser insulation. → How? Use high & correct quality of insulation..
  - 2) Heavey sections in the die cavity are not chilled. → Provide VCS for indicating the chilled areas.

Tree diagram for Blow hole investigation (General)

What? Blow holse

- **Basic causes** 1) Air entrap -ment → **Process parameters** Die →
  - **1) Why?** 1)Suction of air while pouring metal through pouring basin →
    - **2) Why?** 1) The basin is not kept full all the time → **3) Why?** Rate pouring is slower than Rate of filling → **4) How?** Adjust filling speed. → **5) How?** 1) Training of operator 2) Adjust auto ladle
    - 2) Faulty runner system design → Why? No taper in the down sprue → How? Redesign with 2 degree taper
  - 2)Turbulence While pouring through riser directly →
    - How? 1) As far as possible avoid direct pouring → How? If needed pour slowly on the riser walls.
    - 2) Use tilt pouring through riser → Keep the first phase of tilting as slow as possible.
  - 3) Blocking of air vents **or** No air vents in the pockets & deeper bosses →
    - How? 1)Clean air vent periodically → How? Establish schedules for ceaning /replacements
    - How? 2) if needed provide new/ additional air vents → How? If sand cores are, used provide many sintered air vents.
- 2)Resin gas entrap -ment → Resin sand →
  - Why? Resin % in the sand is more → How? Check & control the resin with in 3% or lesser. → How? 1)Avoid liquid resin as far as possible 2) Use Flake resin
  - Humid atmosphere → Why? Moisture pick up in the shell core → How? 1) Avoid very long time storage. 2) Use wooden blanks for storage 3) cover the core by polythene sheets during rainy seasons
  - Gas from the uncured portions of the core. → How? Check shell core box heater locations. → Relocate heaters to avoid uneven curing of cores.
  - Direct impinge ment of gate entry metal on the sand core → How? Avoid / shift the gate entry → How? Redesign gating
  - Gas from the shell core coatings /Paints → How? Burn the alchohol if any
  - Too finer the sand → **With out affecting the casting finish, use coarser sand**

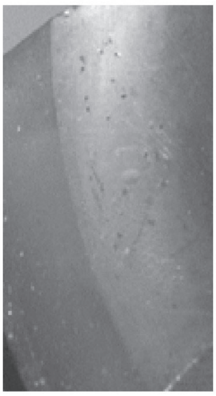


Blow holes

Tree diagram for Pin holes investigation (general)

What? Pin holes → **Basic causes:** Hydrogen gas pick-up in the molten Aluminum more than 0.12cc/ 100gram →

- **Process parameters**
  - 1.Molten Alum Alloy →
    - 1)Too high a metal temp in the holding furnace (1) Why?)
      - → 1)Pyrometer may be faulty (2) Why?) → Thermocouple welding gave way (3) Why?) → 1)Get it corrected (4) How?) → Establish periodical checking. (5) How?)
      - → 2) Initial setting it self may be more than 760 C (Say) → 2) Maintain metal temp below 710 C
    - 2)Too high a metal temp in bulk melting. furnaces → 1) Set at higher temp since it might fall while tranfering to holding furnaces (Why?)
      - → 1)The holding furnaces may be far away from melting zone. (Why?) → Explore the possiblity of relocation near by. (How?)
      - → 2) The tranfer ladle may be of 'open type' & not heated properly. → Go for a closed type ladle & heat it conti- -nuously when idling using gas burners. (How?)
    - 3) Emptying the crucible more than half before metal transfer & the crucible walls getting over heated. → Do not deplete the metal in the holding furnaces more 1/3 depth from top edge. (How?) → Study melt- ing capacity & transfer schemes. (How?)
    - 3.Poor burner instalation & settings. → Flame is in direct contact with the charges causing Hydrogen pick up. (Why?) → Take corrective actions on the burner settings. (How?)
    - 4. Poor quality of Charge material, (Dirty& oily) → Avoid 100% scrap matl & oil mixed/ wet scraps. Use 60: 40 ,Ingot : scrap (How?)
    - 5.Improper degassing practices
      - → 1.Use rotary degassing with dry Nitrogen with granular fluxes. (How?) → Check H- content by gas cone pouring & occasionally by H- Analzser (How?)
      - → 2. Stop using when N2 pr. drops too much in the cylinder.
    - 6. Using wet flexes → Keep the flexes in closed container
- 2)operator → 7. Charging scrap castings in the holding furnace. → Bring awarness & avoid such pratices.



Part 2 :- Case study

To illustrate the effectiveness of the above tree diagrams and the theoretical back ground, an actual case study will be illustrated in this paper.

Casting back ground:-

Name of the casting:- Body

Aluminum Alloy: LM 25 # Customer : USA

Volume off take / year : 24000 nos,

Fettled wt of casting : **1. 345 kgs**

Full shot wt of the casting: **2.675 kgs**

History of the casting:-

Die No.1:- This casting was first developed by a foundry & it failed to meet the requirements. The die was scrapped after trying it for a lot of time. The details are not available.

Die No.2:- One other foundry attempted & also failed. The second die was also scraped after lot of unsuccessful tryouts. In the same foundry a third die was developed .They used magma software & conducted several iterations were made before selecting the better one.

Degree of difficulty in a 10 point scale is about : 7

Quality requirements:-

Pressure tightness:-10 bar

Heat treatment:-T6

A steel insert is to be encast to form the valve seat.

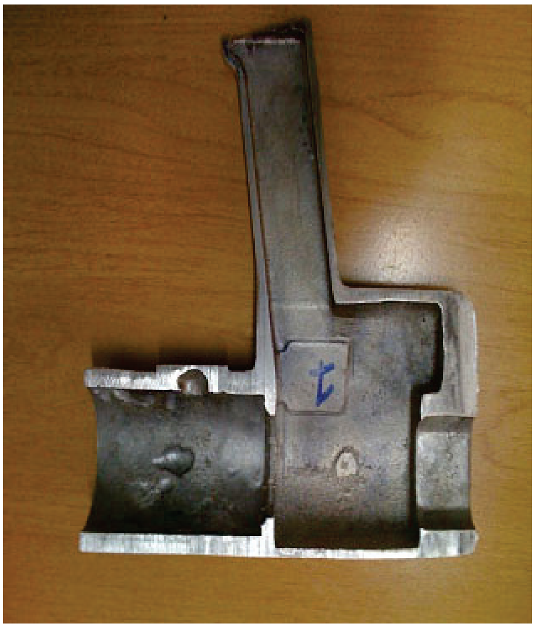
A shell sand core is required to form the so internal surfaces of the casting

Shot blasting is required before painting.

Aesthetically critical.

In the main bore 80dia,"not even tiny blow holes " are acceptable.

Very fine finish is called for smooth " O ring movement in the 80 dia bore.



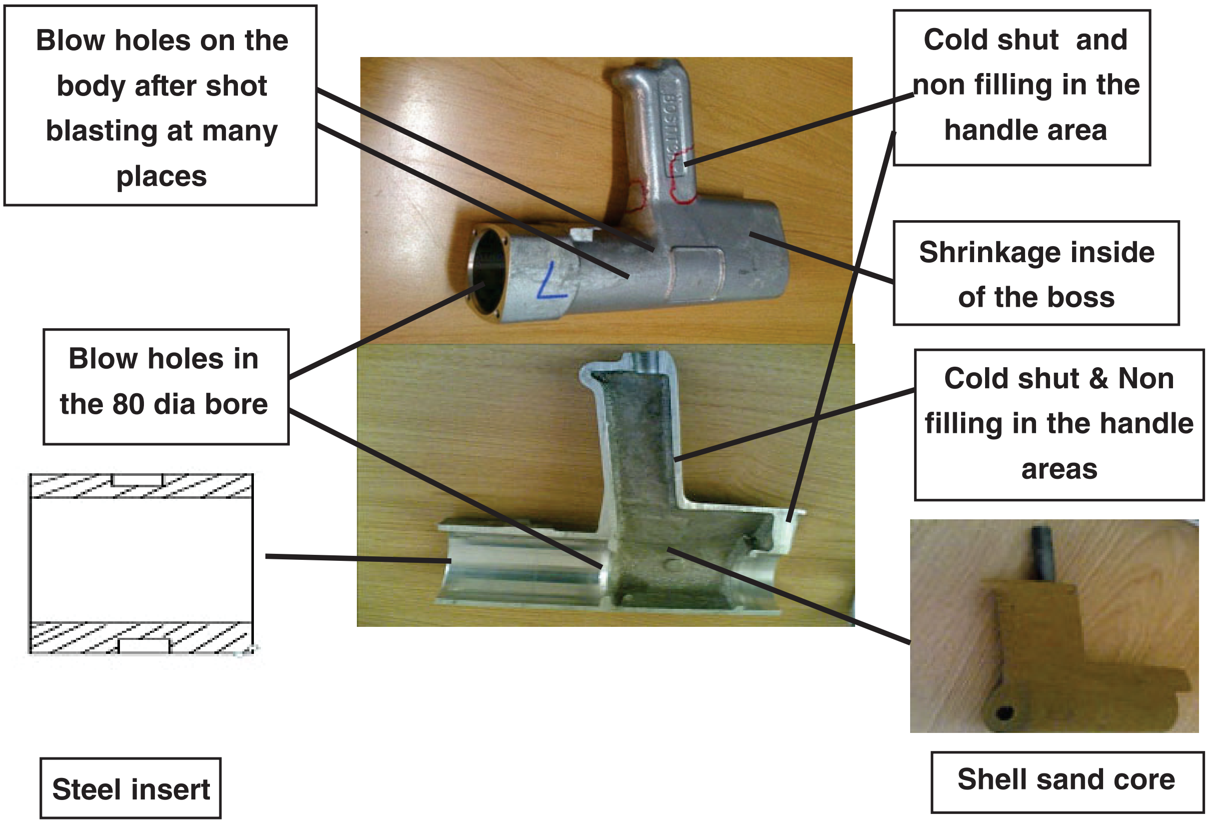
Finished casting

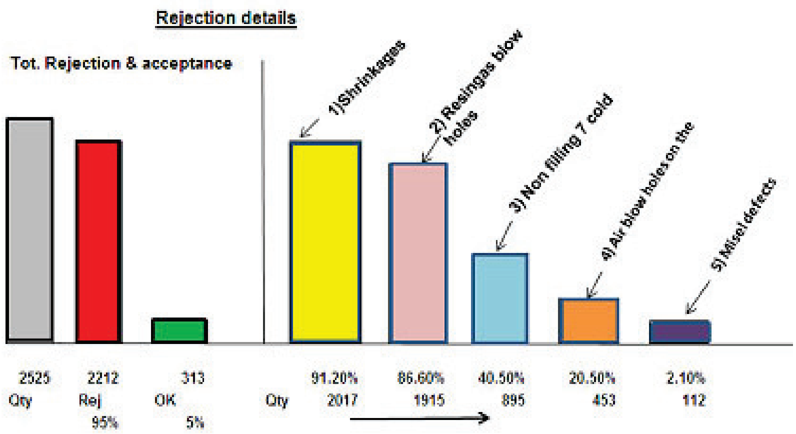
Process followed: Stationary GDC die casting process

Machined casting

Full shot of the casting

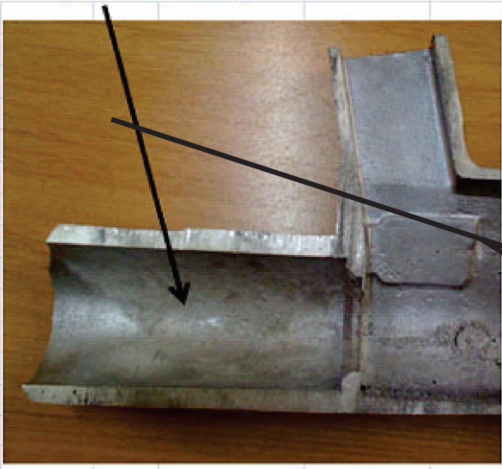
Rejection areas in the casting

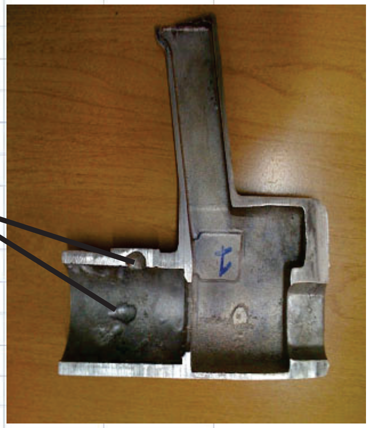




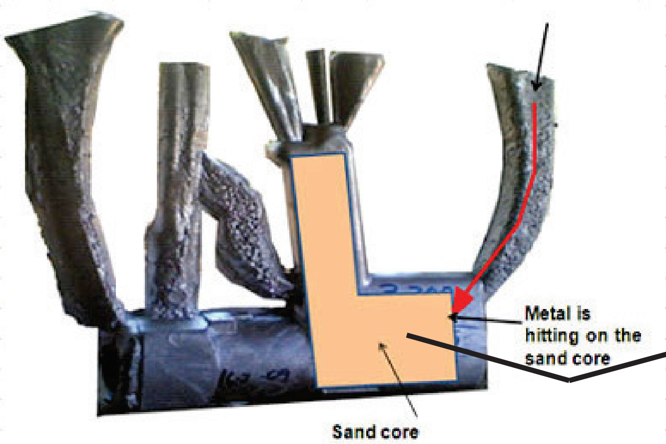
The rejections were very much alarming, 95%. Unable to meet the customer requirements. Management instructed to form QC and CFT teams & all must work intensively on the rejection. Based on the above rejection data "Brain storming" sessions were conducted with various groups such as die design, die maintenance, Sr operators of die casting etc. At first "**cause and effect diagrams** "were drawn for **each defect** . Then " Tree diagrams were drawn were after eliminating the " non causes". Many new ideas & suggestion & actions emerged. for correcting the existing problematic die. The action plans were finalized & implemented & the **results** are given below in a **very short form.**

1) Gas blow holes in the 80 dia bore:-

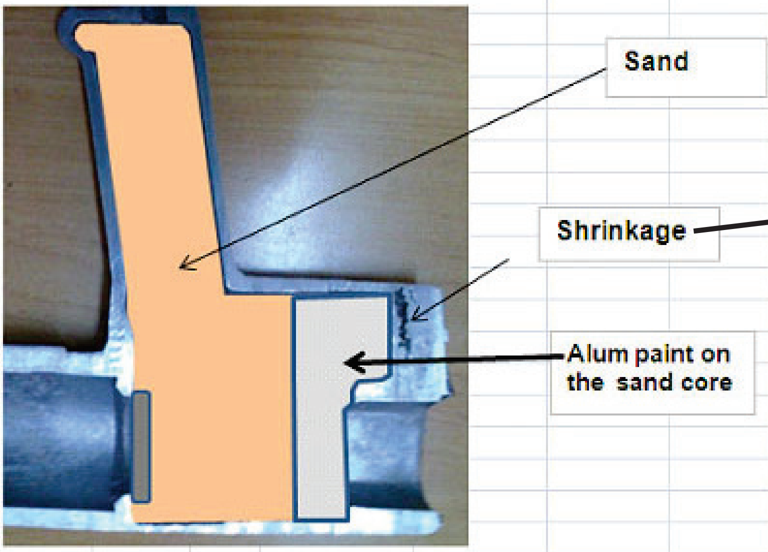




Why gas blow holes in the 80 dia bore? → 1. Metal is directly impinging on the shell core. → How? Try to avoid this. → How? Explore the the possiblity for shifting the gate → The die construction is such that it was impossible to shift the gate. → Result Resin gas BH continued to occur.

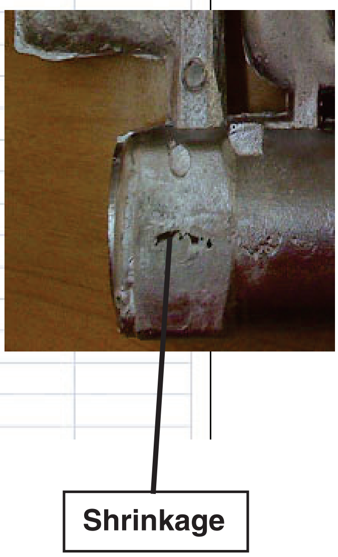


2) Shrinkage in the rectangular boss inside of the 80 dia bore:



Why shrinkage?	How?	Result
Lack of feeding →	1) Provide riser over this boss. 2) Apply aluminum paint on the sand core →	Shrinkage had notcome down , but gas blow holes had started to occur due to aluminum paint application And the presence of the sand core agravate the shrinkage

With in the available place in the die halves, it was tried to provide a modified gating system. But it did solve the problems



3) Non filling in the handle area.

Thin wall section of the handle area where non filling occurs frequently

Why non filling in the handle area?
1) while pouring the metal , it has to raise from the bottom of the cavity and therefore loses it's heat and velocity.

2) Section thickness is only 4

3) Casting orientation in the die cavity was wrong. Instead of orienting the handle portion down words, it was down 180 degrees upwards.

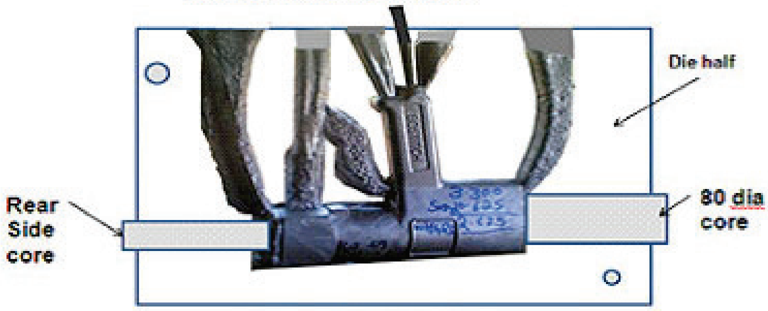
How?
1) Try to go for top gating.

Since the die was already made, and the shape was such that it was <u>impossible to</u> modify.

2) Try to increase the section section thickness

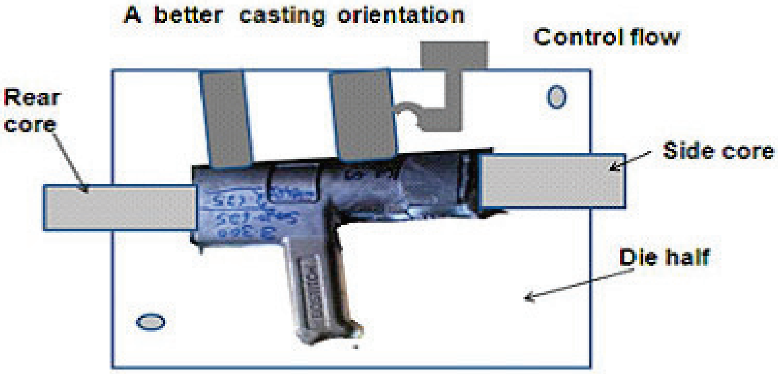
Custome r did not accept this due to casting wt increase. Hence not possible

In correct orientation of the casting in the existing die



The metal has to raise from the bottom of the die cavity

A better casting orientation



Up side down

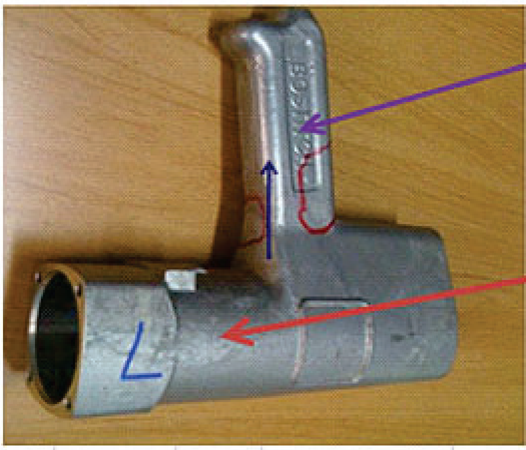
The basic mistake was in the casting orientation. It was wrong. This should have been 180 degrees upside down.

4) Air blow holes in the " as cast surface of the casting after shot blasting.

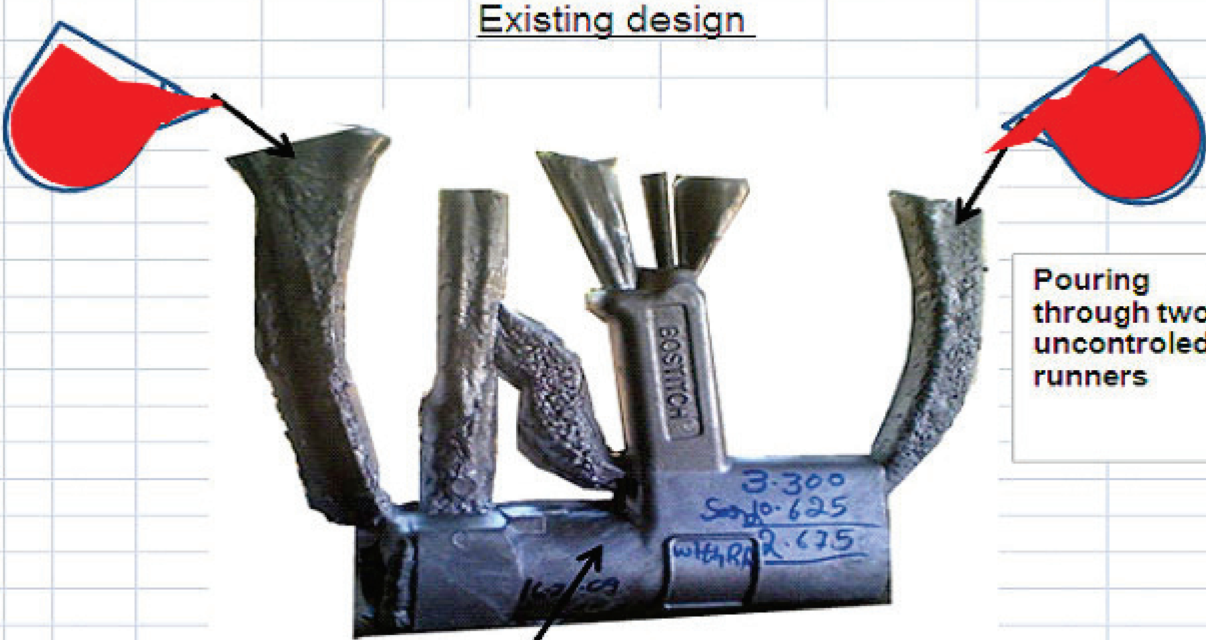
Why	Why?	How?
Air blow holes in the " as cast surface of the casting after shot blasting. Air blow holes in the " as cast surface of the casting after shot blasting.	Uncontroled pouring from the two runners on both the sides of the die cavity	Try to provide control flow running system

→ The die shape is such that it was <u>impossible</u> to modify the die.

Uncontrolled filling of the die through top runner creates lot of turbulence, which leads to air entrapment.



Existing design



Sever turbulence due to which " heavy flow lines"

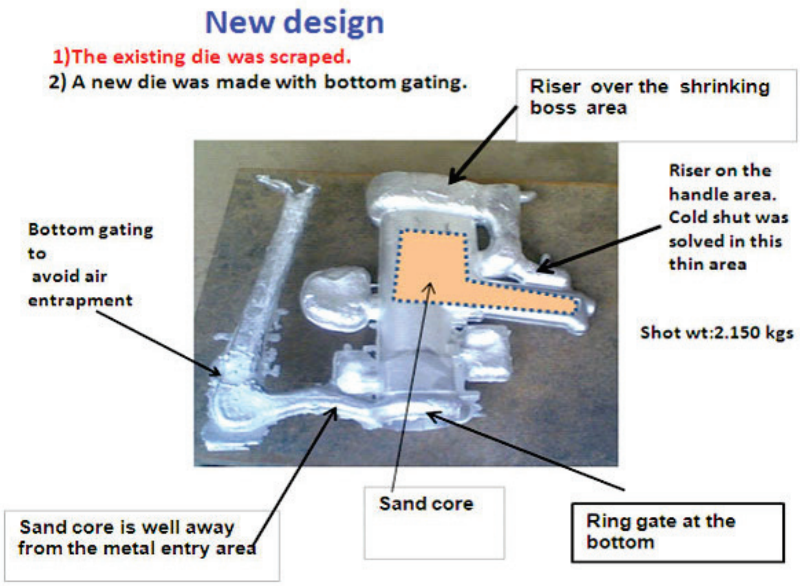
Decision to scrap the die

Considering all the above difficulties, casting problems, & very high rejections, management decided to make a new die with different orientation & gating system.

1) Reduce / avoid turblence and by bottom pouring.

2) Reduce resign gas evolution by avoiding the metal hitting the sand core.

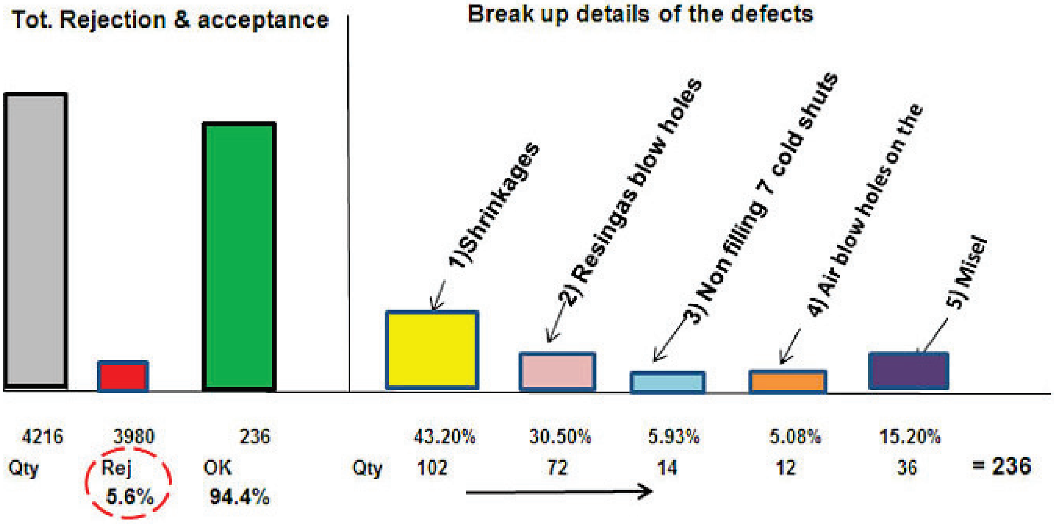
3) Provide sufficent riser above the recet boss to avoid shrinkage.



The die was run castings were produced and the defects had reduced very much.

From the rejection data of the castings produced, we can see the rejections had come down from <u>94.4 % to 5.6%.</u> Every body in the team was very happy. Customer requirements were met.

<u>Rejection details of casting producec from the new die</u>



Conclusions and the lessons learnt

1) **Never allow the molten metal to hit the sand core areas at the gate . It can cause shrinkages. And also it will increase the resin gas evolution & more gas blow holes .**

2) **Whenever shot blasting is specified for the casting, select only bottom or side gating.**

3) **Avoid as far as possible ,aluminum paint touch ups on the shell core. Because this will cause gas holes.**

4) **Do not exceed the resin content beyond 3.2% by wt (Phenol formaldehyde) .**

5) **Avoid " Two men pouring " from the two runners of a casting as far as possible. This can cause " non fusing of cold metal fronts inside of the die cavity.**

6) **The tree diagrams and why? why? and How? How? Analysis will help to pin point the problems and develop correct solutions.**