

CASTING DEFECTS HANDBOOK: ALUMINUM & ALUMINUM ALLOYS

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Technical Editor



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Foreword

Metalcasting is one of the most consistent metal forming manufacturing processes. Metalcasting is used as a primary manufacturing technique of critical components, that must perform safely under the most strenuous and demanding requirements. Metal castings are used for a wide variety of applications, which are used across a broad spectrum of industries.

Improved foundry procedures have led to better application of melting and pouring process controls. Computer modeling can predict locations of potential defects before manufacturing. Research leads to better metallurgical understanding and improved inspection methods lead to reduced variability and defect rates in metalcasting operations. Indeed, in many world class operations, the product return rate can reach parts per million. Yet, common defects may occur on the surface of a casting, which are easily remedied with surface finishing practices. Process defects may pertain to mold and core materials and pouring practices. Metallurgical defects that relate to melt quality (inclusions, gas, porosity, etc.) are a constant concern given the nature of alloy charge materials and liquid metal, which is susceptible to the occurrence of such defects. As with any manufacturing process, the occasional occurrence of defects in the casting process is not uncommon—although all successful producers will minimize defects to the greatest extent possible.

In general, foundries produce complex cast-to-shape designs very efficiently with few defects, based on percentage. Specific casting defects that are encountered repeatedly are resolved with diligent evaluation of causes and prevention, which then leads to development of prescribed standard casting process procedures to avoid and minimize such casting defects.

In *Casting Defects Handbook: Aluminum & Aluminum-Base Alloys*, many of the common types of casting defects encountered are categorized by production method: sand-casting, permanent mold, high pressure diecasting, low pressure, investment, plaster and lost foam. Possible causes and, in some cases, prevention techniques are presented under defect categories. In many instances, the remedies are intuitively the opposite of the cause of the defect, even if not stated.

The organization of the material is presented in an easy-to-review format suitable for foundry floor operators, as well as process engineers, metallurgists and quality control personnel. It is the intention of this publication to provide a comprehensive visual atlas of the more common casting defects, which are encountered, to enable the aluminum base foundry personnel to quickly identify the type of defect, address possible causes, and establish corrective actions.

Dave Neff
Technical Editor

Acknowledgments

There have been many contributors to this project. In the best interests and confidentiality of all concerned, individual defect image photos are not tagged with their source. Previously published sources are identified, however.

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Introduction

In the aluminum casting industry, foundry shapes are produced by several different processes: sand casting, permanent and semi-permanent mold, die casting, lost foam, plaster, investment, low pressure, squeeze casting, and other newer alternative processes. In previous casting defects publications a particular organizational style, nomenclature, and format have been used, in which the specific process employed, while noted, is not an integral part of the organizational structure. For this handbook, a different path has deliberately been chosen, organizing the defect information largely by specific casting process. This avoids unnecessary duplication of text where possible, and draws the reader/user more directly to the process employed by him/her. However, there will naturally be some overlap as certain defects—especially those 'metallurgical' in nature—will have some commonality in all casting processes.

An attempt has been made to display a wide variety of casting defects, which can be observed visually or by examination of the microstructure, but this compilation is by no means meant to be complete. Further, the causes and potential remedies of such casting defects provide a full spectrum of possibilities. In examining a particular defective casting, all efforts must be made to gather the information on the several factors, which can be at play—molding materials and methods, handling, melt preparation, processing and quality, pouring, casting design, gating and risering, and solidification conditions. Casting simulation studies have proven to be very valuable in determining how to produce a good casting consistently. Maintaining a well-developed casting process control is also essential.

In certain cases specific information concerning the defect is known precisely. In other examples, probable cause or possible causes are stated. It is well recognized by aluminum metalcasters that defects may have multiple causes. Solutions may or may not be obvious, but common sense and intuitiveness play a big role when the defect cause(s) are isolated.

The focus of this handbook is to provide a ready visual reference to foundry floor operating personnel, process and quality engineers, metallurgists, and foundry management on the various types of aluminum casting defects, which are encountered by specific process, although certain types of defects—those metallurgical in nature—are common to all processes.

CHAPTER 1

Sand Casting

The organizational structure, used in this chapter, includes defects related to: sand, core, and molding practice; gating, risering and pouring; and metallurgy. The latter is divided into inclusions, gas defects, and microstructural anomalies.

I. Sand, Core and Molding Practice Related

Sand Defects (Mold Cracking, Crushes, Swells, Sags, Drops, Erosion, Stickers, Cuts and Washes, Poor Surface)

There are several defects, which relate strictly to casting processes with sand molding materials. These include crushes, sags, drops, erosion, stickers, cuts and washes, and poor surface. Molded cores can create defects due to inadequate and/or incorrect core production (poor strength, insufficient curing, etc.) or poor alignment and placement in registry with the main casting mold cavity.

1. **Mold cracking**—Molds may crack due to insufficient strength during the molding process; mishandling prior to pouring can cause mold cracks.
2. **Crushes**—Crushes are non-geometric projections on vertical or oblique surfaces of the casting in the direction in which the mold is closed or in which a core is placed.
3. **Drops**—Drops are defects due to the loss of a portion of the sand from the cope or other overhanging sections. Core drops may occur in either sand or semi-permanent molding.

4. Erosion Scab—Similar in appearance to an expansion scab, an erosion scab is usually found in the drag, where sand has been loosened by the metal-lostatic pressure of flowing metal during pouring.
5. Stickers—Sticker defects are irregular massive projections usually found on the cope surface and suggest a detachment of the mold wall.
6. Cuts and Washes—They are irregular, rough projections on the surfaces of a casting, usually in the vicinity of gates or on the drag surface following a line along the course of metal flow into the mold cavity.
7. Poor Surface—Generally the result of molding material grain fineness distribution being too coarse, insufficient green sand strength or erosion of the mold surface during pouring (too turbulent).
8. Buckle—A sand expansion defect, beginning of a scab, but resulting in a smooth edged groove on a horizontal or flat surface of a casting.



Fig. SC-1. Mold crack.

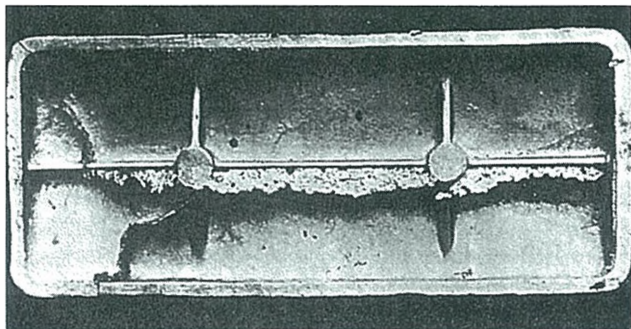


Fig. SC-2. Scab on aluminum casting due to mold cracking during baking.

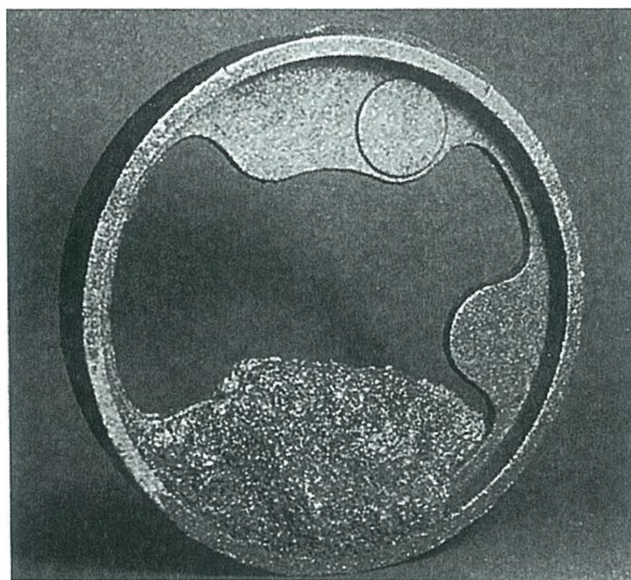


Fig. SC-3. Drop caused by weak mold in green sand aluminum casting.

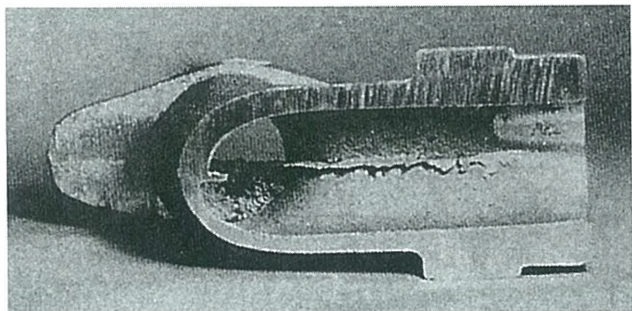


Fig. SC-4. Core breakages due to mismatch in expansion capability between dry sand core and green sand mold.



Fig. SC-5. Buckles on a plate casting.

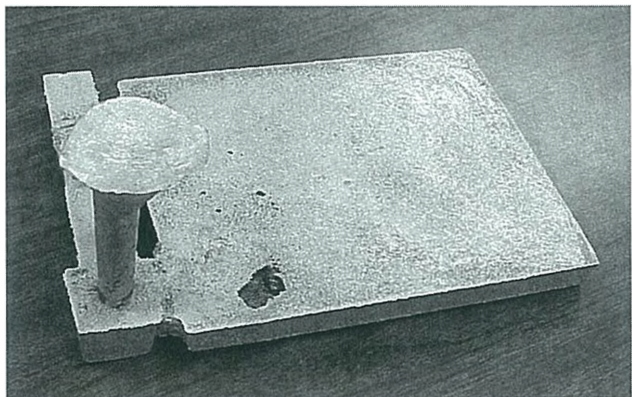


Fig. SC-6. Erosion near gating on 356 alloy casting.



Fig. SC-7. Erosion near gating on 356 alloy casting.

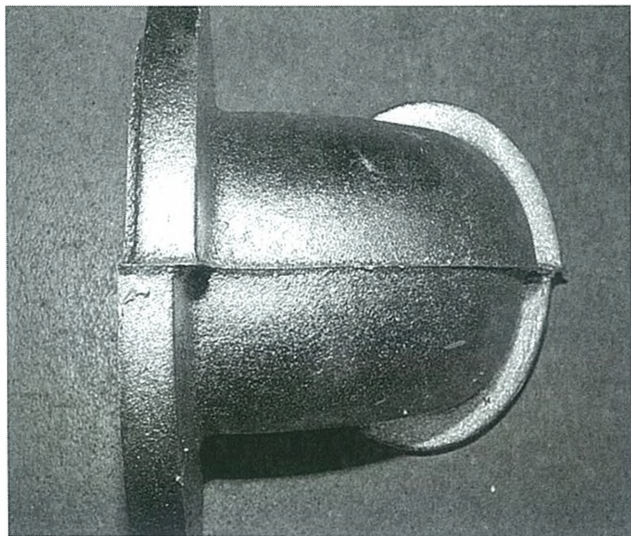


Fig. SC-8. Core shift causing casting to be misaligned.



Fig. SC-9. Hole on casting surface caused by loose sand.

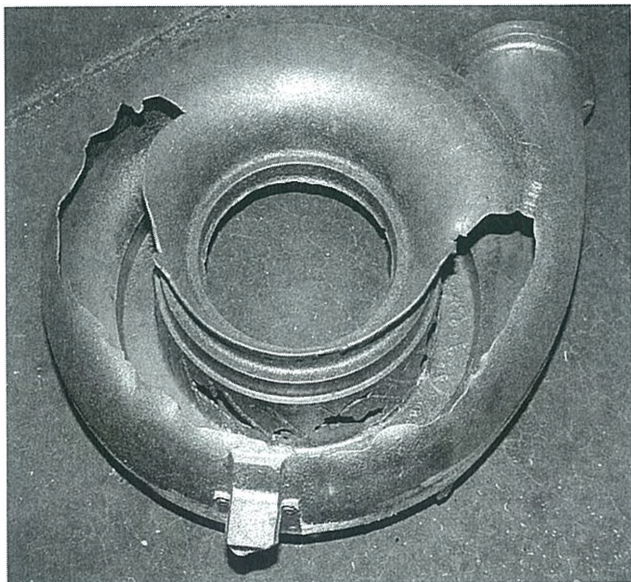


Fig. SC-10. Core drop (can occur with cores in sand or semi-permanent molding).

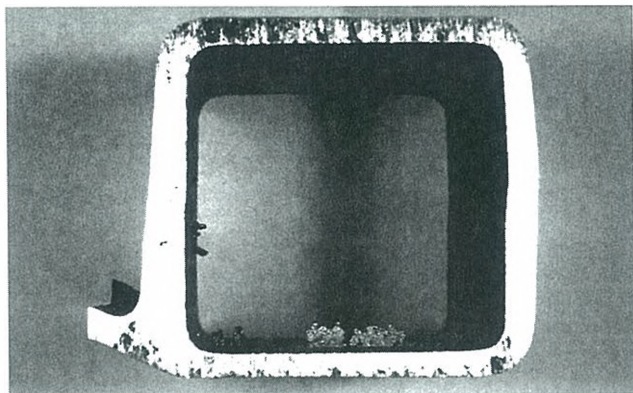


Fig. SC-11. Broken core.

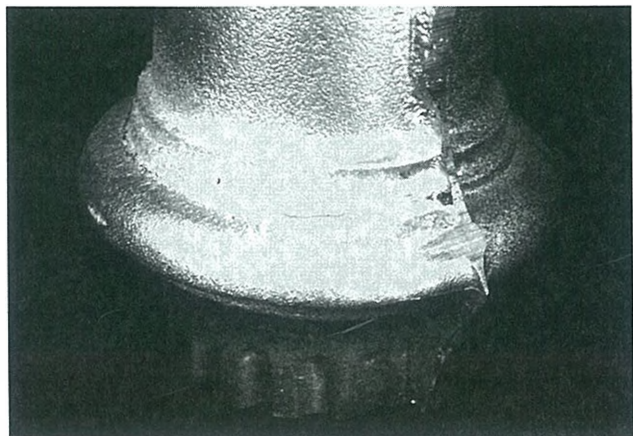


Fig. SC-12. Heavy flash—caused by mold mismatch, improper closure, and/or excessive metal fluidity.

II. Gating, Riser and Pouring Related

Misruns and Coldshuts

A misrun casting is one in which the casting detail is incomplete due to failure to fill the mold cavity. A portion of the casting may be missing and/or necessary sharp corners may be rounded.

A cold shut involves a visual and structural discontinuity due to separate metal flows, or where two or more metal streams have come together and fused. This can occur especially in large thin flat sections of the casting.

Both defects result from incorrect gating design, low pouring temperature, and inadequate pouring practice. Casting geometry, molding equipment, and mold condition play important roles as well. Misruns and cold shuts can occur with any of the aluminum shape casting production processes; therefore, the reader should also refer to other chapters in this book for additional visual images.

Causes

1. Casting Geometry

- Irregular casting sections resulting in interrupted metal flow
- Casting sections too thin relative to metal fluidity
- Isolated thin sections

2. Mechanical and Equipment Related

- Worn pattern equipment
- Misalignment of pattern equipment
- Core shift
- Weak or improperly reinforced flasks
- Cope or drag shift

3. Sand, Core and Molding Practice Related

- Excessive moisture
- Sand organic components too high
- Sand too weak causing mold distortion
- Permeability too low creating back pressure
- Inadequate venting
- Improper core size resulting in decreased metal sections
- Excessive mold wash
- Mold and core material with excessive chill reducing metal fluidity

4. Gating, Riser and Pouring Practice

- Inadequate gate and/or runner sizing and gate placement
- Sprue too small
- Interrupted pouring
- Pour temperature too low
- Inadequate pour height and/or metal pressure
- Pouring too slowly
- Debris in mold hindering metal flow
- Solid debris in metal pour stream
- Poured short (pour volume inadequate)
- Inadequate venting
- Dirty or gassy metal, which reduces fluidity



Fig. SC-13. Cold shut in aluminum casting due to low temperature and large flow distance.

Shrinkage Defects

As a casting solidifies, there is a contraction from liquid to solid state. The casting design geometry should allow for generalized controlled overall shrinkage. Often however, there is undesirable localized shrinkage. A shrinkage depression or cavity in a casting may form and may or may not be related to the presence of gas. Shrinkage, as a depression on the surface, is considered macroshrinkage, while in the interior of a casting there may be dispersed or microshrinkage. Macroshrinkage is usually associated with or surrounded by a cast interdendritic structure, often spongy, related to inadequate mold filling. Microshrinkage takes the form of pinholes or small cavities within the interdendritic network. Microshrinkage often occurs in the last section of the casting to solidify and also may be related to gas content evolving during solidification as well as related to inadequate feeding. Remedies for shrinkage defects often involve the intuitive opposite to those causes listed below.

Causes

1. Mechanical and Equipment Related

- Abrupt changes in casting section thickness
- Inadequate fillets
- Insufficient feeding
- Insufficient cope height

2. Sand, Core and Molding Practice Related

- Wet sand
- Low compressive strength
- High hot deformation
- Core shift
- Weak cores
- Lack of fillets
- Soft ramming
- Mold wall movement under pouring pressure

3. Gating, Riser and Pouring Related

- Inadequate riser volume
- Insufficient riser placement
- Lack of necessary chills
- Need for exothermic riser compounds or sleeves
- Pouring too hot or too cold
- Failure to top off risers with hot metal

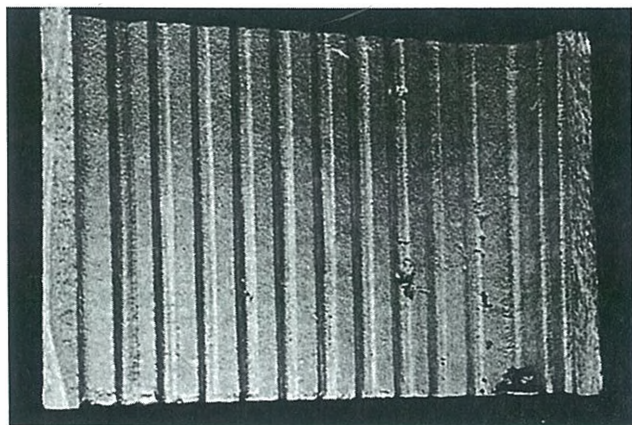


Fig. SC-14. Shrinkage in green sand aluminum casting.

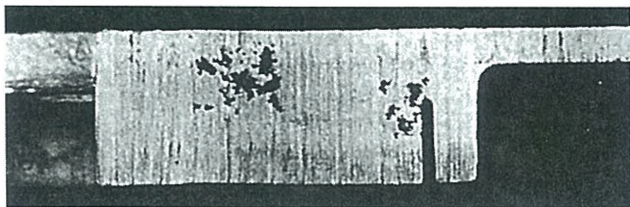


Fig. SC-15. Internal shrinkage in green sand casting caused by excessive section thickness and insufficient feeding.

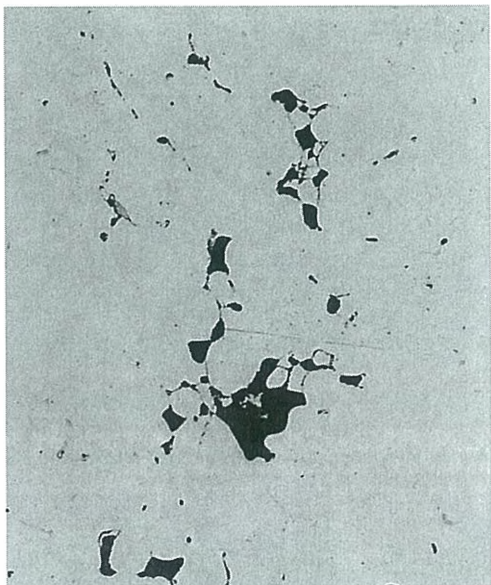


Fig. SC-16. Gross microshrink.

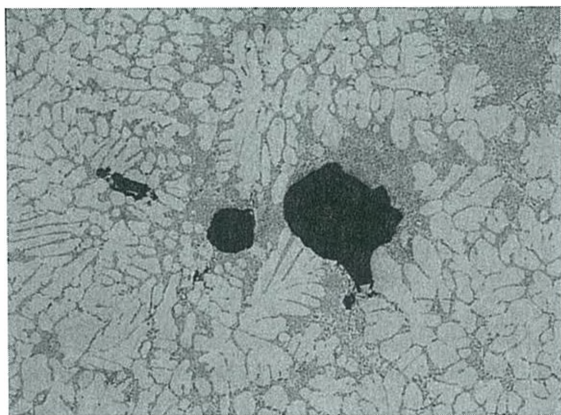


Fig. SC-17. Concentrated microshrinkage in modified alloy.



Fig. SC-18. Internal sponge observed with zygo (black light) caused by inadequate feeding and/or poor solidification.



Fig. SC-19. Dross-induced shrink (restricted metal fluidity) in 356.

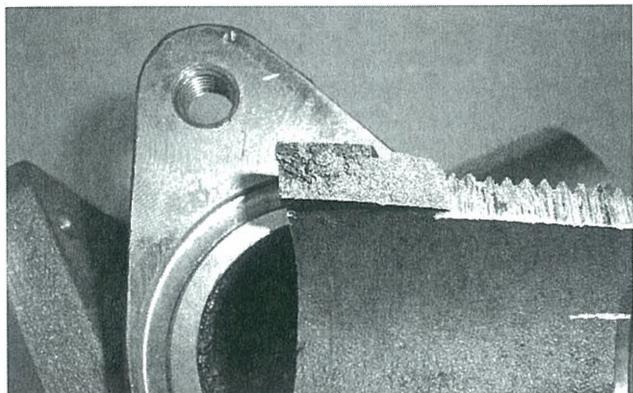


Fig. SC-20. Shrink in 356.

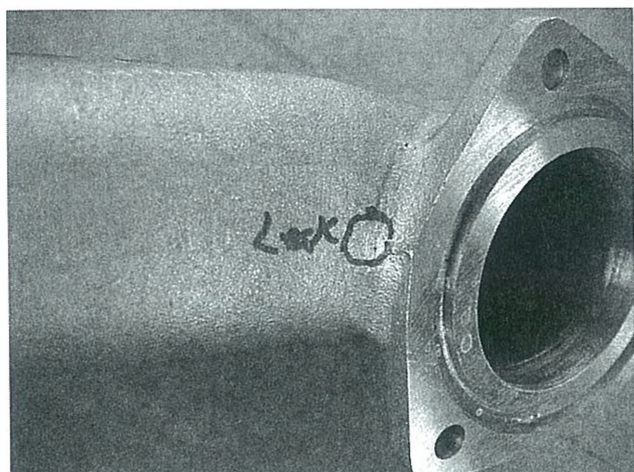


Fig. SC-21. Shrinkage and parting line leakage in 319F due to sharp radius; eliminated by increasing the radius.

Hot Tearing

Hot tearing is a defect which occurs in nonferrous casting during the pouring and/or solidification process before the casting becomes completely solid, and in which physical constraints restrict the casting from normal contraction. There are many causes of hot tearing—casting design, molding practices, pouring and basic metallurgy of the alloy. The copper-containing 2xx alloy series are especially prone to hot tearing. The crack or tear in the casting is often inter-dendritic with an oxidized surface because of the high temperature. Remedies include appropriate application of grain refining, as well as improved casting design and gating system, avoidance of hot spots and reduced pouring temperatures.

Causes

1. Mechanical and Equipment Related

- Lack of adequate fillets
- Abrupt changes in section thickness
- Flask equipment preventing adequate casting contraction
- Rough handling too soon after pouring

2. Sand, Core, and Molding Practice

- Poor sand collapsibility
- Low hot deformation capability
- Vitrification (glassy thermal transformation) of the sand
- Excessively rigid molds and cores
- Failure to use chills or chills improperly placed
- Delayed shakeout

3. Pouring

- Pouring temperature too low to promote collapsibility
- Excessive pouring temperature creating hot spots in thin sections
- Inadequate flow (filling) of liquid metal in the mold cavity
- Cooling too fast
- Shakeout too soon

4. Metallurgical

- Alloy segregation with low melting point metal (tin, lead, zinc) concentrations in last metal to solidify
- Contaminants, tramp elements
- Large grain size
- Alloy compositions with substantial volume change as last fraction of liquid transforms to solid

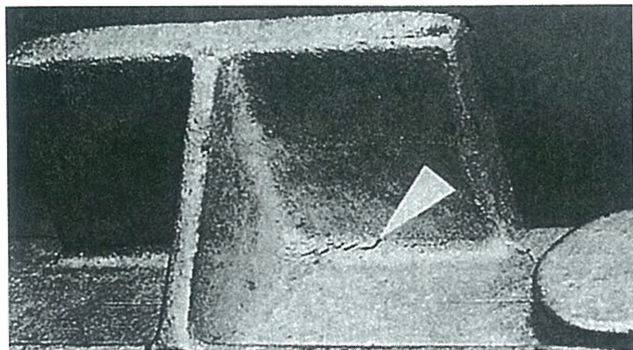


Fig. SC-22. Hot tearing in an aluminum alloy casting due to restrained contraction during solidification.

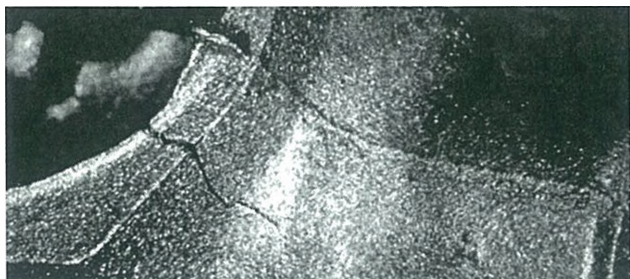


Fig. SC-23. Hot cracking of alloy casting.

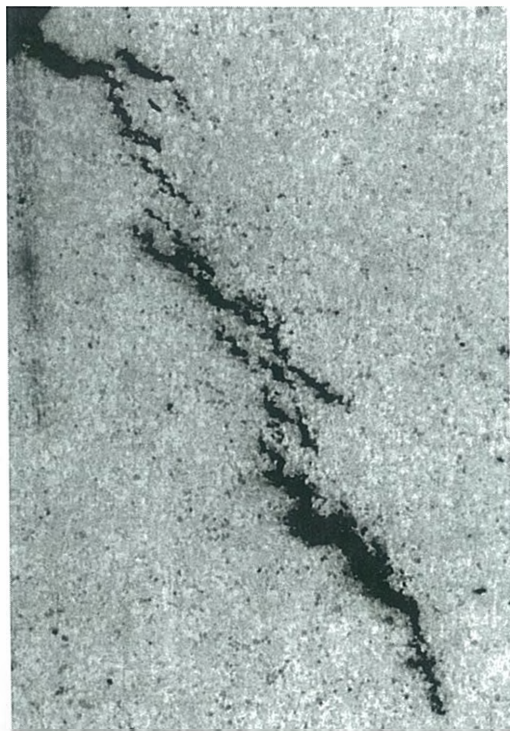


Fig. SC-24. Hot crack tear.



Fig. SC-25. Hot microtear.

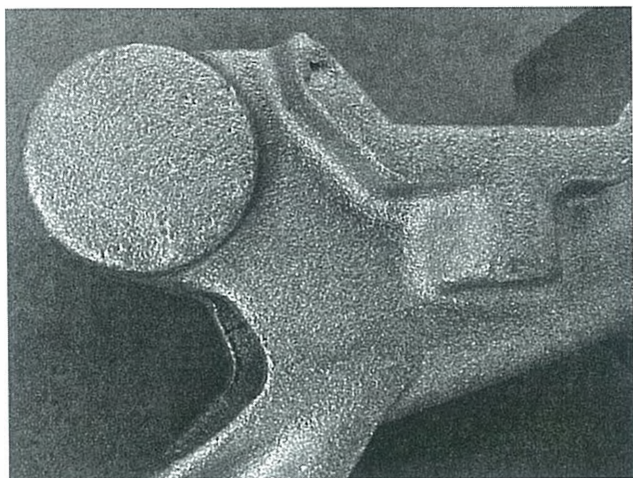


Fig. SC-26. Hot tear at parting line and sand particles on drag surface of 356 alloy.

Metal Penetration

This defect could be classified in three ways:

1. Mold-related defect (weak or overly porous mold materials);
2. Pouring defect (excessive head pressure or turbulence) or
3. Metallurgical defect (excessive metal fluidity.)

Metal penetration defects occur in the sand casting process due to high fluidity of the liquid metal and weakness in the mold surface. While not a frequent occurrence, a somewhat less insidious interaction between the liquid metal and the mold is burn-on caused by excessive metal pouring temperature. In this case a visual discoloration of the casting surface results, as well as localized increased grain size in the microstructure, which may or may not be detrimental depending upon the casting's utilization. Burn-on, if limited to a surface or cosmetic defect only, can often be removed by carefully grinding away the defective area.

Causes

1. Mechanical and Equipment Related

- Sharp corners

2. Sand, Core and Molding Practice Related

- Poor sand mixing
- Irregular grain size distribution leading to poor ramming
- Low mold density
- Excessive mold permeability
- Soft cores
- Incorrect core material
- Rough core surface
- Insufficient core binder or curing

- Poorly patched areas
- Excessive usage of parting compounds
- Uneven mold coating application

3. Gating, Riser and Pouring Related

- Too close positioning of gates and risers promoting overheating of the sand
- Pouring too hot
- Excessive pouring height

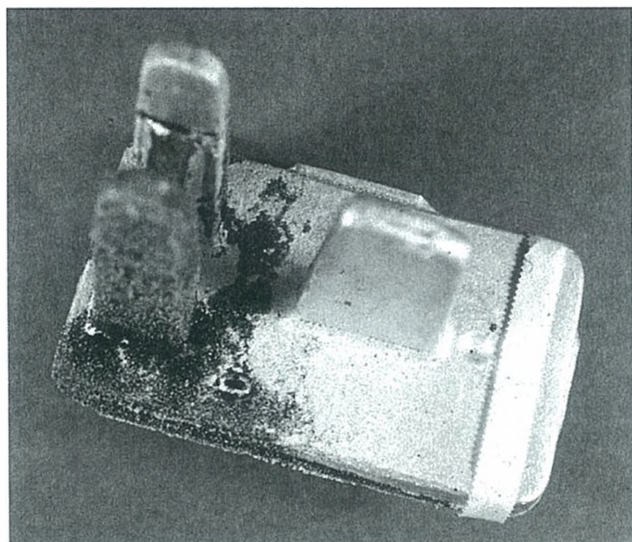


Fig. SC-27. Metal penetration in an aluminum casting.

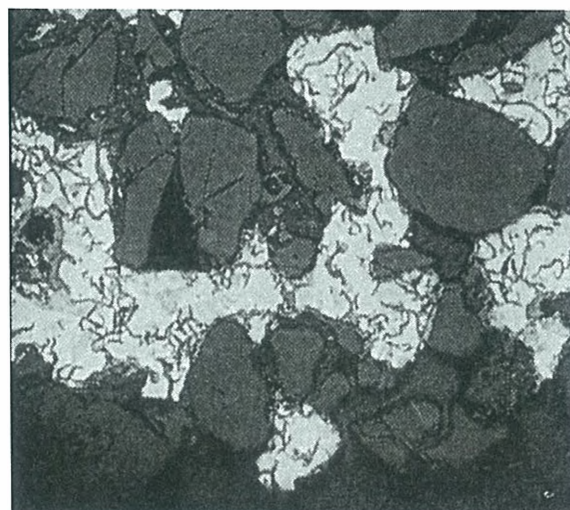
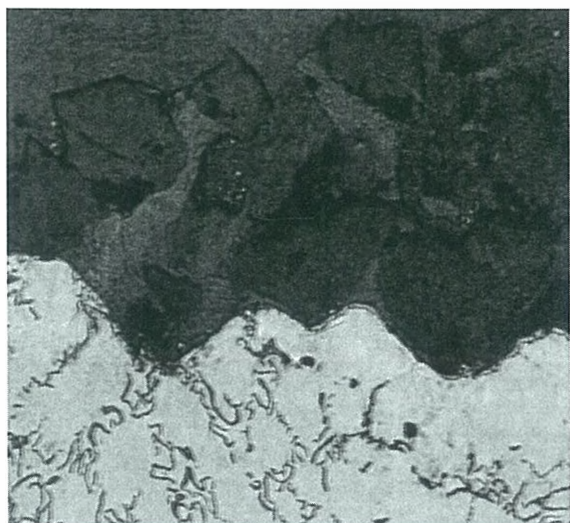


Fig. SC-28. Micrograph showing burn-on versus penetration (magnified at bottom.)

III. Metallurgically Related Gas Defects

Gas defects arise from the presence of gas in the liquid metal which forms porosity in the casting as the metal solidifies. The porosity may take the form of a cavity or visual blowhole, pinholes or blisters. Sources of the gas—which may include hydrogen, air or volatile organics—include gas soluble in the liquid metal, gas arising from moisture in the sand, core out-gassing, entrapped air and mold and core wash out-gassing. Gas defects are detrimental to machining, surface finishing, and mechanical properties of the casting.

Gas defects that originate from high hydrogen in the melt can be minimized or eliminated by minimizing excessive melt temperatures and by proper and complete degassing techniques.

Causes

1. Mechanical and Equipment Related

- Insufficient mold and/or core permeability
- Lack of adequate venting of mold cavity

2. Sand, Core and Molding Practice Related

- Moisture content too high
- Poorly mixed sand
- Clay content too high
- Wet coatings
- Inadequate permeability for volatile organic burn-off
- Under-cured cores
- Excessive binder
- Inadequate venting
- Wet core paste
- Absorbed moisture during storage
- Chill or sealing materials not dried
- Excessive gas-producing material in core sand or wash

- Insufficiently dried molds
- Excessive patching
- Hard spots caused by improper ramming for conditions involved

3. Gating, Riser and Pouring Related

- Wet pouring basins and/or sprues
- Sprue and/or gating system inadequately sized
- Entrainment of air due to turbulence in the sprue and runner system
- Turbulent and/or interrupted pouring
- Short pours unable to fill mold cavity
- Cold, damp ladles
- Pouring rate too fast or too slow
- High humidity condensation on cold mold sprue and gating system

4. Metallurgical Related

- Melt too gassy or inadequately degassed
- Excessive melt and/or pouring temperatures
- Metallic impurities in the melt with affinity for hydrogen

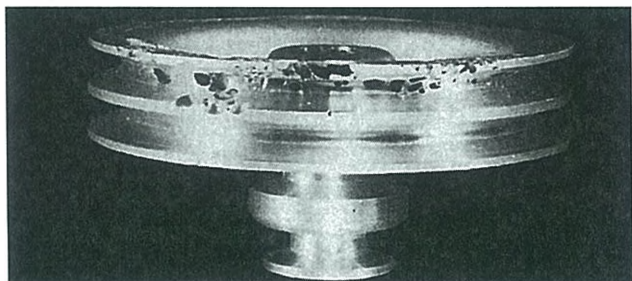


Fig. SC-29. Blowholes in green sand aluminum casting.

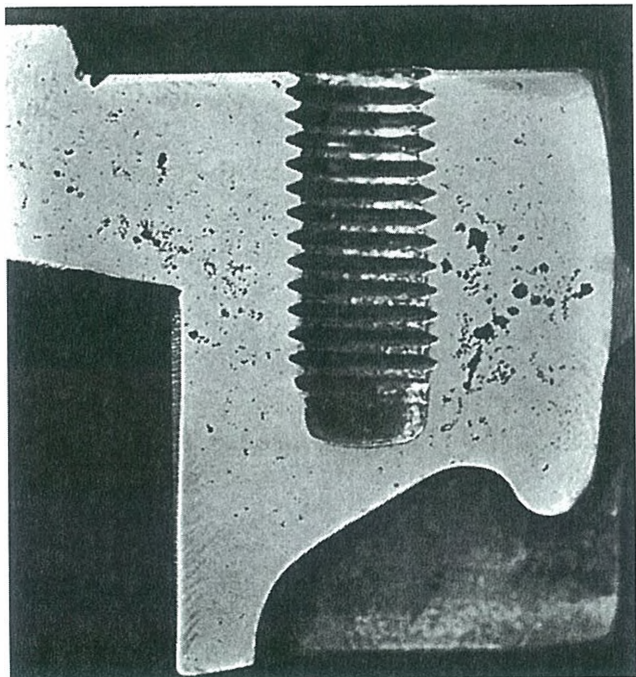


Fig. SC-30. Blowholes in green sand aluminum casting.

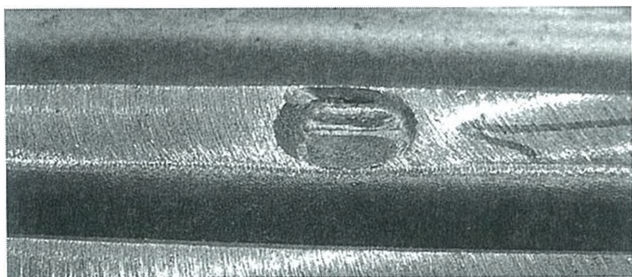


Fig. SC-31. Blow caused by entrapped gas; possible reaction with wet sand.



Fig. SC-32. Cylinder head has blowholes in vicinity of insert ring. Insert was oily and too cold. Defect was eliminated with degreasing and preheating the insert.

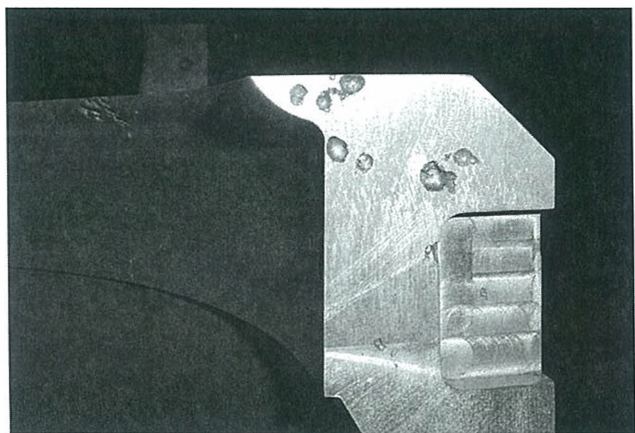


Fig. SC-33. Porosity due to entrapped air in 356-sand casting.

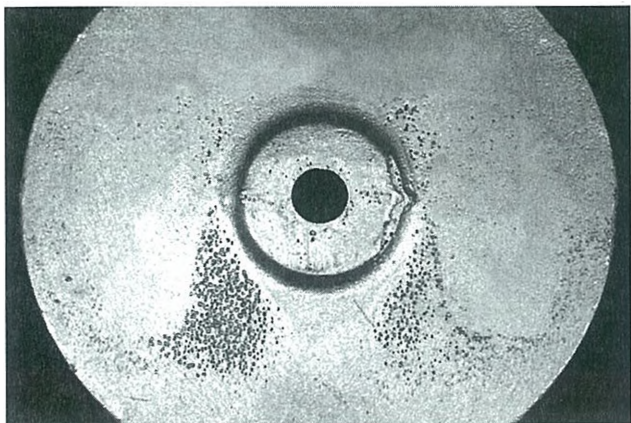


Fig. SC-34. Steam porosity in 356 due to high hydrogen content in the melt and/or excessive moisture in the sand.

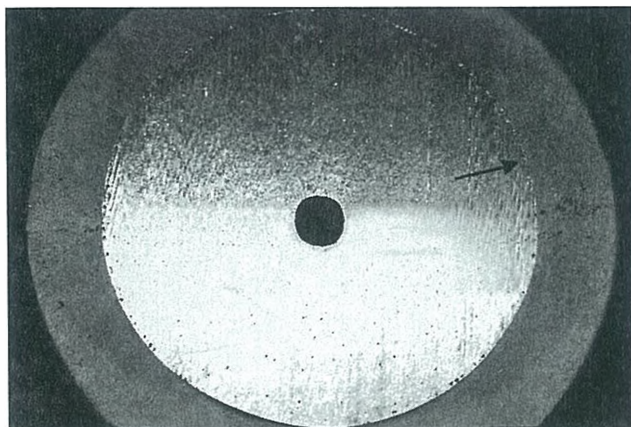


Fig. SC-35. Surface steam porosity due to excessive moisture in the sand.

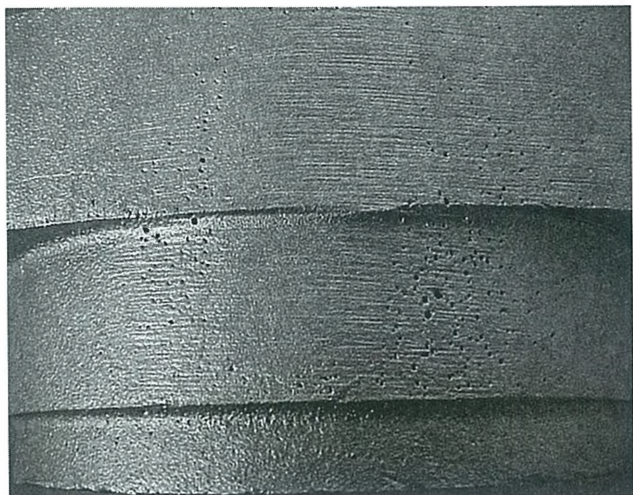


Fig. SC-36. A356; possible shrinkage or hydrogen porosity under surface oxide skin.

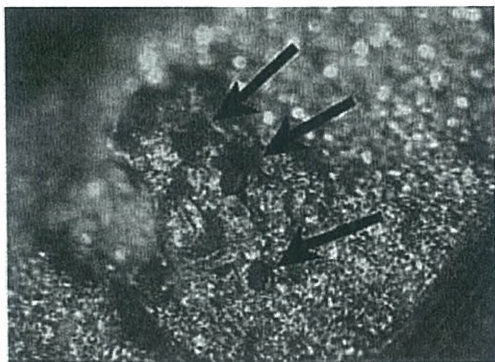


Fig. SC-37. Porosity due to loose sand, observed on fracture surface.

Inclusion Defects

Inclusion defects occur as the existence of insoluble particulate material trapped within the casting during solidification. Inclusions arise from the melting process; from contaminants; from fluxes and other melt-treatment product debris; from breakdown of furnace and ladle refractories; from breakdown of mold and core materials and coatings during pouring and from turbulent pouring. In addition, there may be inclusions arising from undissolved alloy additives. Inclusions may be oxides or intermetallic compounds.

Inclusions can be responsible for poor fluidity during pouring; for blockage of sprues, gates and runners when concentration and/or sizes are excessive; for hot tears, hot cracking, and fracture during solidification and for residual stress reaction during hot extraction and handling. Inclusions are responsible for tool wear and breakage during machining and blemishes during surface finishing processes. When castings are used for their engineering properties and performance, tensile strength, ductility and fatigue strength are reduced by inclusions.

The various types of melt-related inclusions are:

1. Dross—from the melting process that is not adequately skimmed can be carried over during pouring and into a casting.
2. Corundum—a very hard form of aluminum oxide, and which forms in the melting furnace at high temperatures over time and with free silicon in the refractory, which may be present.
3. Sludge—a heavy-metal segregation, which has settled like sediment to the furnace bottom, and may become entrained into the pouring stream during transfer and ultimately poured into the casting. Generally, this sludge is an aggregate. *Metal-lurgical* sludge is generally a discrete particulate, an intermetallic compound that forms from iron, manganese, and chromium together with aluminum and silicon.

4. Flux—inclusions arise from fluxing operations in which the fluxing debris is inadequately skimmed from the melt surface or when this debris does not have the opportunity to rise to the melt surface.
5. Oxides from melt oxidation, melt additives, and refractory erosion, in addition to returns of gates, risers, trim scrap, scrap castings, and sand debris.

In addition to inclusions which may be retained from the melting operation, melt treatment in pouring ladles, pouring turbulence into the mold, and high metal velocity or separated metal flows in the gating system can also result in inclusion problems. Such turbulence-related inclusions are manifested in 'oxide fold' or 'oxide bi-films' within the casting. These are often discovered during microscopic examination and may be the culprit(s) relating to defective castings or less-than-desirable mechanical properties.

Machining, surface finishing operations and mechanical properties are usually compromised by the presence of any of these types of inclusions. Additionally, fluidity and feeding of the metal during pouring and casting solidification may be compromised.

The effect of inclusion defects is sometimes manifested visually and causes misruns; incomplete casting fill if the size, amount or concentration of inclusions is excessive; or may cause obvious surface imperfections. Internal inclusions within the body of the casting may only be detected by microscopic investigation. Often poor mechanical properties can be related to such internal inclusions.

Minimizing or eliminating inclusion-related defects requires careful attention to employing clean charge materials; control of melt temperatures; prudent maintenance of furnace refractory; careful skimming of dross and employing in-furnace filtration and/or in-mold filtration. Melt treatment employing flux injection and degassing also aids in partial removal of inclusions by flotation.

Causes

1. Mechanical and Equipment Related

- Casting design factors that contribute to metal flow problems in sand molds will increase tendency for inclusions to become entrained.
- Casting pattern design that prevents inadequate molding will increase tendency for loose sand to become entrapped within the casting.
- Rough handling of molds and flasks
- Gouging of the mold during closing or core setting
- Inadequate venting provides for air entrapment and subsequent oxidation.

2. Sand, Core and Molding Practice Related

- Inadequately mulled sand creating loose sand grains
- Sand grain size too irregular
- Inadequate molding yield low green strength
- Metal-mold reaction generating steam formation, which may loosen sand grains
- Weak cores
- Excessive and/or improperly cured mold and core wash coatings.

3. Gating, Riser and Pouring Related

- Gating systems which create turbulent flow
- Turbulent pouring
- Dirty ladles
- Inadequate dross and/or skim separation from the melt prior to pouring
- Weak ladle refractories, which spall during pouring
- Intermittent pouring allowing greater accessibility for melt oxidation
- Excessive pouring temperature

4. Melt and Metallurgical Related

- Tramp element impurities in excess of solubility limit, forming inter-metallic inclusions
- Charge mix with excessive fines and/or oxides
- Inadequate dissolution of melt additives and/or modifiers
- Flux inclusions
- Melting furnace refractory erosion
- Corundum formation and entrainment in the melt
- Heavy element segregation and sedimentation carried over in metal pouring or transfer
- Excessive melt temperature accelerating oxidation
- Excessive sand contained in returns



Fig. SC-38. Oxide film inclusion in green sand casting due to turbulence during filling.



Fig. SC-39. *Oxide films folded into casting during solidification.*

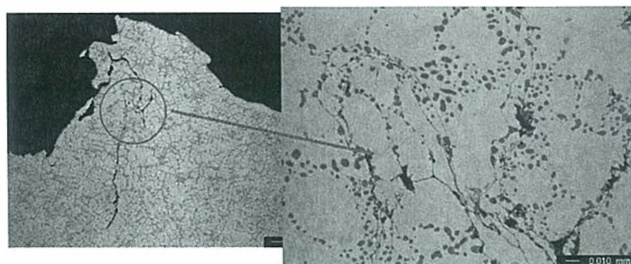


Fig. SC-40. *Oxide fold defect.*

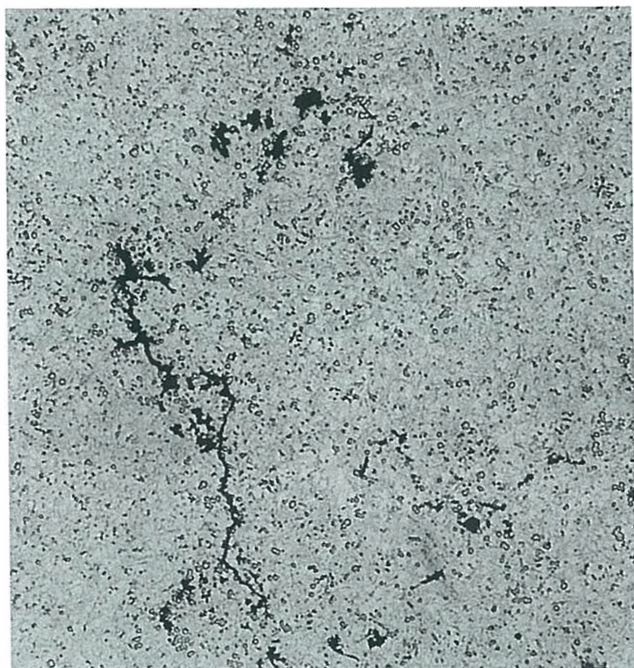


Fig. SC-41. Oxide stringer resulting from skim carryover.



Fig. SC-42. Oxides found in fracture site on a casting.

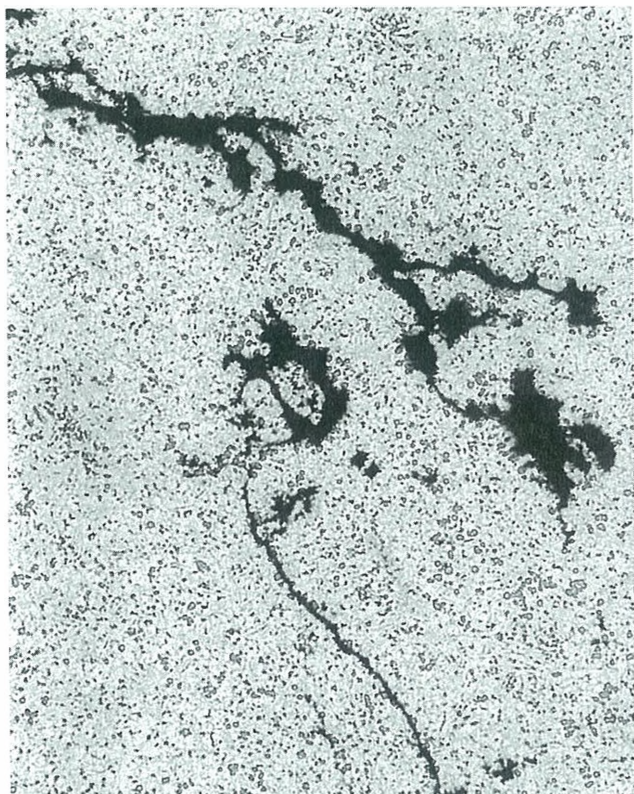
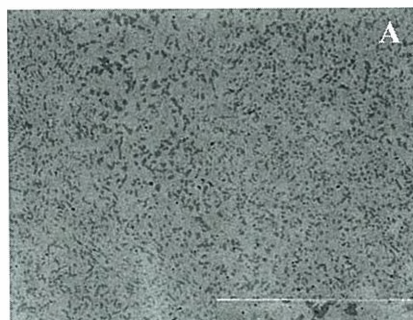


Fig. SC-43. Oxide stringer.



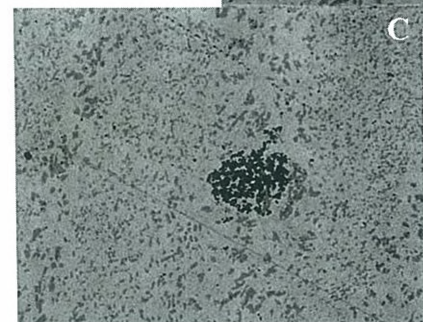
A Sr master alloy rod,
fine, 500X



Sr master alloy rod,
coarse, 500X



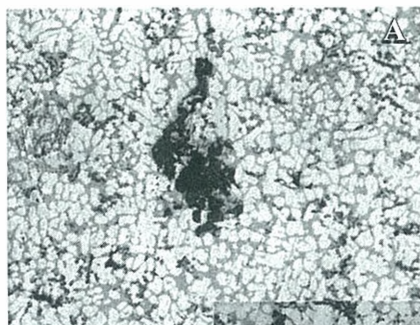
B



C

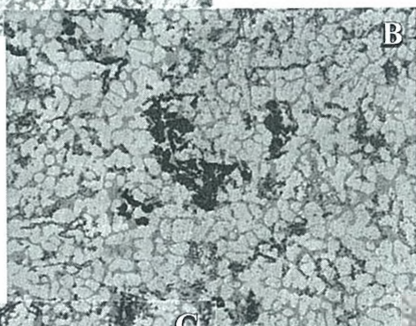
Al_2SrSi_2 -like
substance, 500X

Fig. SC-44. Calcium-silicon inclusion from undissolved silicon addition.



"Mushy" material,
Al-Sr-Si concentration,
likely Al_2SrSi_2 , 200X

"Mushy" material,
more Al_2SrSi_2
type, 200X



Al_2SrSi_2 type + filmy
spinel, 200X

Fig. SC-45. Undissolved Al-Sr-Si from modifier addition.



Fig. SC-46. Hard spot (oxide or intermetallic) in 319 casting.

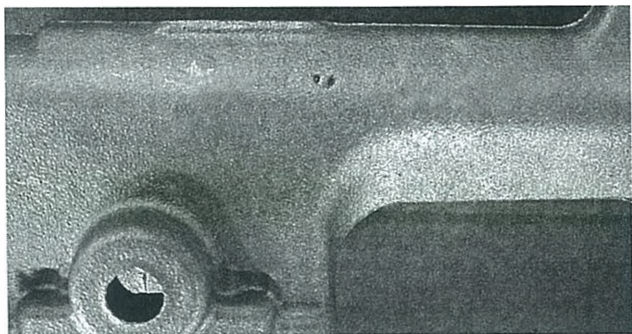


Fig. SC-47. Dross (319F) near ingate on cope surface; altered pouring velocity to reduce it.



Fig. SC-48. A356 alloy; dross or inclusion on cope surface near ingate; remedied by adjusting pouring practice.



Fig. SC-49. A356 inclusion from shell core breakdown or dross entrained in pouring.

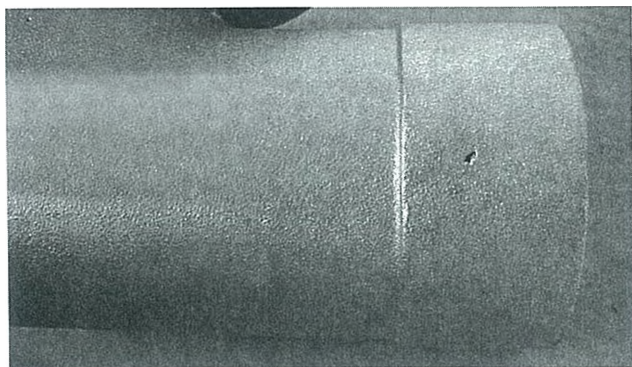


Fig. SC-50. A356 cope surface inclusion due to refractory erosion or dross carryover.

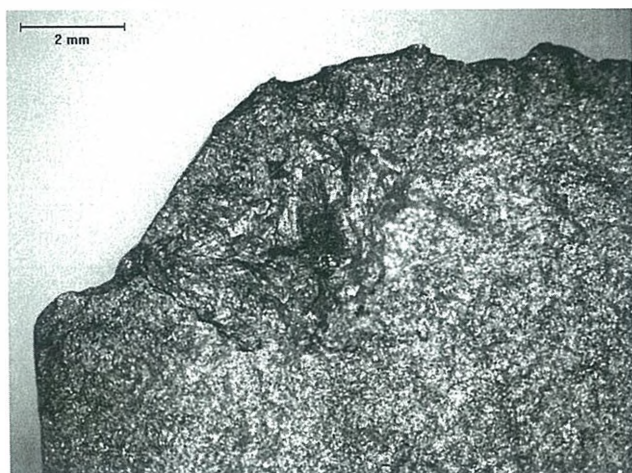


Fig. SC-51. Oxide observed to have caused fracture on fracture surface.

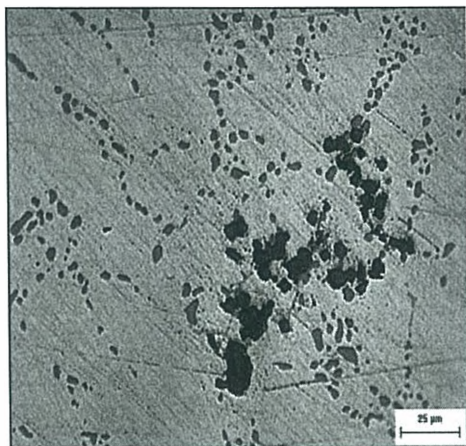


Fig. SC-52. Undissolved Al-Sr-Si from Sr master alloy addition.

Other

Other types of defects can occur upon heat treatment (see also Chapter 2, "Permanent Mold").

Incipient melting during solution treatment, blistering and dimensional changes can occur with castings produced by sand, permanent mold or other processes as well.

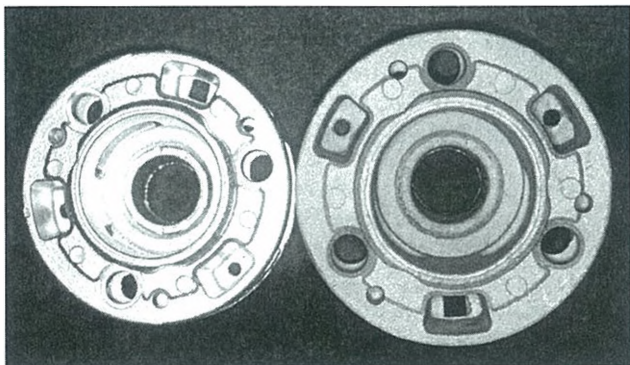


Fig. SC-53. Excessive aging during heat treatment caused casting enlargement (dimensional growth)

CHAPTER 2

Permanent Mold

In permanent mold casting, as with other metal-mold processes, the majority of aluminum alloy casting defects that are encountered are metallurgical in nature, if the permanent mold 'mechanicals,' including alignment, are functioning properly. However, defects relating to problems with cores (semi-permanent molding), mold coating materials and die preparation can also be encountered.

I. Surface and Casting Shape Defects

The mold condition in a metal mold can create an irregular or rough casting surface. In split molds, lack of perfect registry can generate flash or undesirable indentation. Rough removal of the casting from the mold can result in scouring or gouging of the casting. This can also cause tool drag during machining. Surface defects in rigid metal molds can be process related, (i.e. pouring or temperature related, in generating cold shuts, laps, misruns, etc.). However, the mold surface itself can create cosmetic defects, which may impact subsequent fine-surface finishing operations, such as anodizing, polishing, painting, etc.

Casting shape defects (bent, broken or cracked castings) result from premature casting removal, improper ejection and casting complexity, which may cause distortion as the casting cools.

Surface defects also arise from cold metal, interrupted pours and multiple in-gate metal flows, in many cases creating misruns and cold shuts as well.

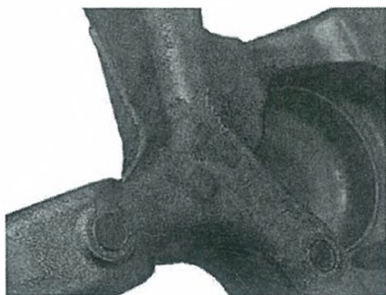


Fig. PM-1. Rough surface due to die coating flake-off.



Fig. PM-2. Rough surface from excessive die coating application.

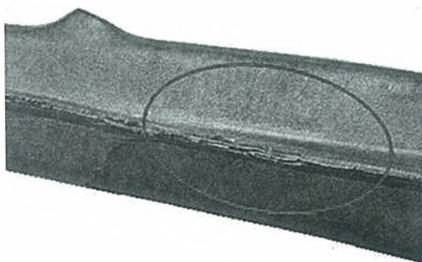


Fig. PM-3. Parting line void creating inverted flash.

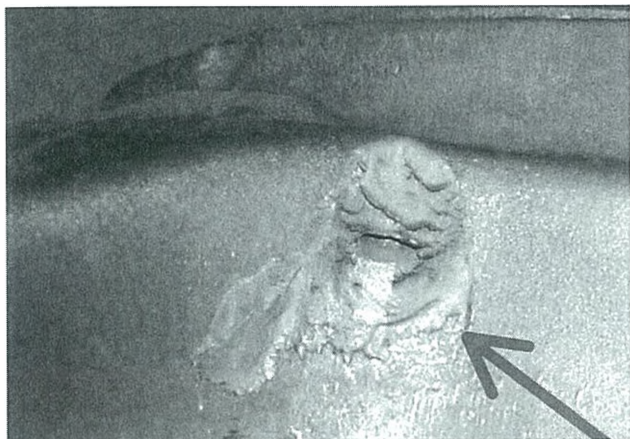


Fig. PM-4. Tool drag.

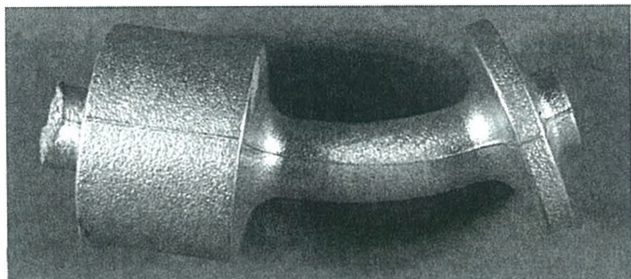


Fig. PM-5. Distortion from improper ejection of the casting from the mold.

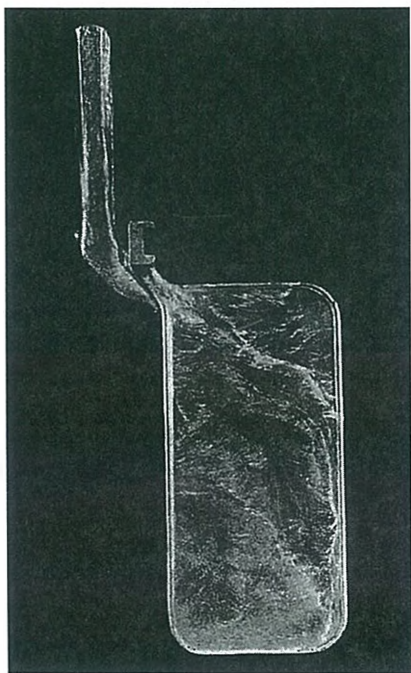


Fig. PM-6. Flow marks with oxide surface due to excessive pour temperature and gating too small.

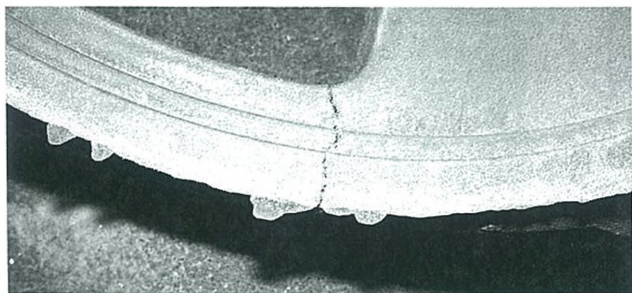


Fig. PM-7. Cracked casting due to mishandling and/or premature removal from mold.

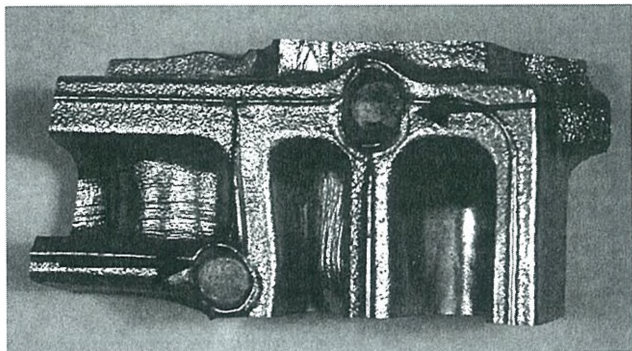


Fig. PM-8. 'Crush' in aluminum casting due to ejector pin action.

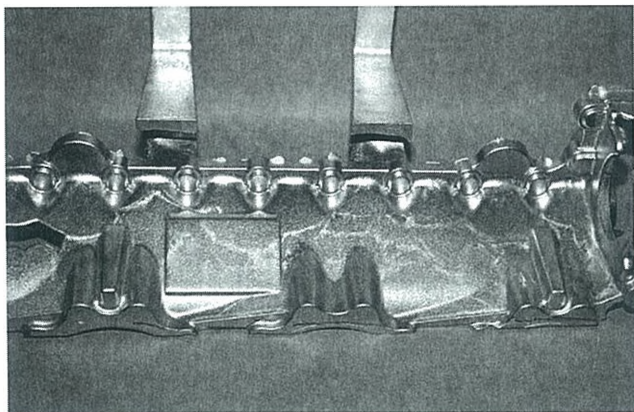


Fig. PM-9. Cold lap, rough surface.

Misruns and Cold Shuts

A misrun casting is one in which the casting detail is incomplete due to the failure to fill the mold cavity. A portion of the casting may be missing, and/or necessary sharp corners may be rounded.

A cold shut involves a visual and structural discontinuity due to either separate metal flows or two or more metal streams that have come together and fused. This can occur especially in large thin flat sections of the casting.

Both defects result from inadequate pouring practice, although casting geometry, molding equipment and mold condition may also play significant roles.

Other defects, such as surface sinks, are also a result of inadequate pouring practice.

Causes

1. Casting Geometry

- Irregular casting sections resulting in interrupted metal flow
- Casting sections too thin relative to metal fluidity
- Isolated thin sections

2. Mechanical and Equipment Related

- Misalignment of molds in split mold application
- Core shift in semi-permanent molding

3. Sand Core Molding Practice Related in Semi-Permanent Mold (SPM) Casting

- Excessive moisture
- Sand organic components too high
- Sand too weak causing core distortion
- Permeability too low creating back pressure
- Inadequate venting
- Improper core size resulting in decreased metal sections
- Excessive mold wash
- Mold and core material with excessive chill reducing metal fluidity

4. Gating, Riser, Pouring Practice

- Inadequate gate/runner sizing and gate placement
- Convergent metal streams
- Sprue too small
- Interrupted pouring
- Pour temperature too low
- Inadequate pour height and/or metal pressure
- Pouring too slowly
- Debris in mold hindering metal flow
- Solid debris (oxides, dross, refractory) in metal pour stream
- Poured short (pour volume inadequate)
- Inadequate venting
- Dirty or gassy metal which reduces fluidity



Fig. PM-10. Non-fill from pouring temperature too low.



Fig. PM-11. Non-fill from improper mold gating.

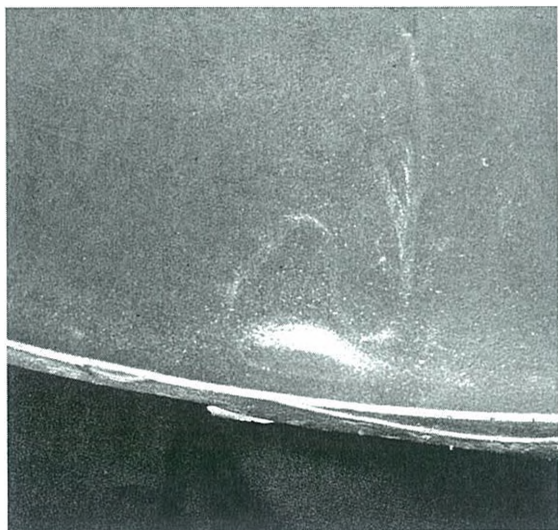


Fig. PM-12. Sink due to flash freezing of metal supply.

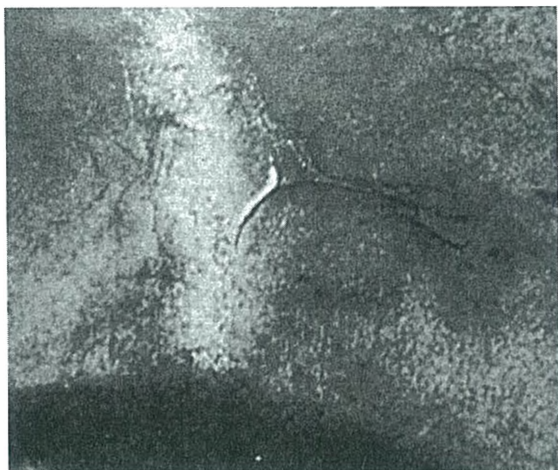


Fig. PM-13. Cold shut due to low temperature and long flow distance

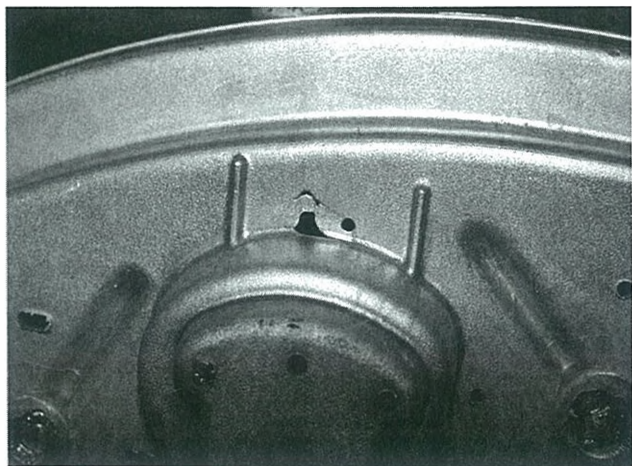


Fig. PM-14. Misrun due to inadequate gating.

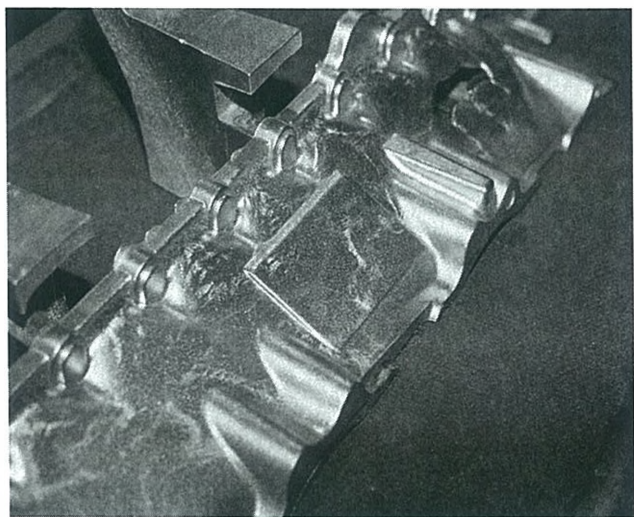


Fig. PM-15. Misrun exhibiting irregular flow lines.

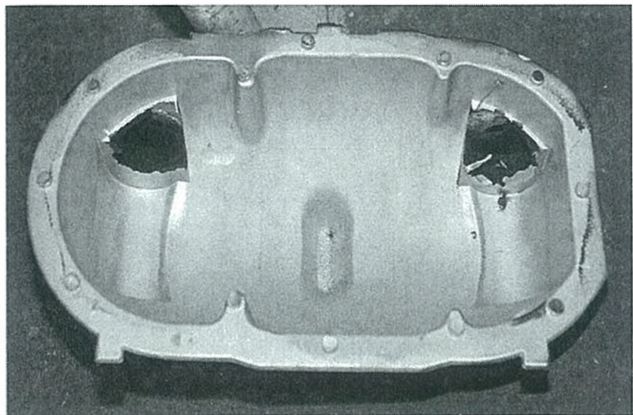


Fig. PM-16. Misrun due to too low pouring temperature.

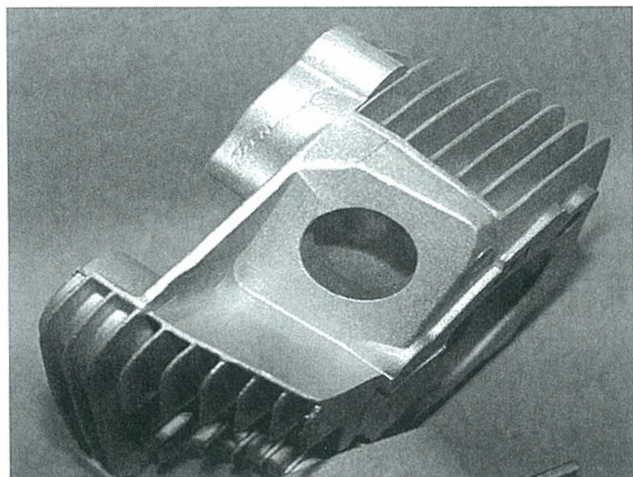


Fig. PM-17. Misrun due to interrupted metal pour.

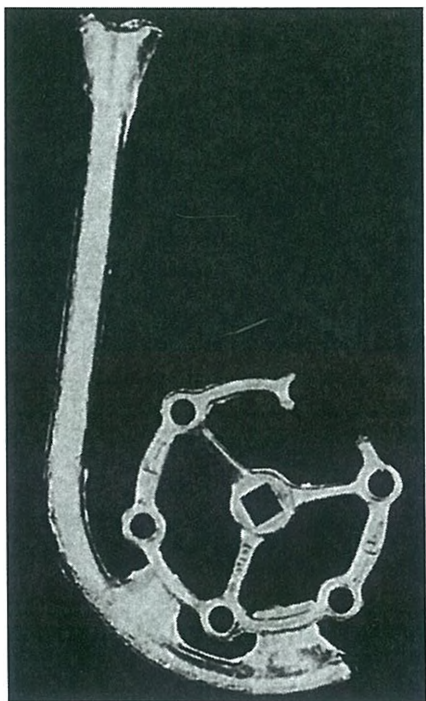


Fig. PM-18. Misrun due to mold temperature too low.

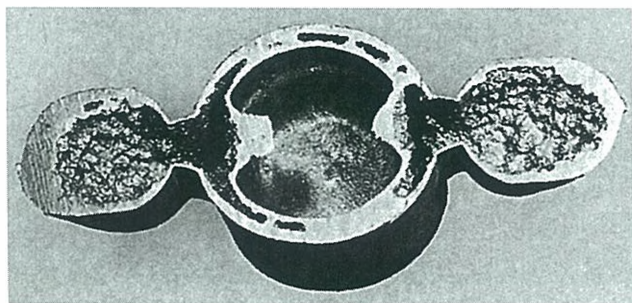


Fig. PM-19. Misrun (run-out) due to opening mold too soon.

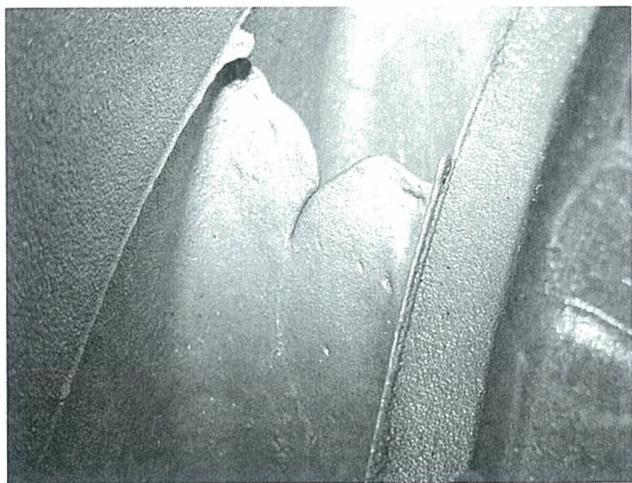


Fig. PM-20. Misrun.

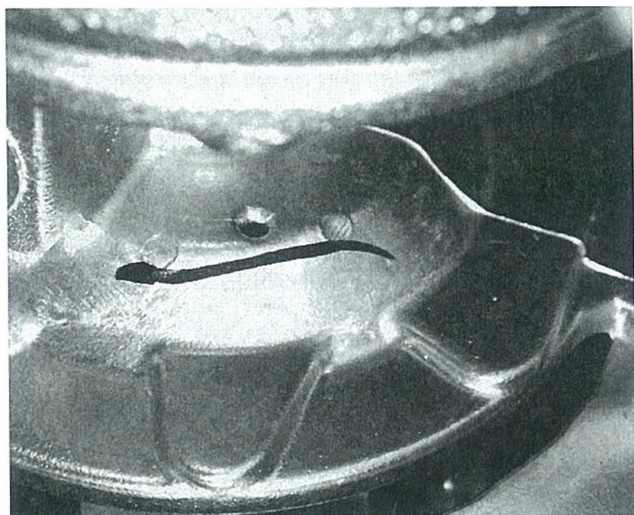


Fig. PM-21. Misrun in 356 alloy.

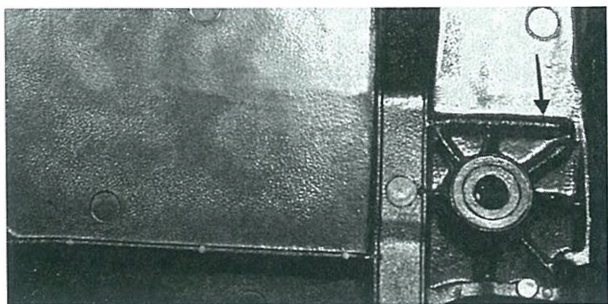


Fig. PM-22. Misrun in A413 alloy casting.

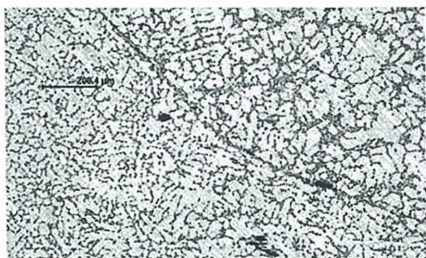


Fig. PM-23. Microstructure of a cold lap and/or shut.

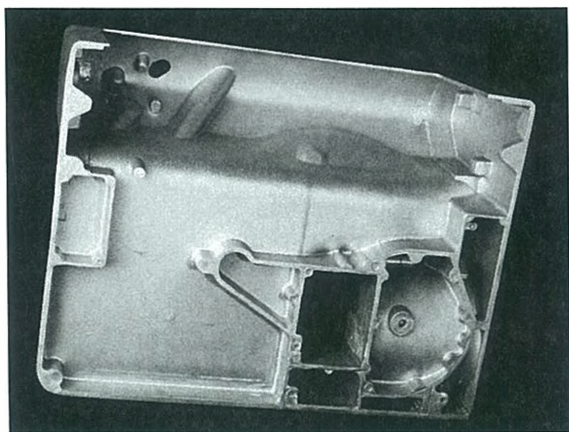


Fig. PM-24. Misrun due to entrapped air and low hydrostatic pressure during pouring.

Hot Tearing

Hot tearing is a defect which occurs in aluminum casting during the pouring and/or solidification process, before the casting becomes completely solid, and in which physical constraints restrict the casting from normal contraction. Causes of hot tearing are many—casting design, molding practices, pouring, and basic metallurgy of the alloy. The crack or tear in the casting is usually inter-dendritic with an oxidized surface because of the high temperature.

Hot tearing can be minimized by proper grain refining, casting design which minimizes sharp corners, better transitions between thick and thin sections and thermal conditions (optimal pouring temperature, die cooling pattern) which avoid hot spots.

Causes

1. Mechanical and Equipment Related

- Lack of adequate fillets
- Abrupt changes in section thickness
- Flask equipment preventing adequate casting contraction
- Rough handling, casting removal too soon after pouring

2. Core Molding Practice in Semi-Permanent Mold (SPM) Casting

- Poor core sand collapsibility
- Low hot deformation capability
- Vitrification of the sand
- Excessively rigid sand cores
- Failure to use chills or chills improperly placed

3. Metal Mold-Related

- Mold open too soon, casting damaged during extraction
- Rough mold surface
- Excessive pouring temperature
- Excessive mold temperature delaying solidification relative to normal cycle
- Poor ejector locations causing bending stresses
- Excessive cooling time prior to casting removal

4. Pouring

- Pouring temperature too low to promote core collapsibility
- Excessive pouring temperature creating hot spots in thin sections
- Inadequate flow (filling) of liquid metal in the mold cavity
- Cooling too fast

5. Metallurgical

- Alloy segregation with low melting point metal (tin, lead, zinc) concentrations in last metal to solidify
- Contaminants, tramp elements
- Large grain size
- Certain long-freezing range alloys or those with substantial volume change nearing the solidus temperature.

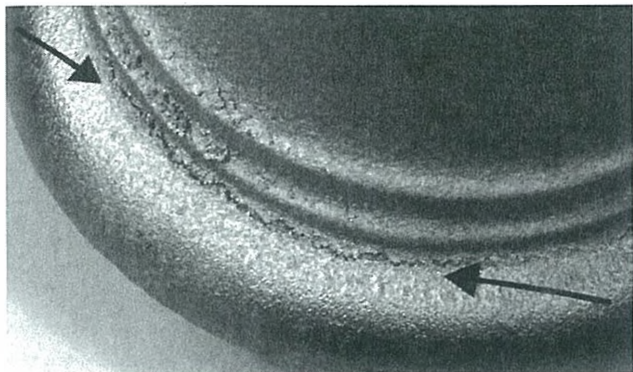


Fig. PM-25. Hot tear due to metal temperature being too hot.

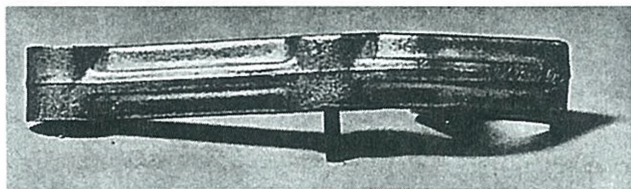
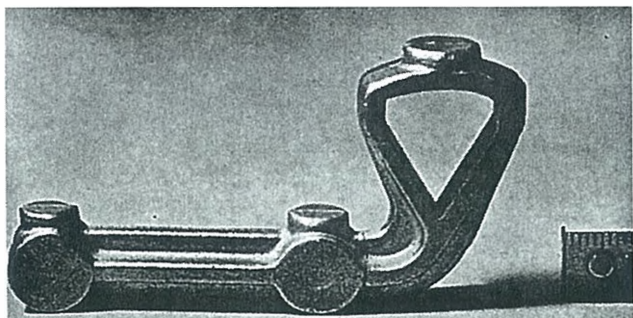


Fig. PM-26. Hot cracking and/or distortion due to premature casting removal.

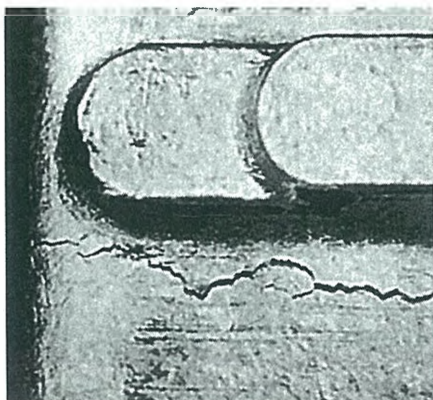


Fig. PM-27. Hot tearing, boss creates thickness difference and prohibits contraction.

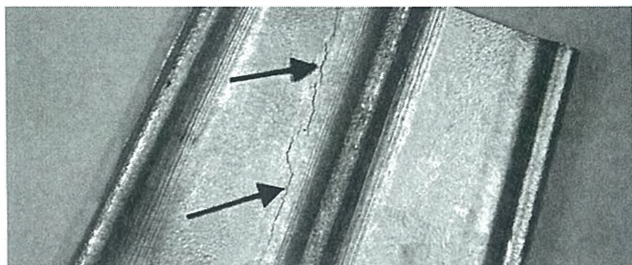


Fig. PM-28. Hot tear in A206.2 alloy casting.

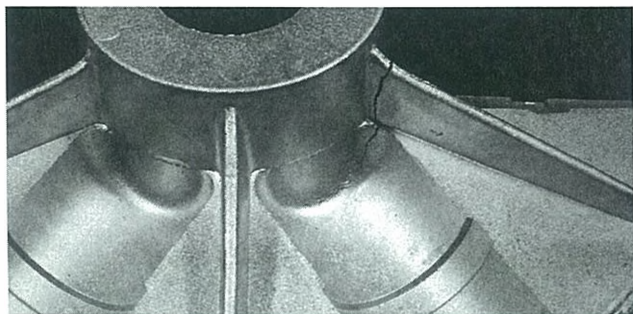


Fig. PM-29. Hot tear in 319 casting.

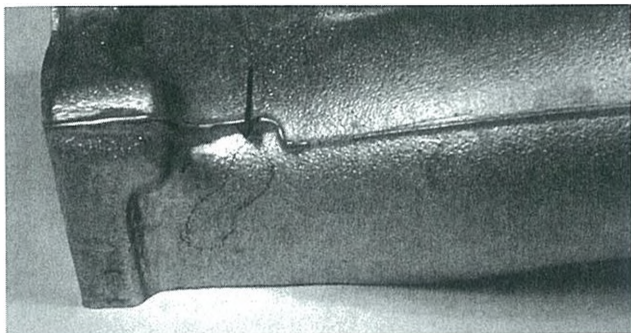


Fig. PM-30. Hot tear in 712 alloy.

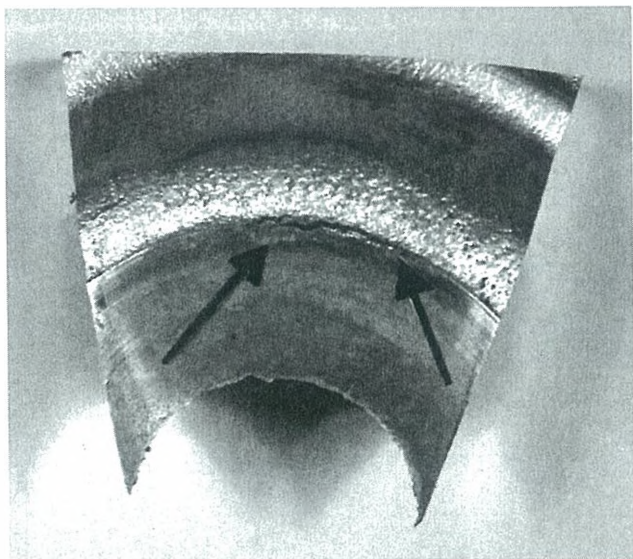


Fig. PM-31. Hot tear in A356—excessive metal temperature.

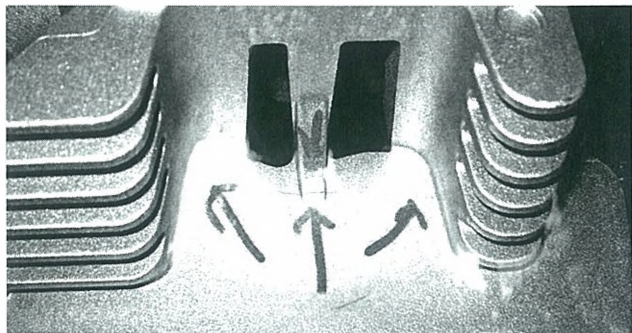


Fig. PM-32a. Crack in casting

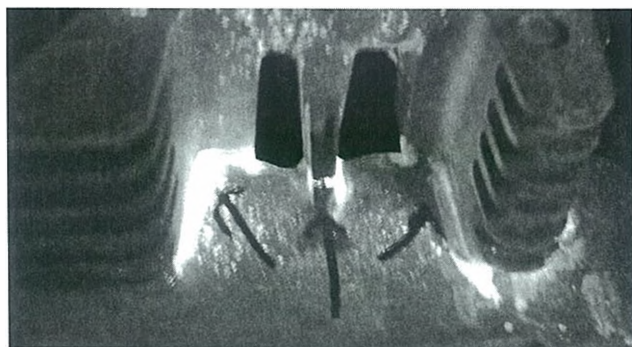


Fig. PM-32b. Crack viewed under black light.



Fig. PM-33. Photomicrograph of hot tear along grain boundary.

II. Gas Defects

Gas defects arise from the presence of gas in the liquid metal which forms porosity in the casting as the metal solidifies. The porosity may take the form of a gross cavity or visual blowhole (one or many). Gross blowholes occur as hydrogen gas evolves in concentrated fashion during the last stages of solidification. More dispersed and finer gas porosity, known as pinholes, can also be encountered. During heat treatment, blisters can be developed as pores congregate and entrapped gas expands, which can be observed afterward. Sources of the gas—hydrogen, air, or volatile organics—include gas soluble in the liquid metal, core out-gassing, entrapped air and mold and core coating out-gassing. Gas defects are detrimental to machining, surface finishing and mechanical properties of the casting when concentrated in a section subject to mechanical stress. However, certain permanent mold castings, especially those with heavy sections that are well gated and risered, can benefit from a degree of hydrogen tolerance. The evolution during solidification counteracts shrink and pipe (see section III on Shrinkage Defects).

Hydrogen-caused gas defects are minimized by proper degassing of the melt prior to pouring.

Causes

1. Mechanical and Equipment Related

- Insufficient core permeability in semi-permanent molding
- Lack of adequate venting of mold cavity

2. SPM Core Practice Related

- Under-cured cores
- Excessive binder
- Inadequate venting
- Wet core paste
- Absorbed moisture during storage
- Chill or sealing materials not dried
- Excessive gas-producing material in core sand or wash

3. Gating, Riser, Pouring Related

- Wet pouring basins and/or sprues with excessive mold coating
- Sprue and/or gating system inadequately sized
- Entrainment of air due to turbulence in the sprue and runner system
- Turbulent/and/or interrupted pouring
- Short pours unable to fill mold cavity
- Pouring rate too fast and/or too slow
- High humidity condensation on cold mold sprue and gating system

4. Metallurgical Related

- Melt too gassy or inadequately degassed and/or de-oxidized
- Excessive melt and/or pouring temperatures
- Metallic impurities in the melt with affinity for hydrogen



Fig. PM-34. Dispersed surface and/or sub-surface porosity caused by hydrogen.



Fig. PM-35. Surface porosity due to excessive hydrogen in the melt.

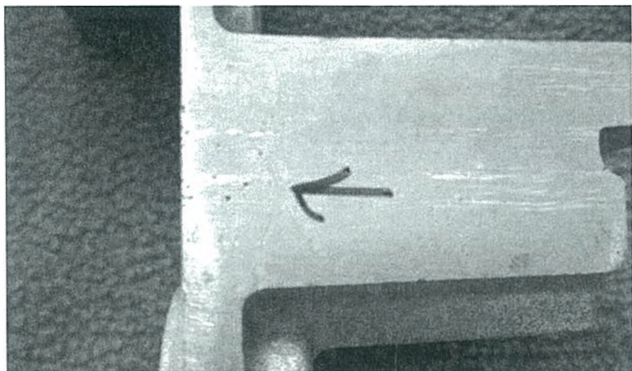


Fig. PM-36. Casting with internal gas.

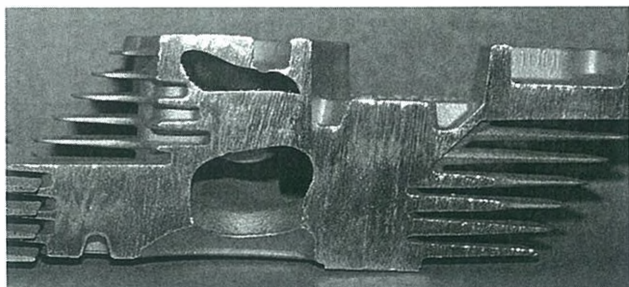


Fig. PM-37. Blowholes caused by hydrogen concentration in a heavy section during latter stages of casting solidification.

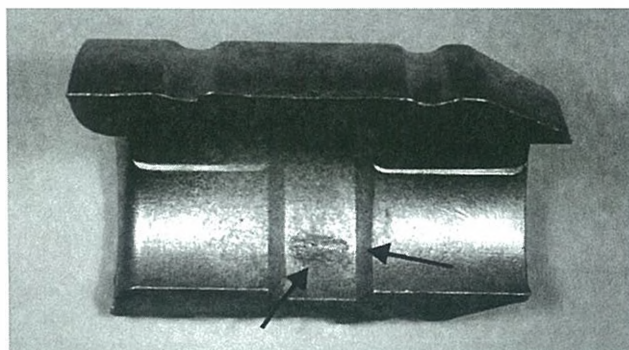


Fig. PM-38. Blow in 319 during final solidification.

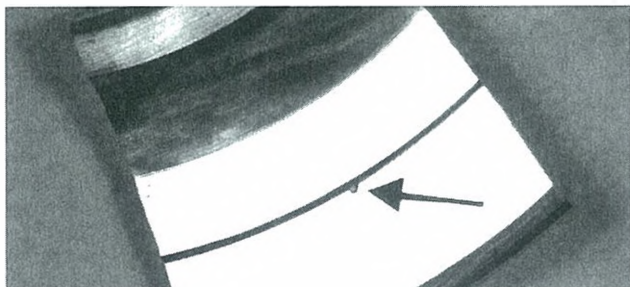


Fig. PM-39. Entrapped gas.

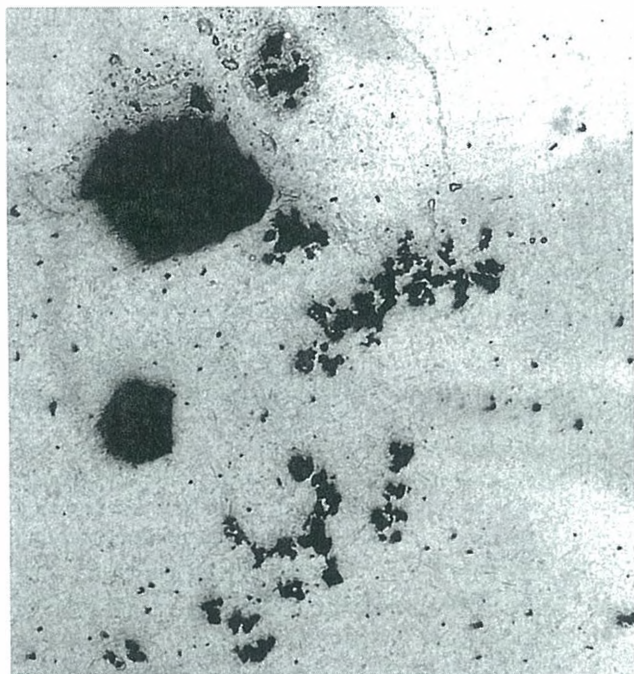


Fig. PM-40. Gross entrapped gas.

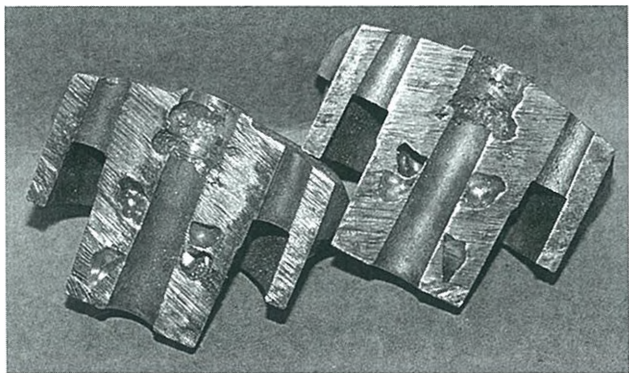


Fig. PM-41. Gas blow in heavy section off core.

III. Shrinkage Defects

As a casting solidifies, a contraction from liquid to solid state occurs. The casting design geometry should allow for generalized controlled overall shrinkage. However, there is often undesirable localized shrinkage. A shrinkage depression or cavity in a casting may form and it may or may not be related to the presence of gas. Shrinkage as a depression on the surface is considered to be macro shrinkage, while in the interior of a casting the shrinkage is dispersed and is termed micro shrinkage. Macro shrinkage is usually associated with or surrounded by a cast interdendritic structure, often spongy, related to inadequate mold filling. Micro shrinkage takes the form of pinholes or small cavities within the interdendritic network. Micro shrinkage often occurs in the last section of the casting to solidify. It may be related to gas content evolving during solidification and to inadequate feeding.

Shrinkage defects are best remedied by adequate risering, control of pouring conditions, die temperature, and degassing of the melt prior to pouring.

Causes

1. Mechanical and Equipment, Design Related

- Abrupt changes in casting section thickness
- Inadequate fillets
- Insufficient feeding (especially for heavy sections)

2. SPM Core Molding Practice Related

- Low compressive strength
- High hot deformation
- Core shift
- Weak cores
- Lack of fillets
- Soft ramming

3. Gating, Riser, Pouring Related

- Inadequate riser volume
- Insufficient riser placement
- Lack of necessary chills
- Need for exothermic riser compounds or sleeves on risers
- Pouring too hot or too cold

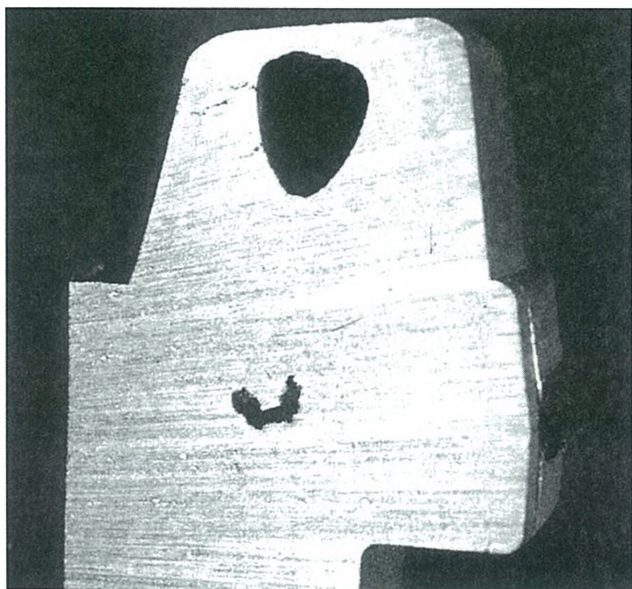


Fig. PM-42. Shrinkage porosity in heavy section.

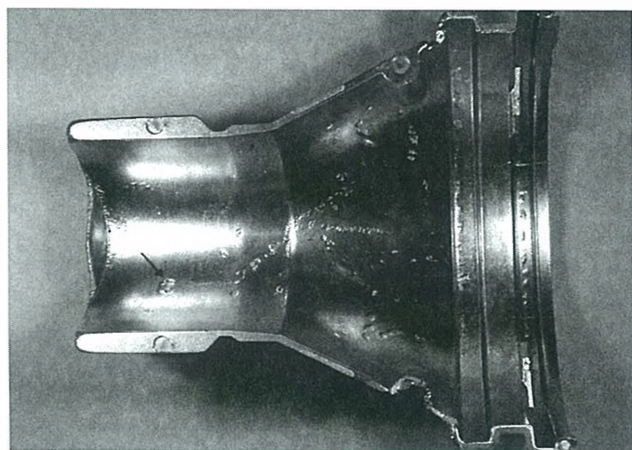


Fig. PM-43. Shrinkage due to inadequate feeding.

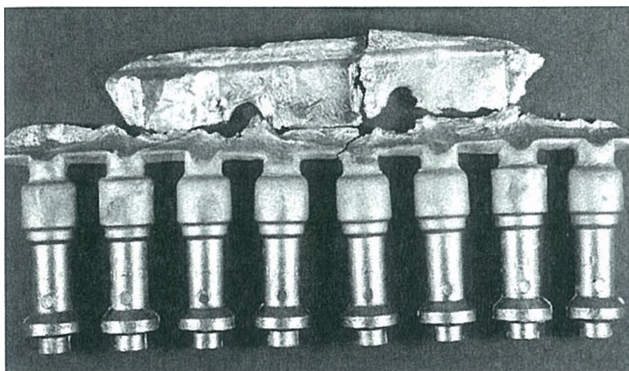


Fig. PM-44. Shrinkage due to inadequate amount of metal (short pour).



Fig. PM-45. Shrinkage in center due to poor casting design (heavy outer band).

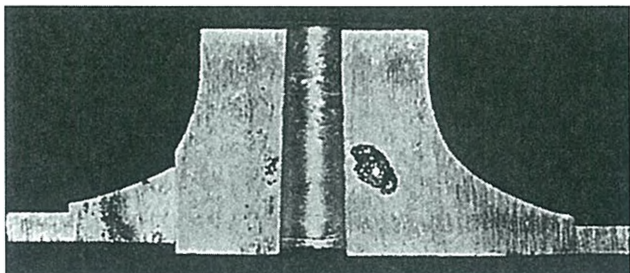


Fig. PM-46. Internal shrinkage due to excessive metal thickness.



Fig. PM-47. Shrinkage due to insufficient riser volume.

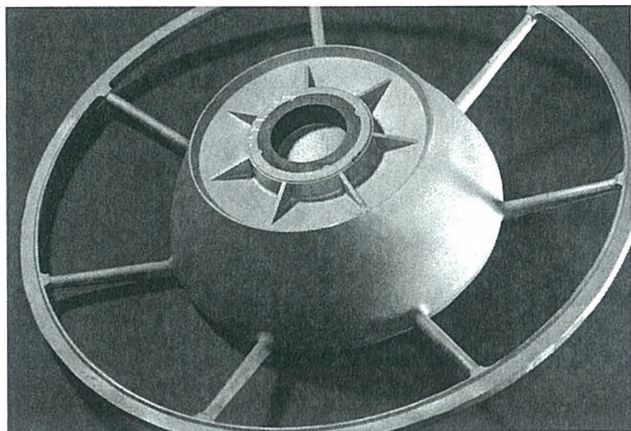


Fig. PM-48. Shrinkage due to poor casting design (thin section feeding thick section).



Fig. PM-49. Surface shrink due to insufficient metal volume or low pour temperature.

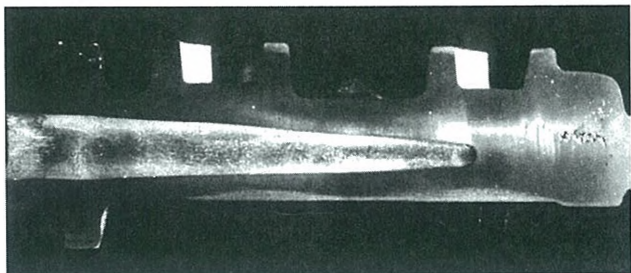


Fig. PM-50. Shrinkage in brake cylinder 356 casting due to too little gas.

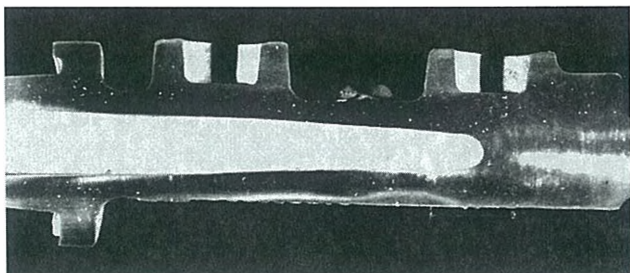


Fig. PM-51. 356 brake cylinder casting with too much gas.

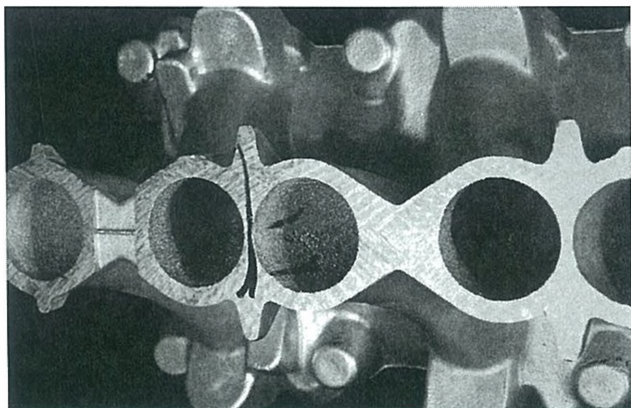


Fig. PM-52. Shrink in 356 cylinder head.



Fig. PM-53. Gross micro shrinkage.

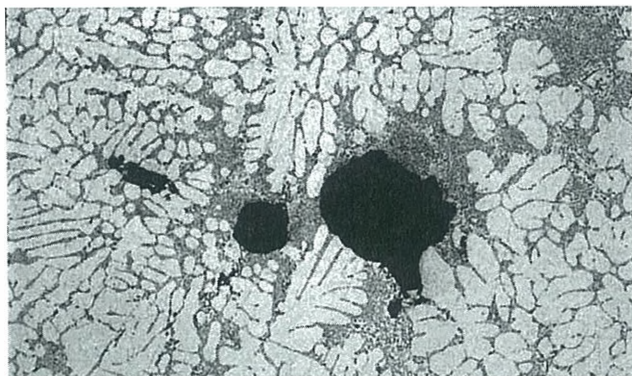


Fig. PM-54. Micro shrinkage view in the casting microstructure.

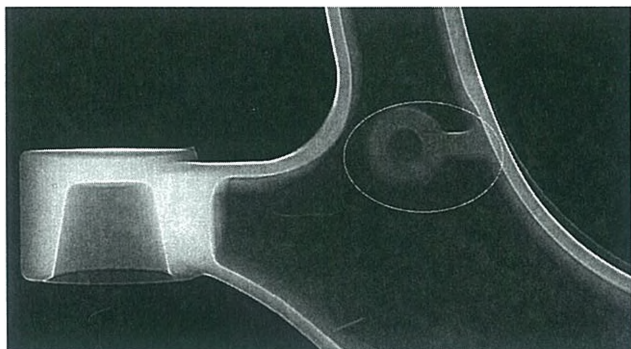


Fig. PM-55. X-ray view of shrinkage in boss.

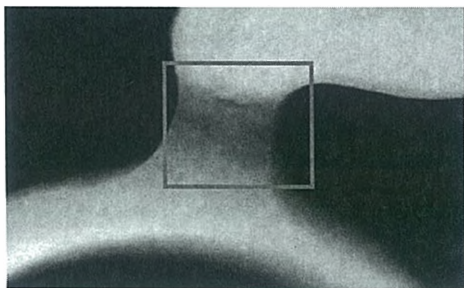


Fig. PM-56. X-ray blow-up of shrinkage zone.

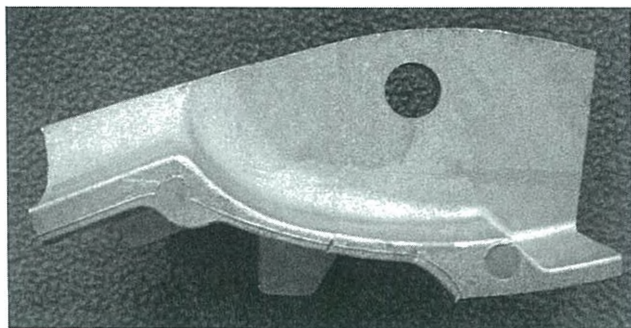


Fig. PM-57. Shrinkage and rough flat surface; caused by low temperature and irregular mold coating.

IV. Inclusion Defects

Inclusion defects occur due to the existence of insoluble particulate material trapped within the casting during solidification. Inclusions arise from the melting process; from contaminants; from fluxes and other melt treatment product debris; from breakdown of furnace and ladle refractories; from breakdown of core materials and coatings during pouring and from turbulent pouring. Inclusions may be oxides, intermetallic compounds or dross. Machining, surface finishing operations and mechanical properties are usually compromised by the presence of inclusions.

Inclusion defects are minimized and/or eliminated by best practices in melting and pouring and by the application of filters in certain instances in the pouring sprue.

As discussed in the sand casting section, the pouring of the casting and filling of the mold cavity will often result in the generation of an internal inclusion defect, an oxide fold or bifilm which forms during solidification, as oxygen at the flowing metal/air interface and oxides from the melt are always present

Causes

1. Mechanical and Equipment Related

- Casting design factors that contribute to metal flow problems in molds will increase tendency for inclusions to form
- Inadequate venting

2. SPM Core Molding Practice Related

- Inadequately mulled sand
- Sand grain size too irregular
- Inadequate molding yield low strength and core material breakdown during pouring
- Weak cores
- Excessive and/or improperly cured mold and core wash coatings

3. Gating, Riser, Pouring Related

- Gating systems which create turbulent flow
- Turbulent pouring
- Dirty ladles
- Inadequate dross separation from the melt prior to pouring
- Weak ladle or furnace refractories which spall during pouring
- Intermittent pouring
- Excessive pouring temperature

4. Melt and Metallurgical Related

- Tramp element impurities in excess of solubility limit, forming inter-metallic inclusions
- Charge mix with excessive fines/oxides
- Flux inclusions
- Melting furnace/ladle refractory erosion carried over during transfers to casting furnace
- Excessive melt temperature generating oxide formation and hydrogen absorption
- Core material debris in returns carried over to pouring

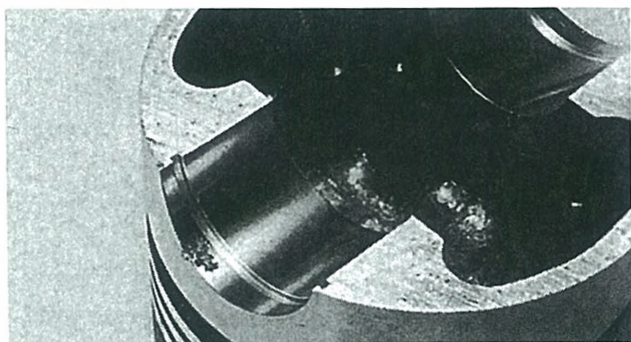


Fig. PM-58. Flux inclusion carryover from inadequate skimming after melt fluxing.

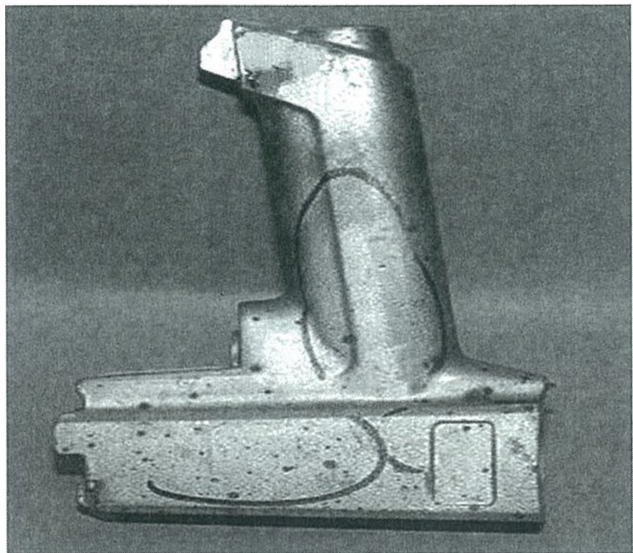


Fig. PM-59. Oxides and dross carried over from top of melt in dirty furnace.



Fig. PM-60. Microstructure showing inter-granular new (from pouring) and old (melting and/or prolonged holding) oxide skins.

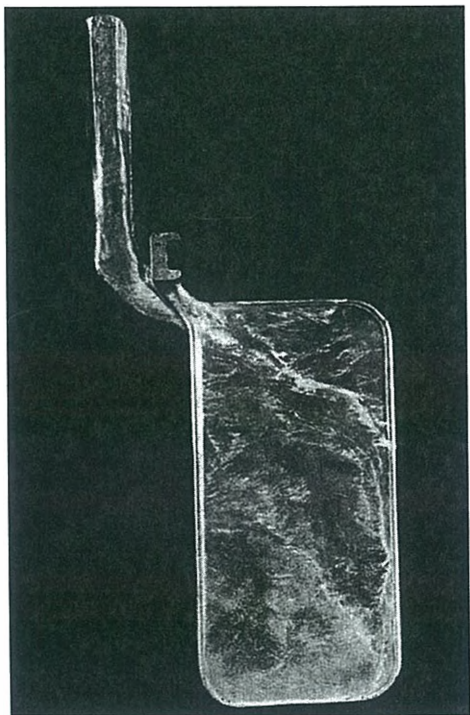


Fig. PM-61. Oxides in flat casting from poor gating (turbulent flow).

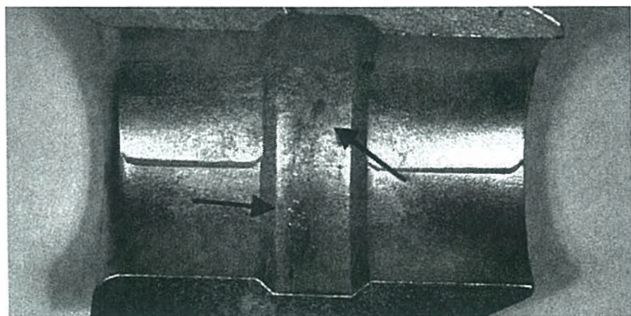


Fig. PM-62. Oxide inclusion in 319 alloy.

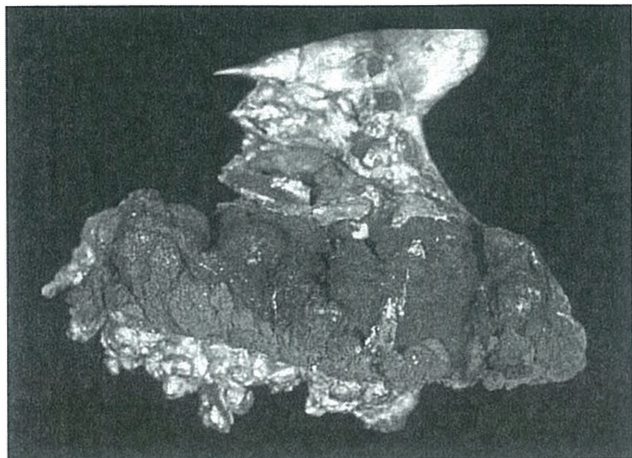


Fig. PM-63. Corundum from furnace refractory.

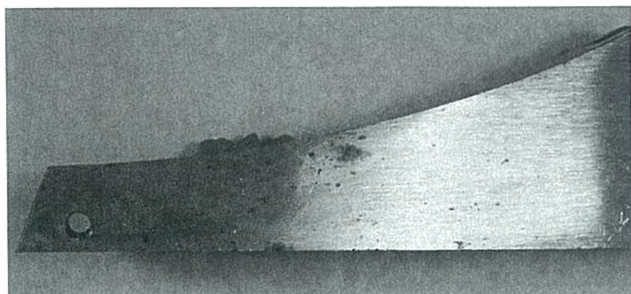


Fig. PM-64. Hard spot inclusions (oxides, intermetallics).

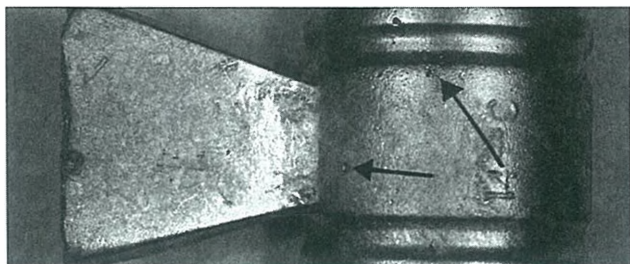


Fig. PM-65. Flux inclusion in 319, inadequate skimming after flux treatment.

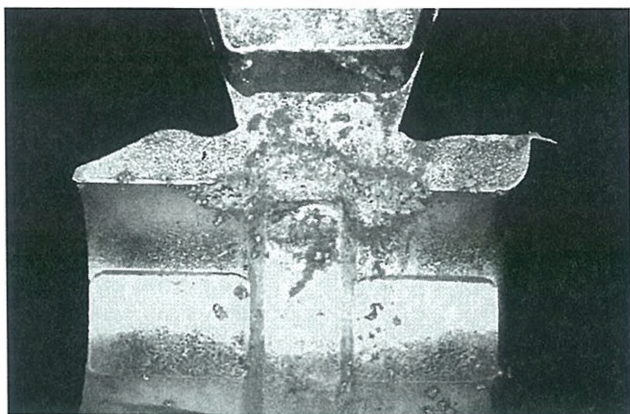


Fig. PM-66. Flux inclusion in 356 casting.

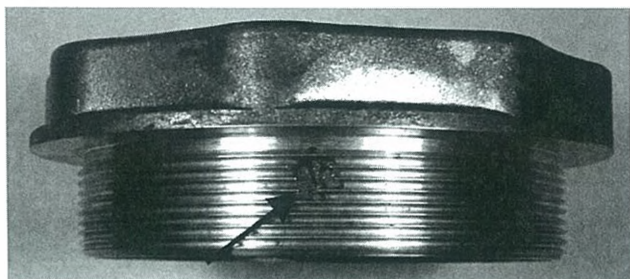


Fig. PM-67. Oxide inclusion, entrapped air in 356.

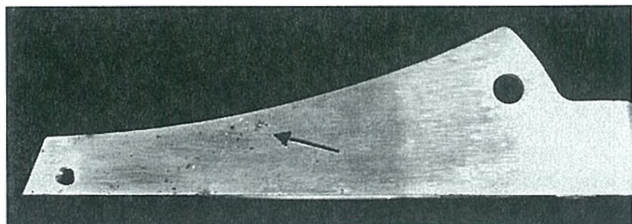


Fig. PM-68. Hard spot inclusion.

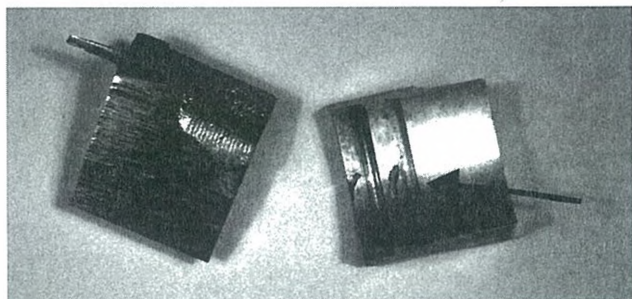


Fig. PM-69. Inclusion from mold coating breakdown.

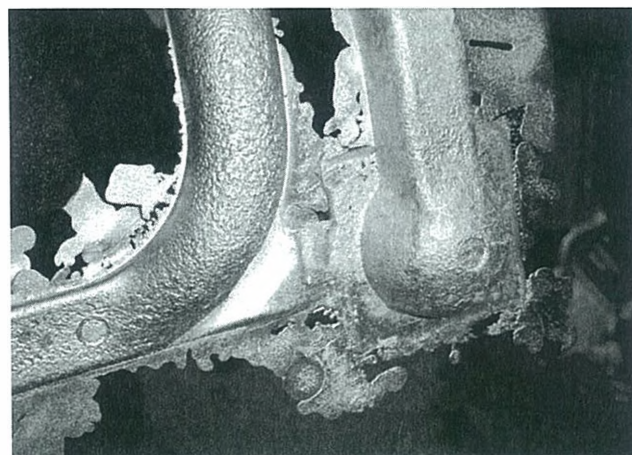


Fig. PM-70. Oxides by-pass filter, excessive flashing.

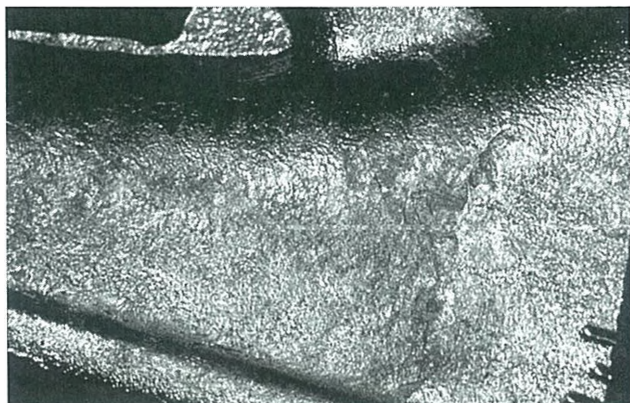


Fig. PM-71. Oxide films folded into the casting during solidification.

V. Other

As there are many aluminum alloy castings which require heat treatment, certain defects can occur when the heat treatment temperatures are exceeded. When the solution treatment temperature is inadvertently higher than the solidus temperature, eutectic melting occurs into the two phase region. The defect is manifested by an exudation, or small bead-like 'cauliflower' appearance on the surface, usually called 'sweating'. This can be exacerbated by low temperature alloy element segregation.

With castings of complex geometry, or abrupt changes between thin and thick sections, the quenching process during heat treatment can also produce cracking, ie 'quench cracking' if the severity of the quench medium is too great.

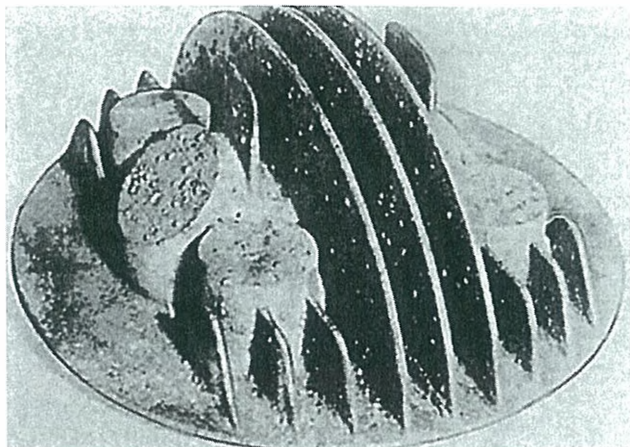


Fig. PM-72. Aluminum alloy cylinder head exhibiting 'sweating'.

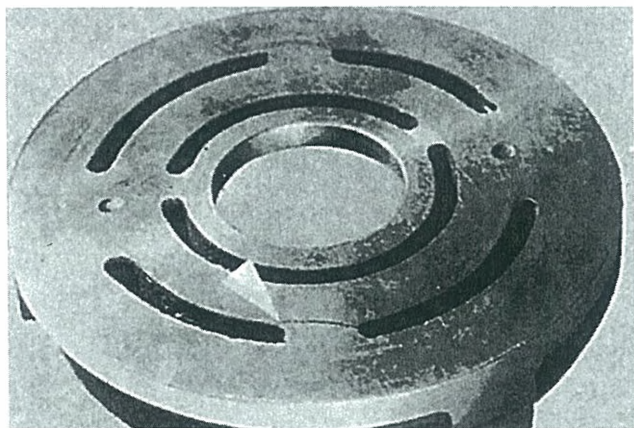


Fig. PM-73. Quench crack in aluminum alloy casting during heat treatment.

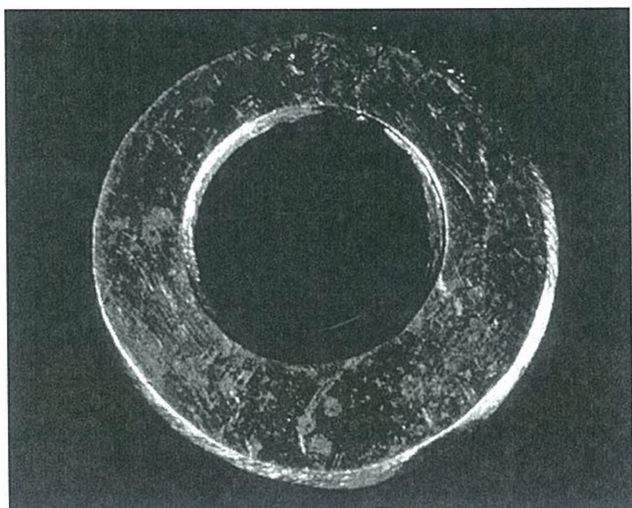


Fig. PM-74. Incipient melting during solution treatment; eutectic exudation

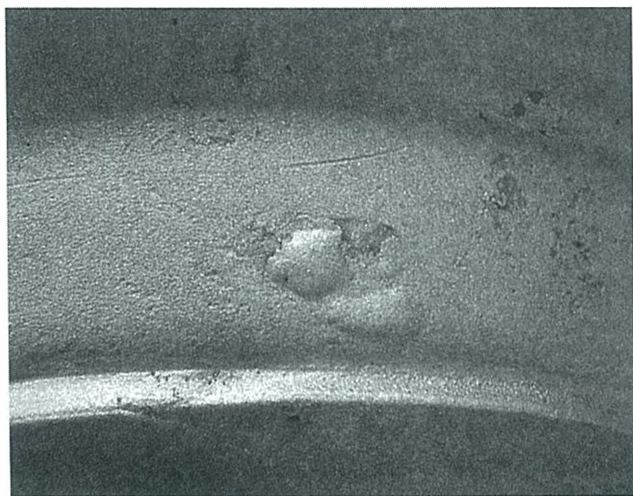


Fig. PM-75. Blister evolving during heat treatment due to entrapped hydrogen.

CHAPTER 3

High Pressure Diecasting

The high pressure diecasting process is another metal mold process. There are specific casting defects which relate to how the process is operated. There are other defects, metallurgical in nature, which relate very similarly to those encountered in other processes. Such defects may or may not be visible on the casting surface itself, but become manifested in less-than-optimum mechanical properties such as tensile strength, elongation, and fatigue.

While high pressure is the constant in the filling of liquid metal into the mold cavity (i.e. die) in this process, it should be noted that many of the surface defects that are encountered are visually similar to those in other metal-mold casting processes. These include all "die" casting processes whether high pressure, low pressure or permanent mold.

The interested reader is further directed to a publication, *Die Casting Defects* published by the North American Diecasting Association (NADCA), for a more comprehensive presentation on defect cause and prevention.

In this chapter, the defects are categorized as either process-related or metallurgical-related, although there is often an interrelationship between the process parameter and metal defects.

I. Diecasting—Process Related (DCP)

Defects—Cold Laps, Cold Shuts, Laminations, Flow Marks, Knit Lines, Scratches, Sinks, Die Soldering, Hot Tearing, Shrinkage Porosity, Misruns, Lubricant Stain

Cold lap, cold shut, lamination, knit lines, and flow mark defects are all surface defects. They may be seen visually on the casting or with the aid of a low power magnification and/or dyglo penetrant techniques. Such defects relate to problems with metal temperature being too low, inadequate gating, incorrect die injection parameters, or combinations of all these factors. Divergent metal streams converge, do not mix properly, and solidify prematurely, which results in such surface discontinuities. The severity of such defects and their effect on casting properties and performance can vary. Because of these defects, there is cause for a careful review of the operating parameters.

Sinks on the casting surface reflect general shrinkage due to inadequate feeding and/or excessive metal temperature. Shrinkage porosity occurs due to inadequate gating, feeding or excessive temperature. Misruns occur when there is inadequate feed metal or lack of venting. This results in the casting detail not filling out, and not completing the desired design features.

Die soldering, which is an obvious visual surface defect, is also related to metal composition (iron content), die and die coating condition. Aluminum has a low solubility for iron, but normally 0.80% or more is required to mitigate die soldering tendencies. Heat checking of the die metal and 'stickers' exacerbate die soldering. Too much or too little die spray and die temperature variation also increase the tendency for die soldering.

Lubricant stains on the surface often relate to the excessive use of lubricant or breakdown in lubricant delivery systems. Poor die surface can also result in casting surface defects.

Hot cracking or hot tearing can result from constraints in the casting design during solidification; mishandling during ejection or trimming operations; or alloy inhomogeneity, resulting in weak sections.

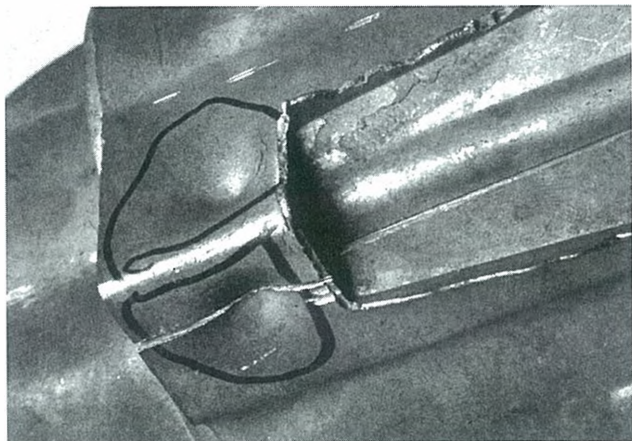


Fig. DCP-1. Sink due to excessive solidification contraction, lack of sufficient feed metal.



Fig. DCP-2. Cold shut.



Fig. DCP-3. Light alloy cold shut



Fig. DCP-4. Cold flow.



Fig. DCP-5. Cold lap, knit line.



Fig. DCP-6. Severe cold shut and /or lap on 380 alloy.

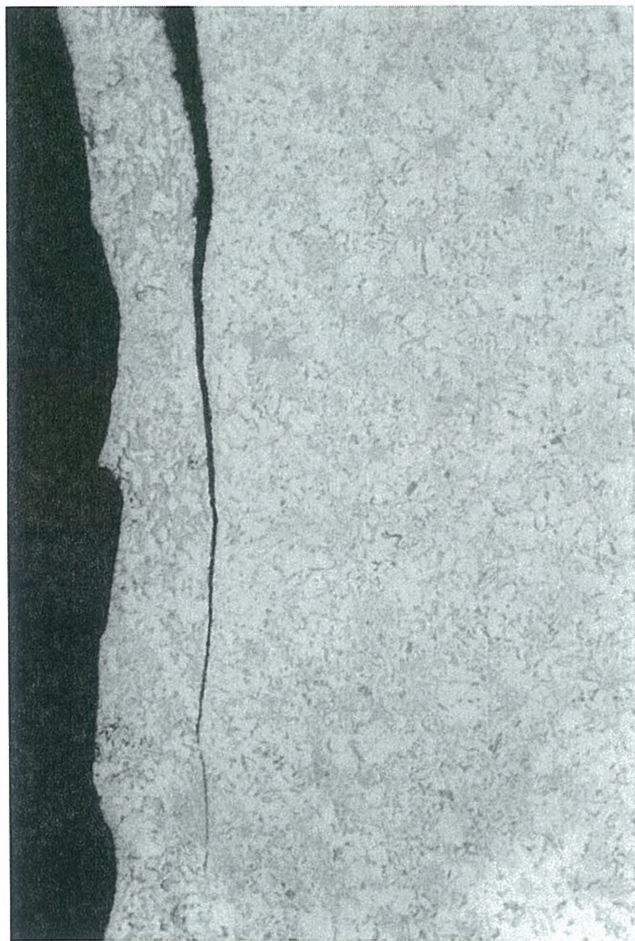


Fig. DCP-7. Severe cold lap, disconnected lamination on 380 alloy.

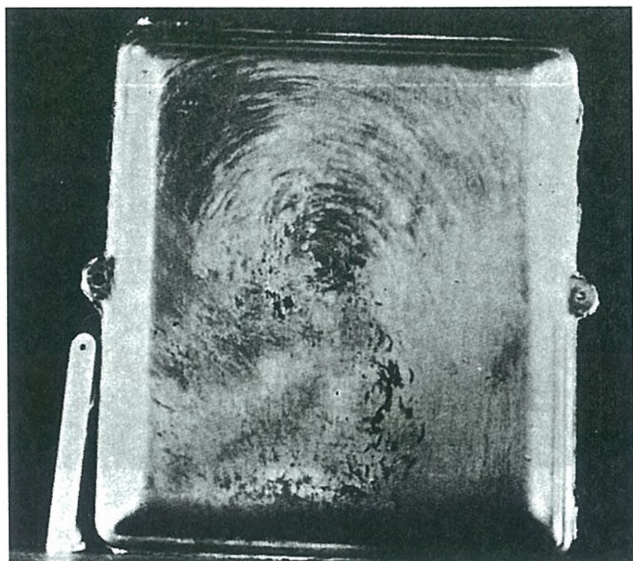


Fig. DCP-8. Flow marks tracing metal streams from gate area.

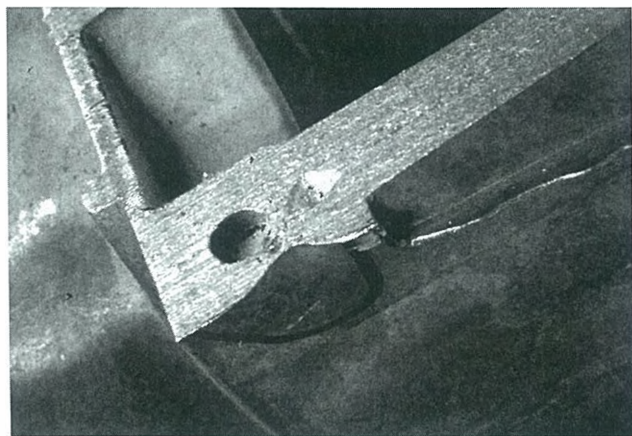


Fig. DCP-9. Shrink below surface sink.

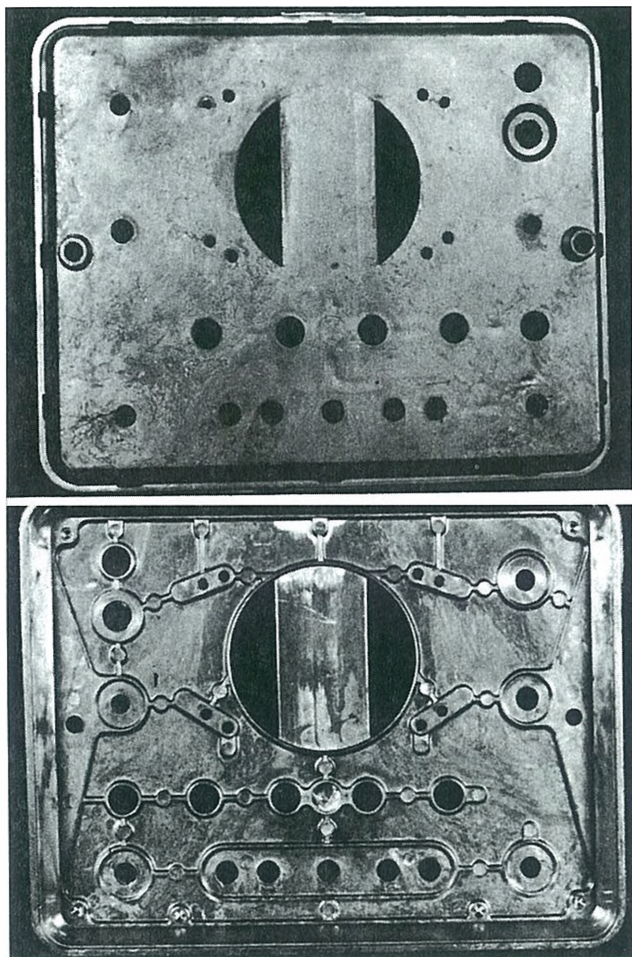


Fig. DCP-10. Sink marks due to excessive solidification contraction (two views).

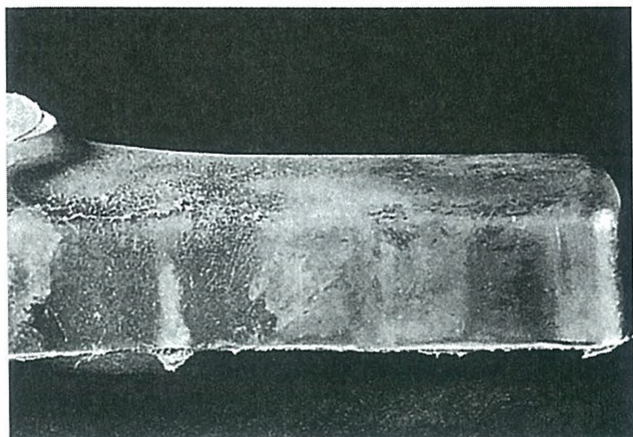
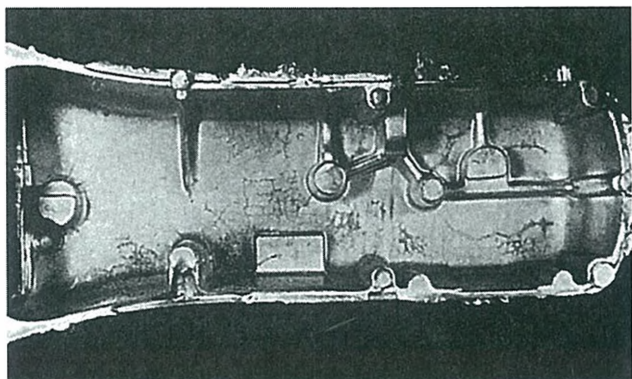


Fig. DCP-11. Heat checked die-causing fins, sticking and scabbed casting surface (two views).

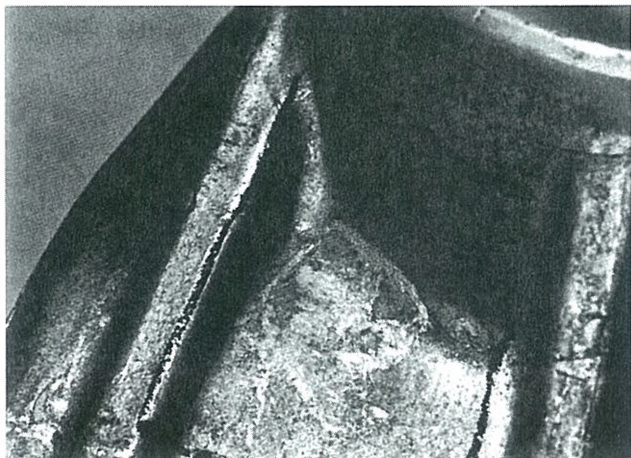


Fig. DCP-12. Die soldering.

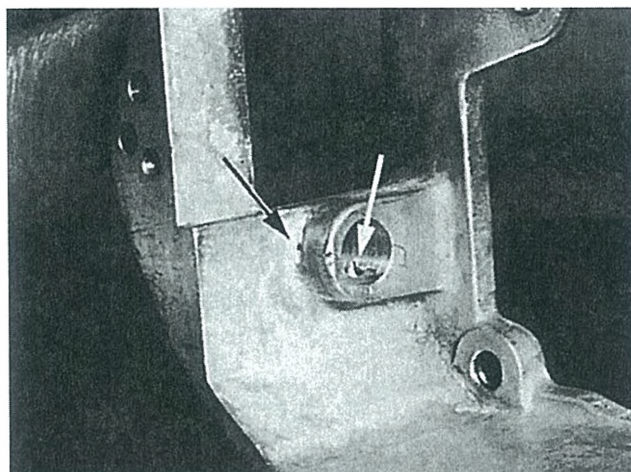


Fig. DCP-13. Internal shrinkage is due to heavy section. Changing die injection parameters, gating or part design may alleviate this defect in this casting.

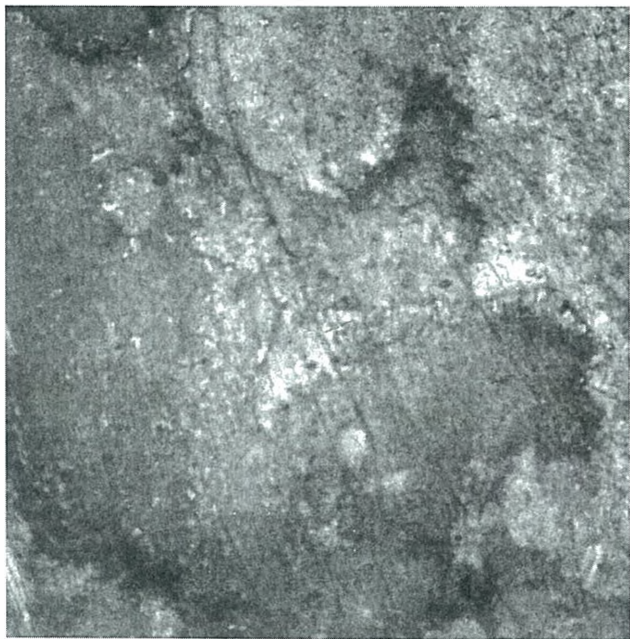


Fig. DCP-14. Die lube stain.

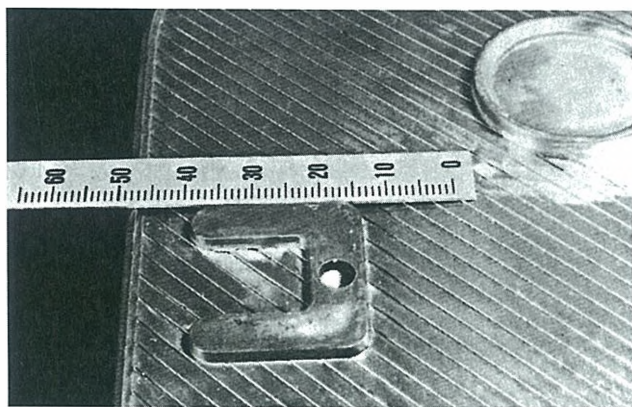


Fig. DCP-15. Hot tearing due to mold cavity constraint.



Fig. DCP-16. Misrun.

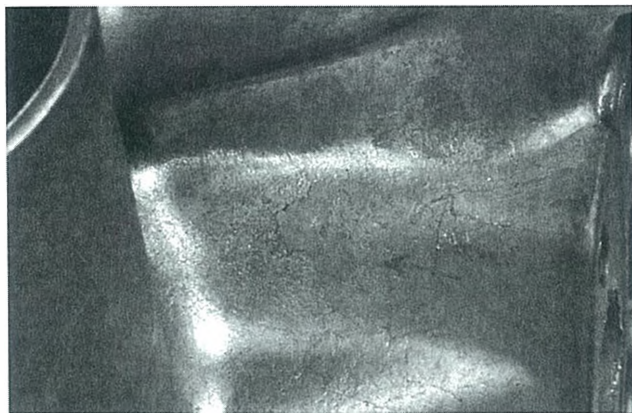


Fig. DCP-17. Die soldering.



Fig. DCP-18. Extreme cold shut with oxide skin is due to lack of best feeding conditions.

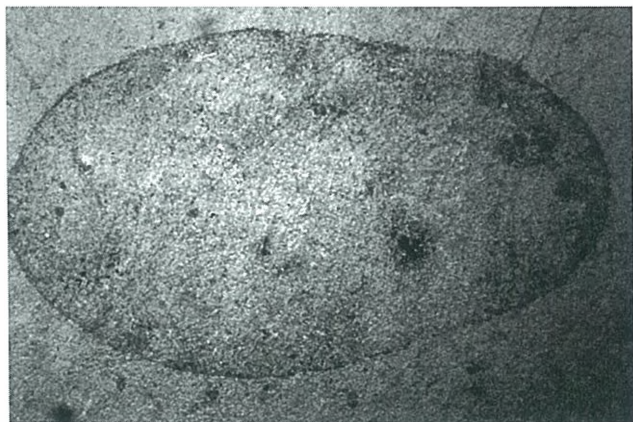


Fig. DCP-19. "Shotting"—atomized metal droplet freezes before main metal flow solidifies.

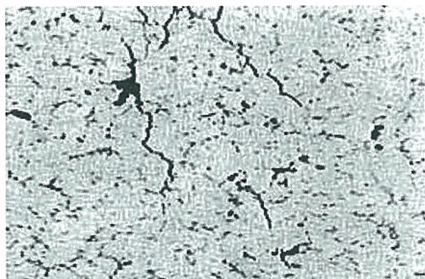


Fig. DCP-20. Hot micro-tear.

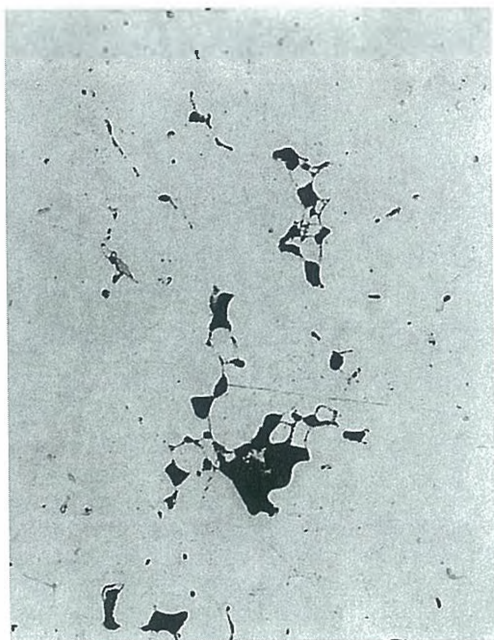


Fig. DCP-21. Gross microshrinkage.



Fig. DCP-22. Rough surface due to scale buildup on die surface.

II. Diecasting—Metallurgical-Related (DCM)

Defects—Gas Porosity (Also Includes Air Entrapment which is Process-Related), Inclusions, (Oxides, Corundum, Refractory, Flux), Blisters, Leakers

Metallurgically related defects often arise from failure to adequately address the natural phenomena, which occurs in aluminum alloy melting process—control of hydrogen and oxidation products (i.e. inclusions). The latter originate with refractory erosion; inherent oxides retained from the melt stock and returns; and inability to completely separate oxide skim and dross from the melt prior to transfer to the casting furnace, which directly feeds the diecasting press. Corundum is an extremely hard form of aluminum oxide, which can form at high temperatures over a long time in the melting furnace. Furnace cleaning often loosens corundum, which can become entrained in the melt during transfers; eventually ending up in the diecasting holding furnace; and subsequently into the diecasting itself as the ladle delivers

metal into the diecasting press. Additionally, intermetallic inclusion formation can occur indigenously within the melt as a function of composition (iron, manganese, chromium content) and temperature. This 'metallurgical sludge' is an insidious form of inclusion, which manifests itself in reduced mechanical properties, machinability, and surface finishing imperfections. Oxide inclusions create the same difficulties.

Gas porosity can originate from entrapped hydrogen, despite the rapid solidification process in diecasting, although this defect is not often encountered unless the melt processing has been very inadequate. More often gas porosity in a diecasting is a result of entrapped air, inadequate venting, or lubricant decomposition.

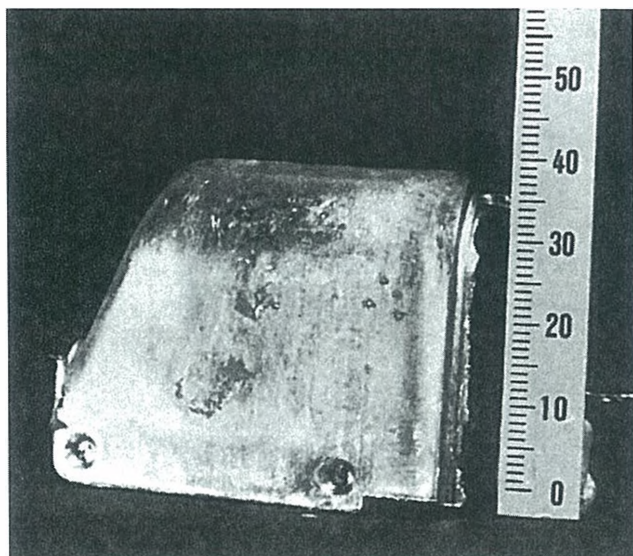


Fig. DCM-1. Surface blowhole possibly arising from air entrainment, excessive mold and/or metal temperature or lubricant decomposition.

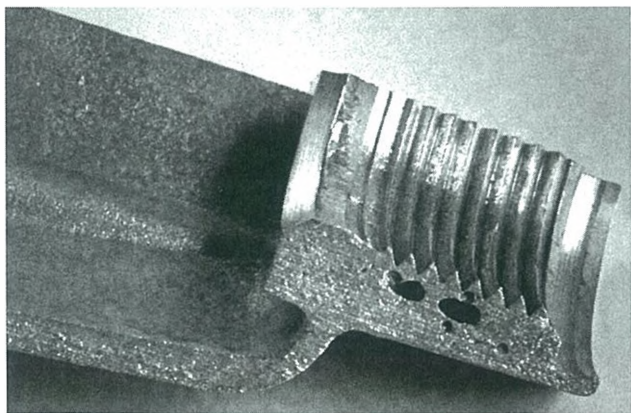


Fig. DCM-2a. Gas porosity caused by entrapped air or possibly hydrogen.

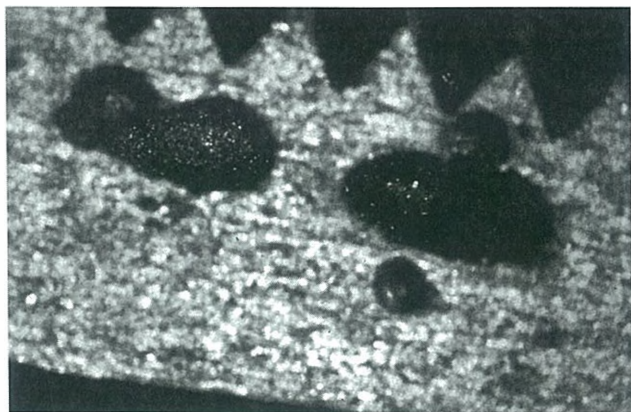


Fig. DCM-2b. Gas porosity caused by entrapped air or possibly hydrogen (high magnification).

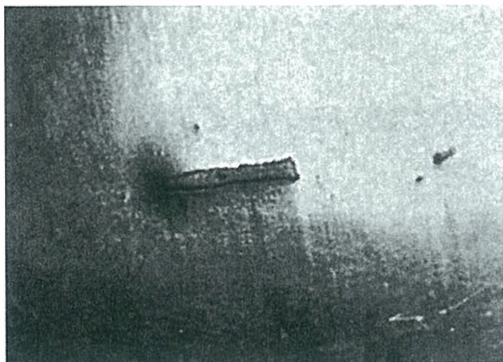


Fig. DCM-3. Hard spot (either oxide or intermetallic inclusion) observed on polished surface.

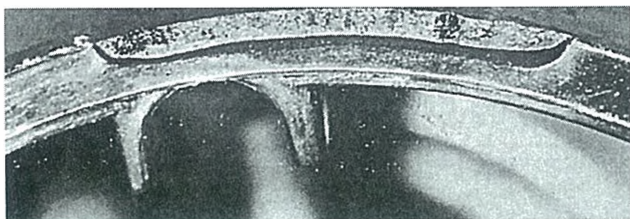


Fig. DCM-4. Metallurgical sludge (Fe-Mn-Cr compound) inclusion at the gate area.

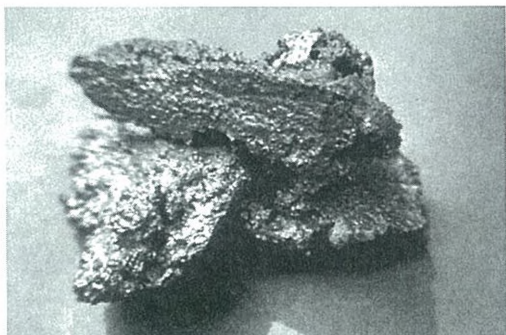


Fig. DCM-5. Furnace sludge.



Fig. DCM-6. Microstructure of "metallurgical sludge"—polyhedral shape.

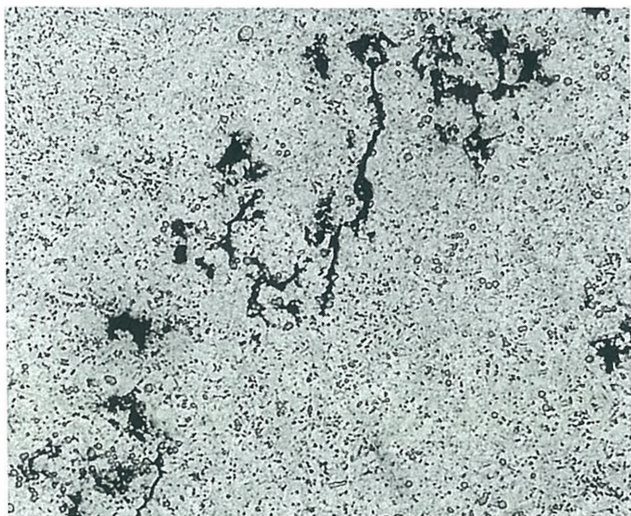


Fig. DCM-7. Oxide inclusion in 380 alloy.



Fig. DCM-8. Oxides in 380 alloy.

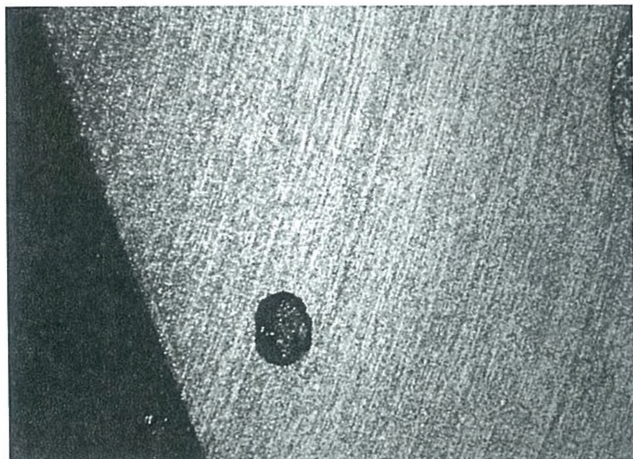


Fig. DCM-9. Aluminum oxide hard spot.



Fig. DCM-10. Flux inclusion.

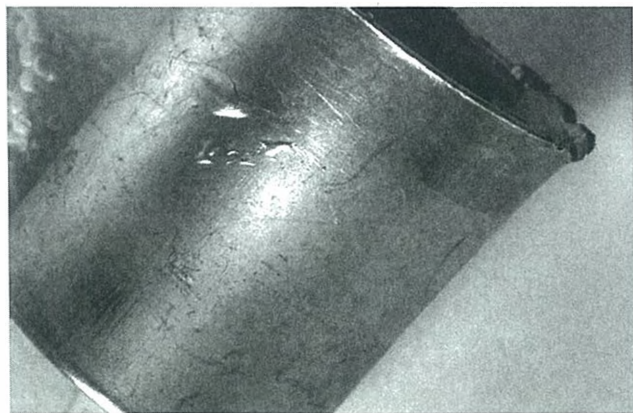


Fig. DCM-11. Blister—entrapped gas or hydrogen, which opens up during thermal processing of the casting.

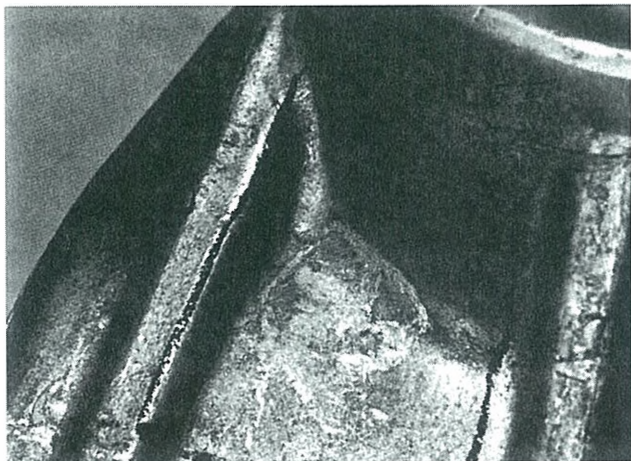


Fig. DCM-12. Shiny black silicon carbide inclusion.

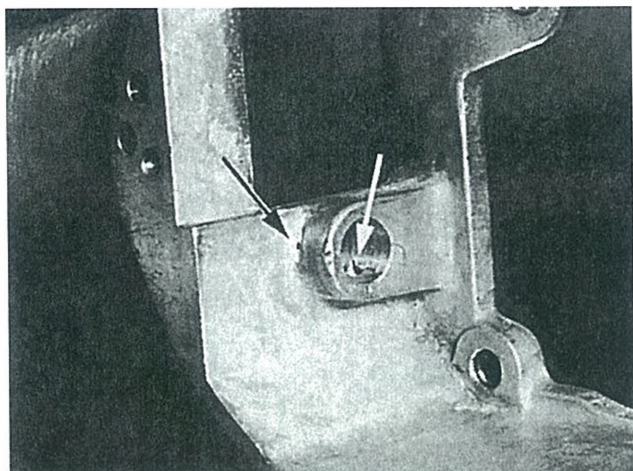


Fig. DCM-13. Gross dross inclusion on casting surface.

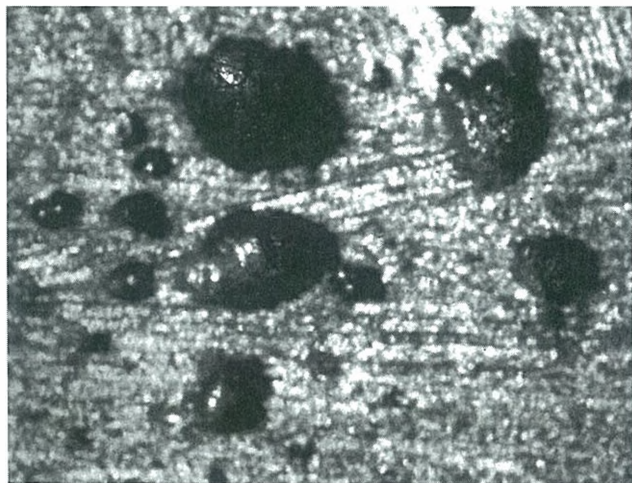


Fig. DCM-14. Entrapped gas—from lack of venting, lubricant decomposition, hydrogen, or combinations.

Low Pressure Casting

Defects can occur during the low pressure casting process which are quite similar to those encountered in other metal mold processes, especially those that are metallurgical in nature—shrinkage, microporosity and macroporosity, inclusions, hot tearing, etc.

The advantages of the low pressure casting process include reduced porosity and controlled directional solidification. Shrinkage and macroporosity are solidification related and with the pressure applied are often minimized by the low pressure casting process. However, an excessive amount of hydrogen present in the melt prior to casting may also contribute to such defects despite the better solidification conditions. Sufficient degassing of the melt is necessary to control both shrinkage and porosity defects that may be due to hydrogen. Many engineered structural castings will require degassing in the process procedures to meet quality requirements.

Oxide films, gross oxide inclusions, and entrapped air due to turbulent pouring can result in a defective casting. Many wheels are produced by the low pressure process and cosmetic or surface defects must be avoided. Blistering, which may arise during the heat treatment process, is caused by subsurface entrapped hydrogen porosity. 'Comet tails' during surface finishing processes arise from the presence of hard-particle oxide or intermetallic inclusions at the cast surface.

Control of inclusions during the melting and pouring processes, adherence to careful refractory maintenance practices. Careful flux injection and degassing processes employed in melt treatment also aid in partial removal of inclusions by flotation. The judicious use of filters will aid in minimization of inclusion defects.

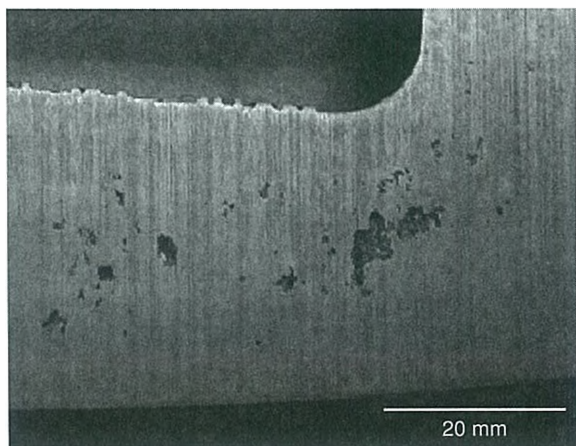


Fig. LP-1. Macroporosity clusters in a hub and spoke section of a cast wheel.

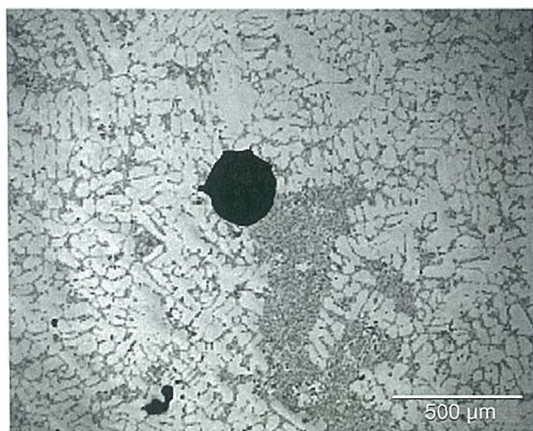


Fig. LP-2. Example of hydrogen microporosity in A356 wheel.

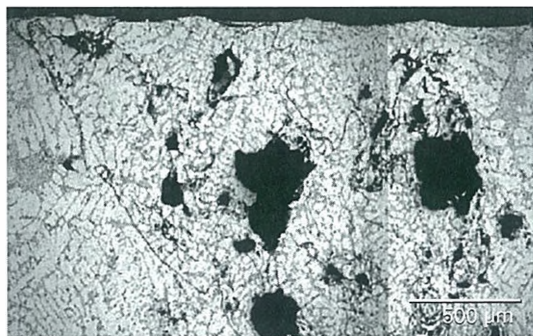


Fig. LP-3. Oxide films and entrapped air associated with a wheel rim leak defect. Oxide films become entrained from inadequate melt practice and/or excessive turbulence in pouring into the low pressure furnace or during the mold filling process itself.

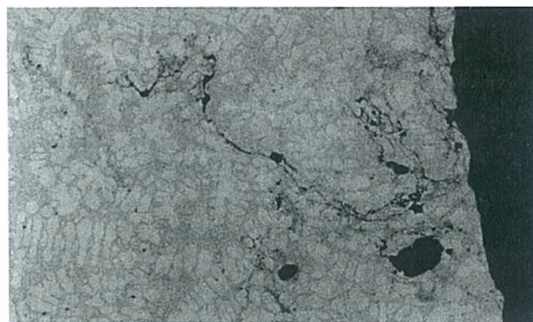


Fig. LP-4. Oxide inclusion in low pressure cast wheel produced without a ceramic filter in the stalk (mold fill) tube.

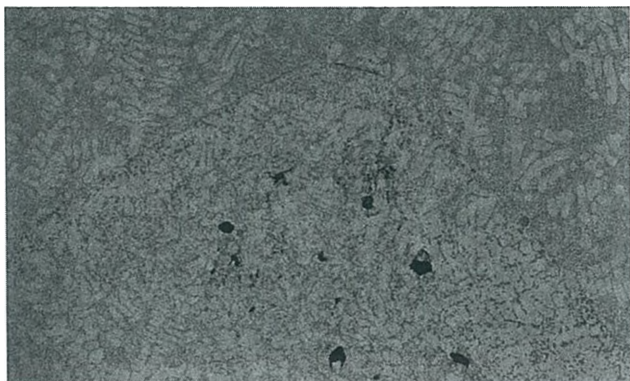


Fig. LP-5. A cold shut arising from a gravity permanent mold wheel casting.

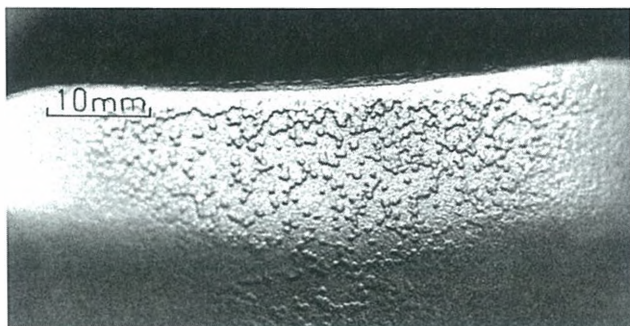


Fig. LP-6. Surface blistering possibly due to entrapped air rupturing the solidifying eutectic structure.

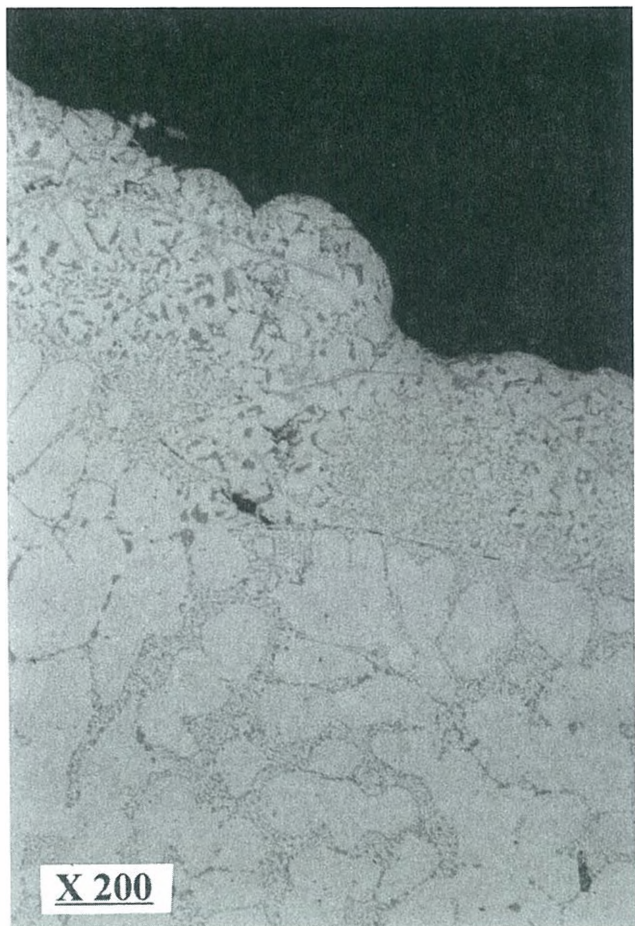


Fig. LP-7. Surface blistering possibly due to entrapped air rupturing the solidifying eutectic structure (cross section microstructure at higher magnification).

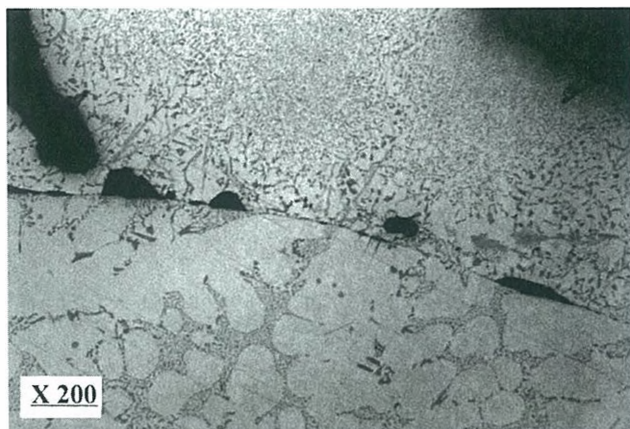


Fig. LP-8. Voids and cold shut at junction between surface blister and the casting substrate

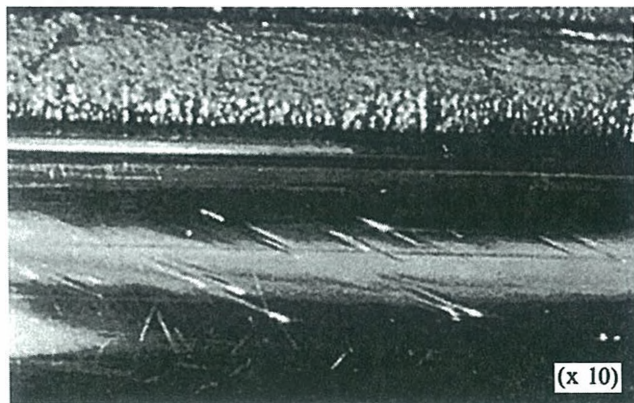


Fig. LP-9. "Comet-tail" during polishing caused by intermetallic hard spot.

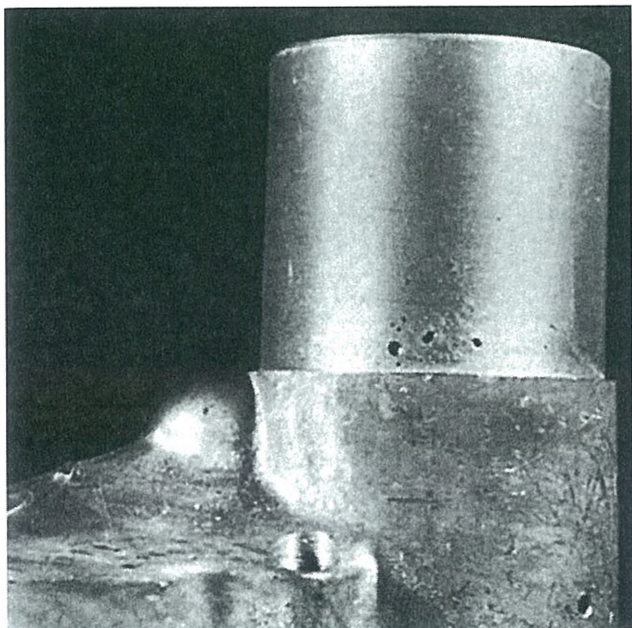


Fig. LP-10. *Subsurface blowholes on low pressure casting exposed during machining.*

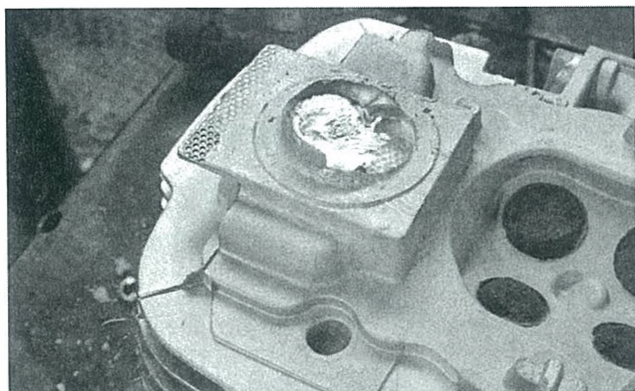


Fig. LP-11. *Incomplete fill; surface dross oxides blocked feed to casting.*

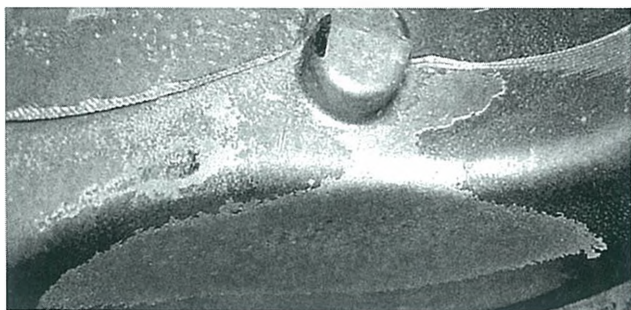


Fig. LP-12. Laps, irregular surface due to double injection metal flows.

Investment Casting

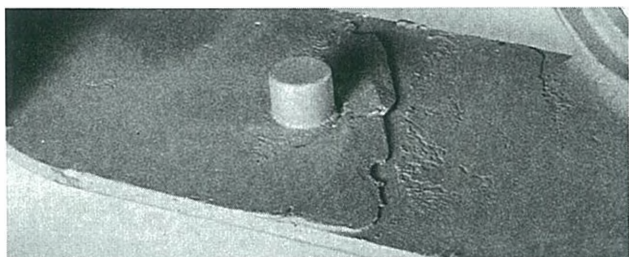
Investment casting is a production method whose application has increased in producing near net shape aluminum articles. This process is historically known as the 'lost wax' process, in which a wax pattern is 'invested' in a ceramic shell. The ceramic shell is built up layer upon layer with a series of ceramic slurries and refractory material coats. It is then fired and the wax pattern is removed by burning and drain-out just prior to pouring the metal into the heated ceramic mold.

Investment casting defects come from three main sources—the shell, pouring and metal-related defects. Shell and pouring-caused defects are on the casting surface and therefore observed visually after the solidified casting has been de-molded. Metallurgically related defects—mainly inclusions and gas-caused porosity—are often observed only microstructurally or with testing and casting usage. These defects are very similar to those metallurgical defects encountered in other casting processes.

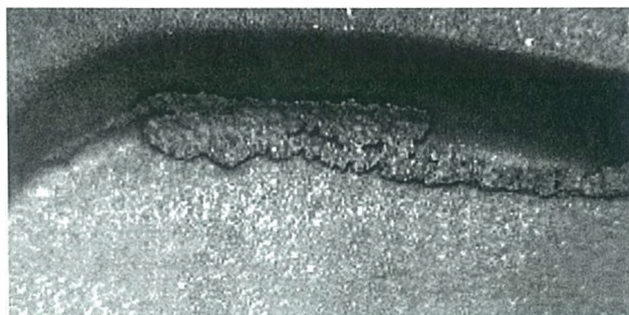
I. Shell and Pouring Defects

Primary Coat Buckle

Primary coat buckle is caused by cracking of the primary coat, which allows the back-up slurry to penetrate between the wax pattern and the primary coat. The slurry viscosity may be incorrect and causes inconsistent thickness, draining that is too quick, or drying that is too irregular. Delamination or localized breakaway of coating can cause a 'scabbing' appearance on the finished casting. Air bubbles are caused by drying conditions, inconsistent slurry viscosity and by mishandling during dipping of the pattern assembly.



Fig, IC-1. Primary coat buckle.



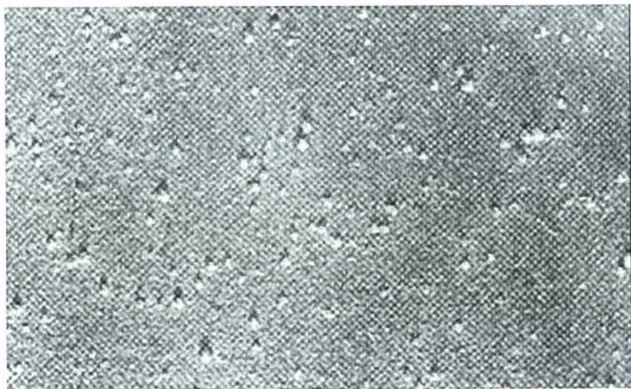
Fig, IC-2. Prime coat delamination.



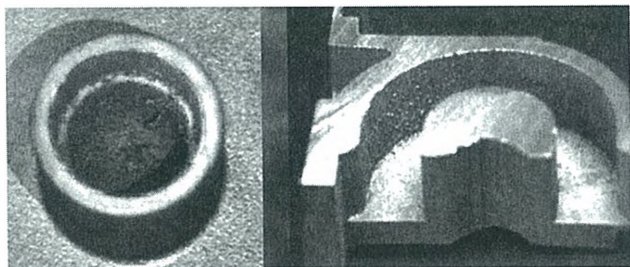
Fig, IC-3. Air bubble in prime coat.

Stucco Penetration

Stucco penetration occurs when the slurry coat does not coat the pattern with consistency; is too thin or the stucco grain size is irregular, causing penetration of the primary coat as the stucco is applied.



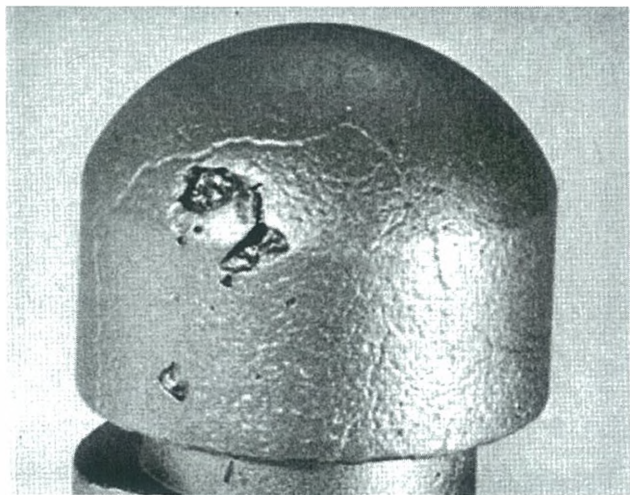
Fig, IC-4. Stucco penetration.



Fig, IC-5. Stucco penetration.

Inclusions

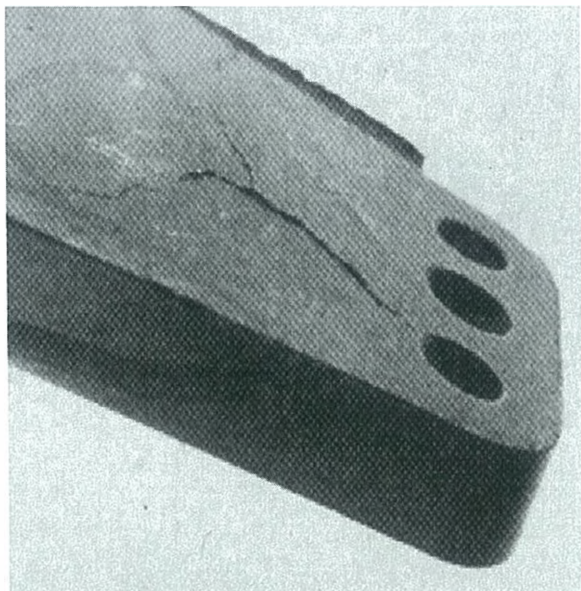
Inclusions that are present on the cast surface arise from problems with the mold buildup. Inclusions that occur within the casting itself are the result of metal quality and melt processing. Sources, causes, and prevention of these internal inclusions are very similar to those in other aluminum metal casting processes.



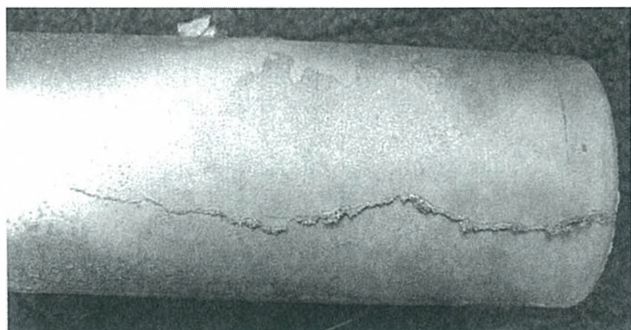
Fig, IC-6. Mold-induced inclusions, potentially related to shell cracking prior to pouring.

Completed Shell Defects

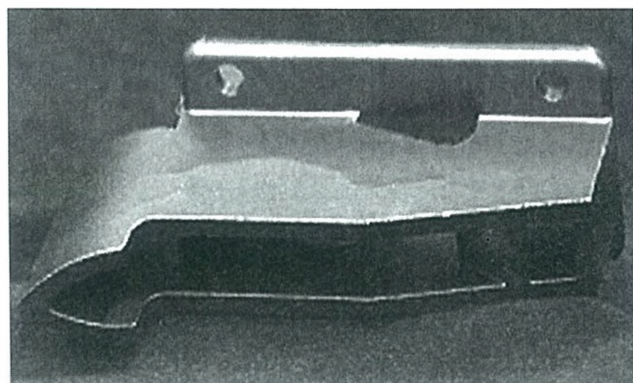
There are a number of shell-related defects which arise from the finished mold and which may be observed before pouring, or as the metal is poured and solidifies, including mold cracking due to shell weakness and/or excessive drying. In addition, bulging, expansion during dewaxing-burnout or during pouring can occur if the shell is too weak or too thin. Irregular slurry application and drying can result in spalling during burnout or pouring. As the metal is poured into the mold assembly, flashing and finning may occur as the metal penetrates, and further cracking and spalling of the mold material can occur when the mold cannot withstand the thermal stress or metallostatic pressure of the liquid metal as it comes into contact with the mold.



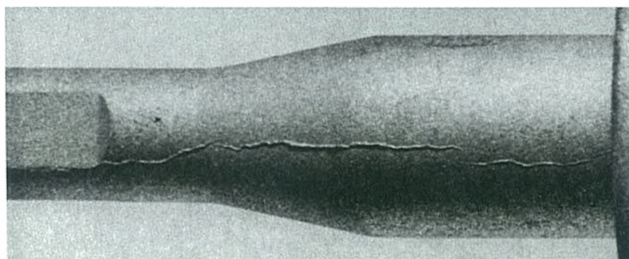
Fig, IC-8. Bulging and cracking.



Fig, IC-9. Mold cracking.



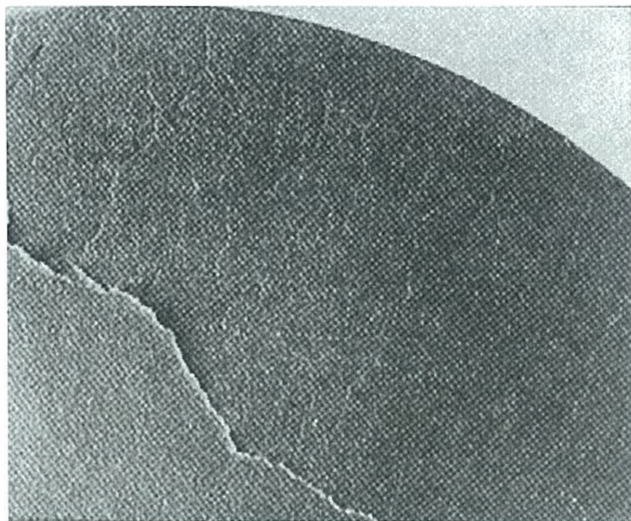
Fig, IC-10. Pre-coat lift.



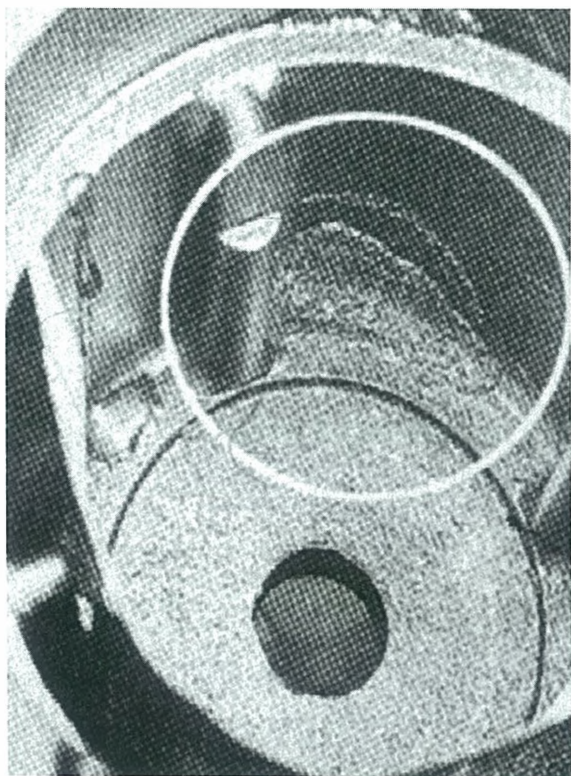
Fig, IC-11. Mold cracking, finning.



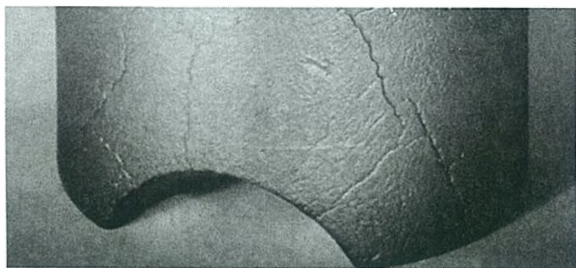
Fig, IC-12. Shell cracking; flashing.



Fig, IC-13. Drying cracks.



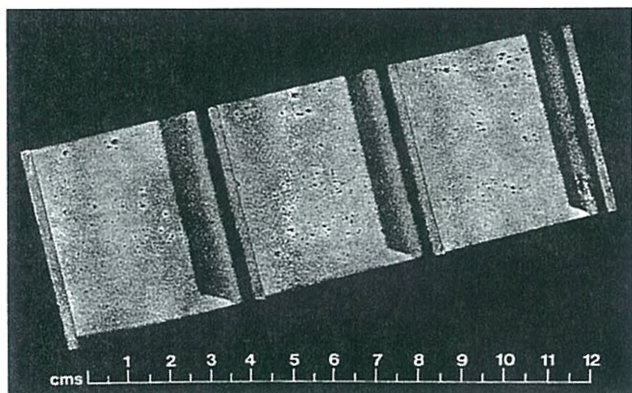
Fig, IC-14. Spalling.



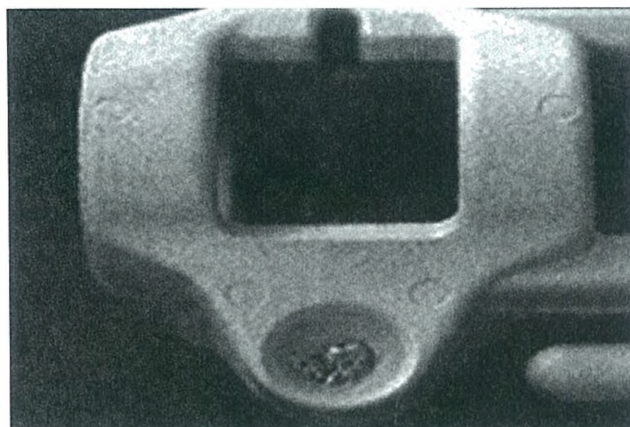
Fig, IC-15. Rat tailing.

II. Metal-Related Defects

Metal-related defects are similar to those encountered in other casting processes with regard to their appearance, cause, and cure. These will include metal penetration, mis-runs and cold shuts, hot tears, gas defects, shrinkage and porosity, and inclusions.



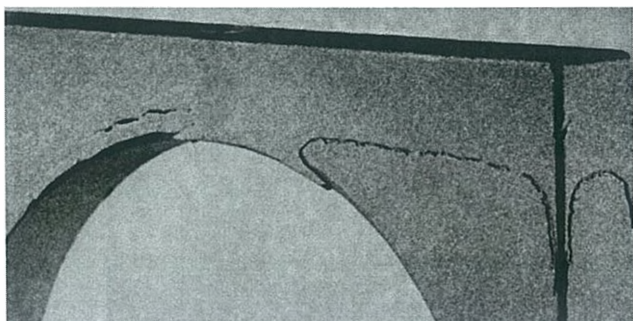
Fig, IC-16. Metal penetration.



Fig, IC-17. Metal penetration.

Misruns and Cold Shuts

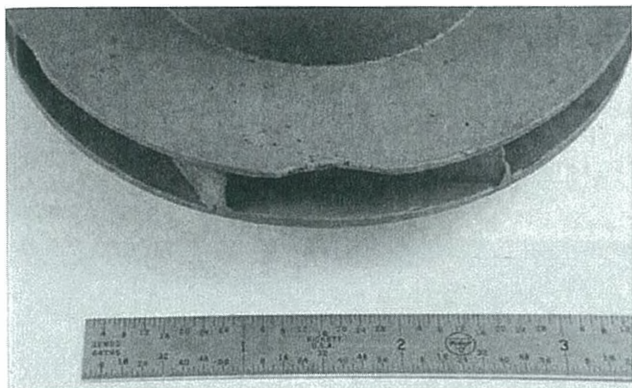
Misruns and cold shuts are caused by a pouring temperature that is too low, pouring too slow or interrupted pouring and multiple-gate flows with separate filling rates.



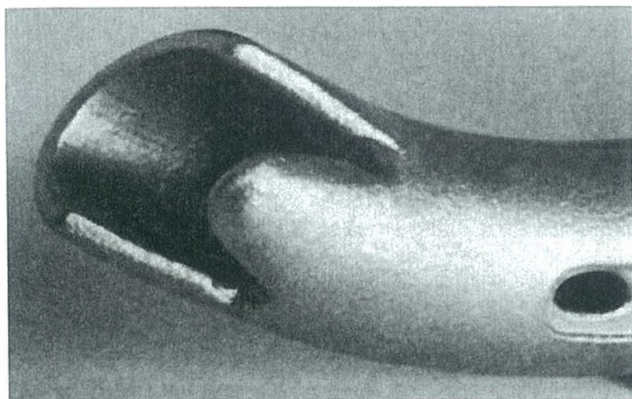
Fig, IC-18. Cold shut.



Fig, IC-19. Cold shut.



Fig, IC-20. Non-fill; misrun.



Fig, IC-21. Non-fill; misrun.

Hot Tears

Hot tears are caused by insufficient fillet radii; inadequate gating; shell constraints during solidification contraction; excessive temperature; poor cooling conditions and mishandling of the mold before final solidification.

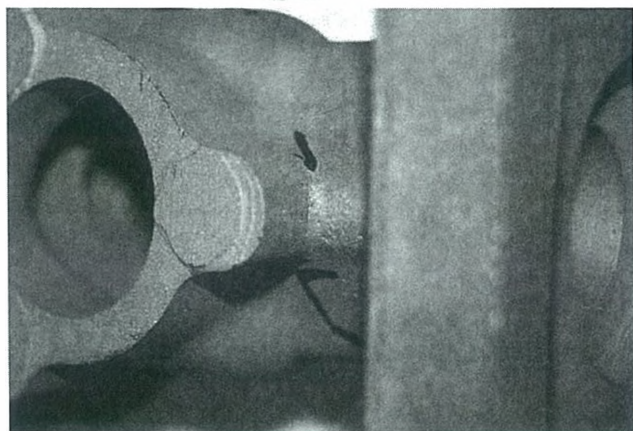


Fig. IC-22. Hot tear.

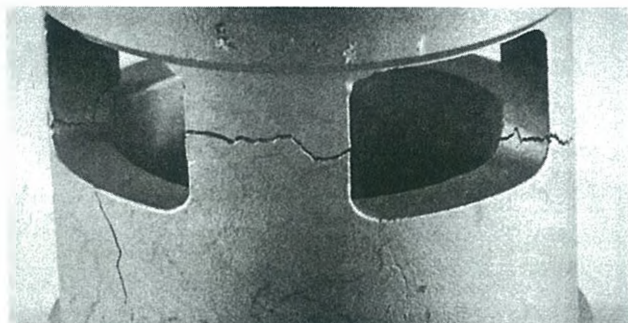


Fig. IC-23. Hot tear.

Gas Defects

Metal-related gas defects are mainly caused by turbulent pouring into the gating system, excessive melt temperatures, and inadequate melt treatment to remove hydrogen. However, gas defects (distributed porosity) may also arise during incomplete burnout from wax materials and poor shell permeability, which prevents venting.



Fig. IC-24. Gas defect.

Shrinkage and Microshrinkage Defects

Shrinkage defects arise from the same principles as they do in other casting processes—a pouring temperature that is too low, inadequate gating design, lack of feed metal, slow pouring and general inability to compensate for solidification shrinkage.

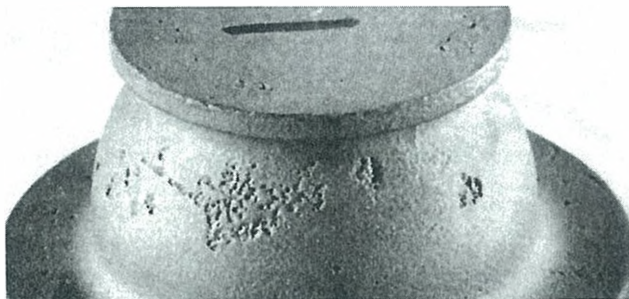
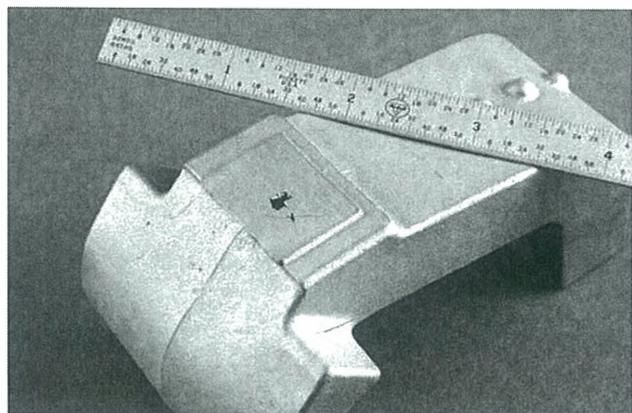


Fig. IC-25. Surface shrink (visual examination may also suggest surface inclusions and/or pull-out).



Fig, IC-26. Shrinkage at gate.

Plaster Casting

Plaster casting is a variant of sand casting. It generates an improvement in properties that may not be obtainable on a given designed component with sand. Plaster gives the finished casting a smoother surface and better dimensional accuracy. The slow solidification of the plaster casting process allows minimal internal stresses to be developed during solidification and allows more uniform hardness, tensile properties, and machinability.

Proper management of the plaster mix and mixing technique are critical to develop consistency in the hardened plaster mold. As consistency (water to plaster ratio) increases, green strength, burnout strength, density, setting expansion and burnout shrink decreases; permeability of burned-out mold increases and pattern removal becomes easier.

Mold-material casting defects which arise in plaster casting are similar to sand casting in cause and effect, involving inadequacies in the plaster slurry consistency and subsequent surface imperfections or defects. Metallurgically related defects—inclusions, hydrogen, etc.—relate mainly to melting and pouring practices, as well as residual moisture in the plaster mold from incomplete mold drying.

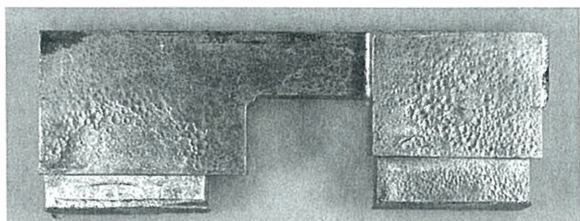


Fig. PC 1. Effect of strontium on slow cooling of 356 alloys.

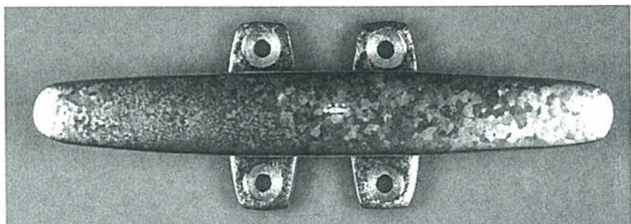


Fig. PC 2. Inadequate grain refinement.



Fig. PC 3. Metal-mold reaction due to residual moisture in the plaster.

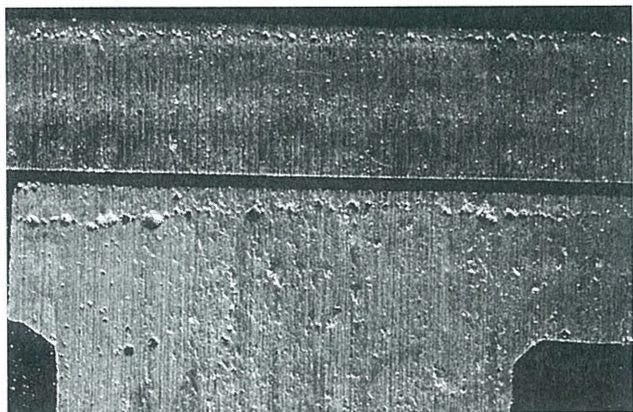


Fig. PC 4. Subsurface porosity caused by hydrogen evolution from wet mold.

Lost Foam Casting

The lost foam process is also known as the evaporative foam process. A mold or die is designed and machined to the final dimensions of the casting (accounting for general solidification shrinkage). Expandable polystyrene beads are then injected and expanded, creating a foam pattern replica of the casting to be produced. The expanded foam must be stabilized and cooled carefully to provide full stability and dimensional consistency. Often the actual casting design is so complex that it is easier and less expensive to create multiple pattern dies and then assemble several foam patterns together by gluing them. The pattern assembly is then coated with a suitable refractory and encased in a sand mold. As the liquid metal is poured or injected into the mold the metal melts, dissolves, vaporizes, and replaces the foam pattern to create the actual casting. How this displacement takes place (the metal flow; the phase transformations in the foam pattern and the escape of gaseous products through the refractory coating) determines the amount and nature of any casting defects that might be formed.

Consequently, there are several specific casting defects associated with this process which uniquely relate to issues with the foam pattern itself. In addition to these defects, unique to the process, there are the usual metal-related defects, which are common to other casting methods as well. Metal-related defects (inclusions, porosity, etc.) which relate to the quality of the aluminum melt itself have been covered in the other casting process chapters in this handbook, and the reader can refer to those chapters for additional defect images. Still, the uniqueness of the lost foam process with the foam pattern and its subsequent pyrolysis during casting gives rise to unique defect situations.

I. Pattern Defects

Clearly if a defect originates in the pattern shape, detail, and dimensions, the defect will most likely be replicated in the eventual casting. Problems with injection of the styrene beads and curing, and/or mishandling of the pattern are the most probable causes of pattern defects.

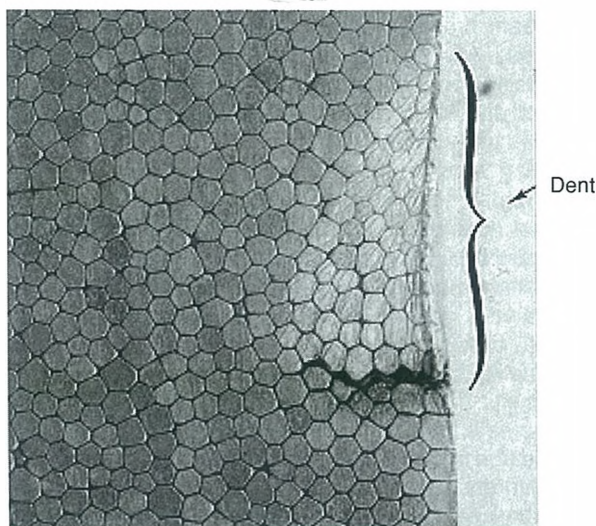


Fig. LF-1. Dent in pattern caused by rough handling.

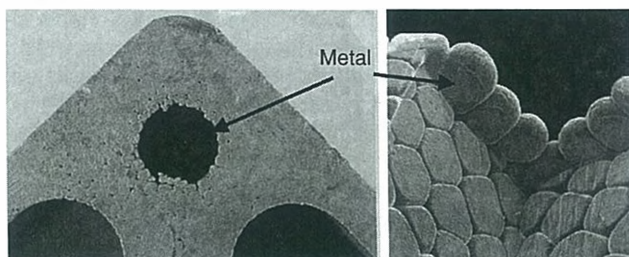


Fig. LF-2. Metal fin at hole edge in casting resulting from bent and/or folded over foam pattern.

FOLDS

A fold is a specific process discontinuity found in lost foam casting principally due to the way in which the foam pattern de-evolves during casting. Folds relating to gas evolution of the pattern material when connected to the drag or other down-facing casting surfaces are called 'bubble-trail' folds. They may vary in color. When folds occur at converging metal fronts or at the last to fill areas, they may be called cold laps or misruns depending on their size and severity. Blisters and gas pores usually occur on the cope side of the casting, and relate to the decomposition of the foam pattern, which will go through a phase transformation from solid to liquid to gas.

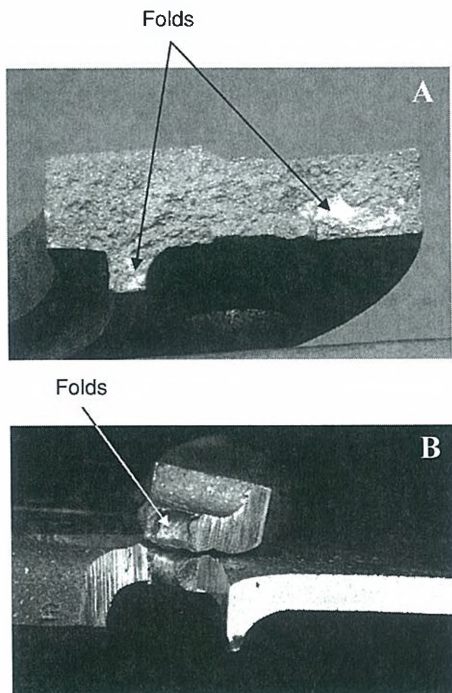


Fig. LF-3a and b. Examples of folds in aluminum lost foam casting.

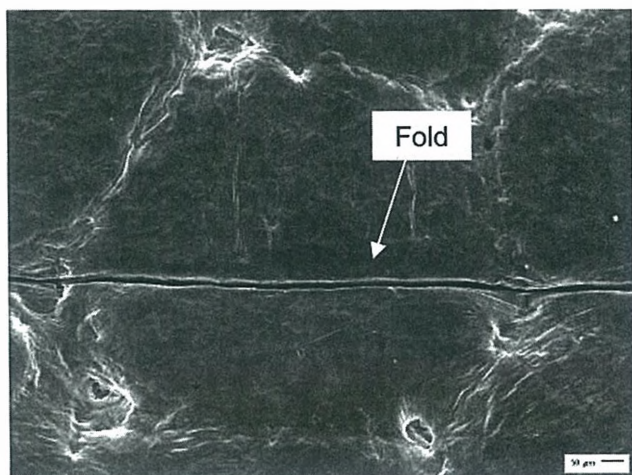


Fig. LF-4a. Scanning Electron Microscope (SEM) image of a fold in aluminum lost foam casting, showing crack caused by the fold and fold defect extending into the casting.

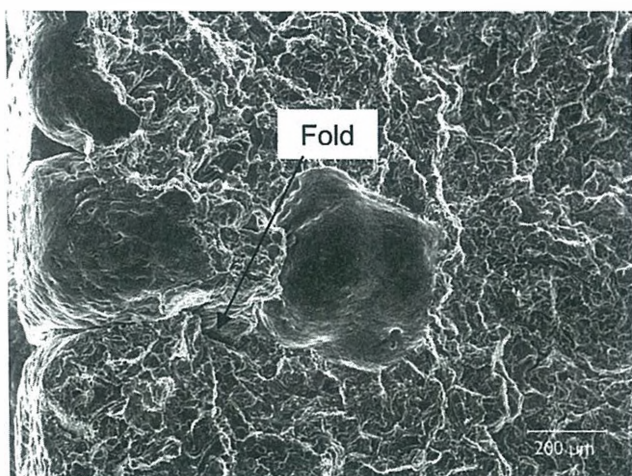


Fig. LF-4b. SEM image of a fold in aluminum lost foam casting, showing crack caused by the fold and fold defect extending into the casting.

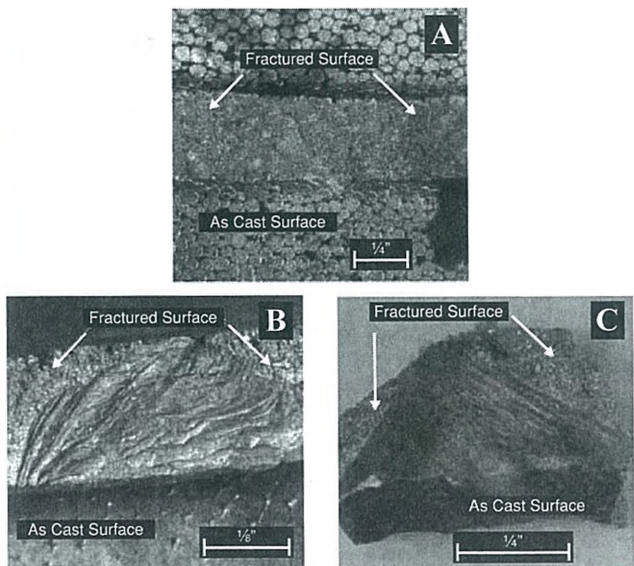


Fig. LF-5a, b and c. Examples of bubble folds found on down-facing surfaces.



Fig. LF-6. Photomicrograph of fold defect in 356, located in interdendritic region of the eutectic, last area to solidify.

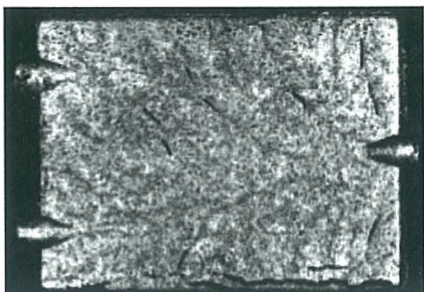


Fig. LF-7. *Fold defects on the as cast surface resulting from incomplete foam pattern fusion and subsequent gaps where liquid foam degradation products merge and do not escape.*

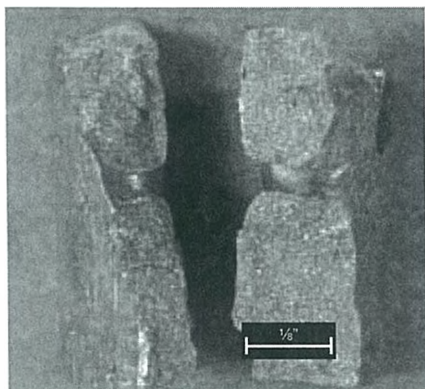


Fig. LF-8. *Fold on fracture surface; last area to fill.*

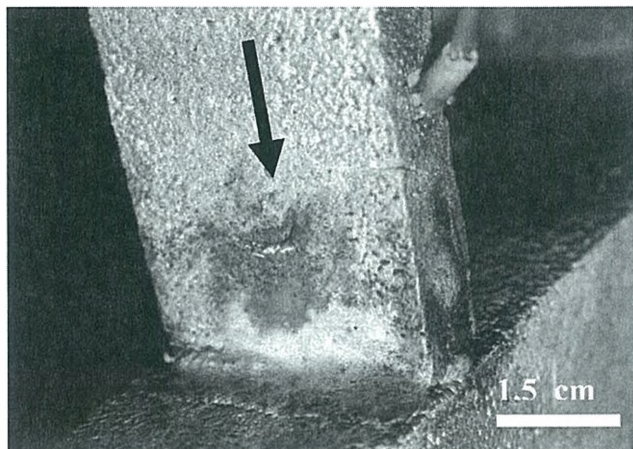


Fig. LF-9. Fold defect in vacuum casting.

Misrun

Unlike other casting processes, the metal to be cast enters an occupied metal cavity rather than an empty one. Consequently, metallostatic pressure (energy) is required to replace the pattern material. Different molten metal flow paths will create the possibility of one or more metal fronts. When these collide, differential solidification can take place, including loss of fluidity where the pattern is not fully displaced (i.e. the casting does not 'fill out').

However, misrun formation in lost foam casting has a very different dependency on metal velocity versus other casting processes. In lost foam casting, the metal velocity and or pressure must not be either too high or too low, in order that the foam pattern may decompose itself and its pyrolysis through transformation (solid-liquid-gas) and has an opportunity to 'escape' the advancing metal front.

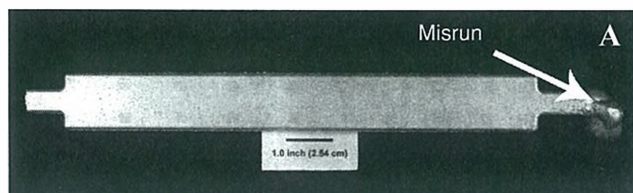


Fig. LF-10a. Misrun defect in aluminum lost foam casting.

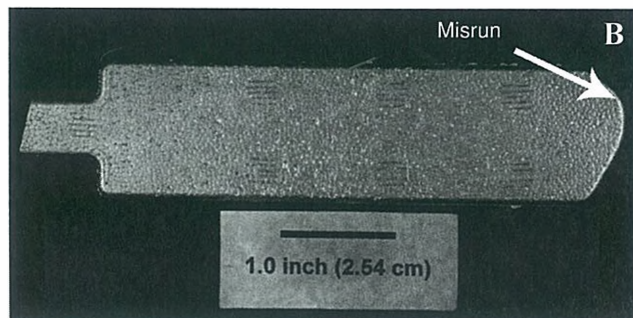
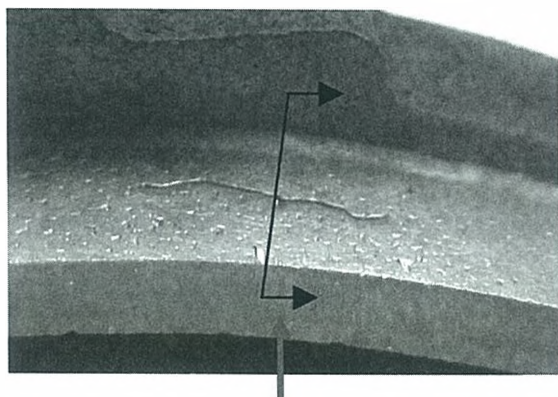


Fig. LF-10b. Misrun defect in aluminum lost foam casting.



Micrographic Location

Fig. LF-11. Misrun on the surface of 356 casting formed by two metal fronts.

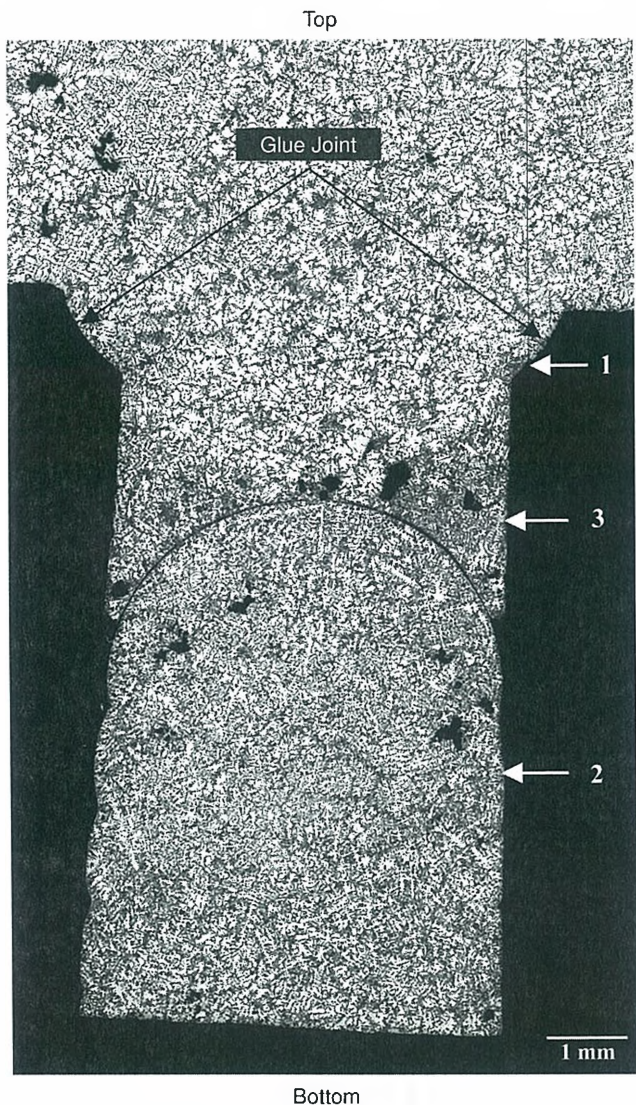


Fig. LF-12. Micrograph showing misrun caused by two converging metal fronts.

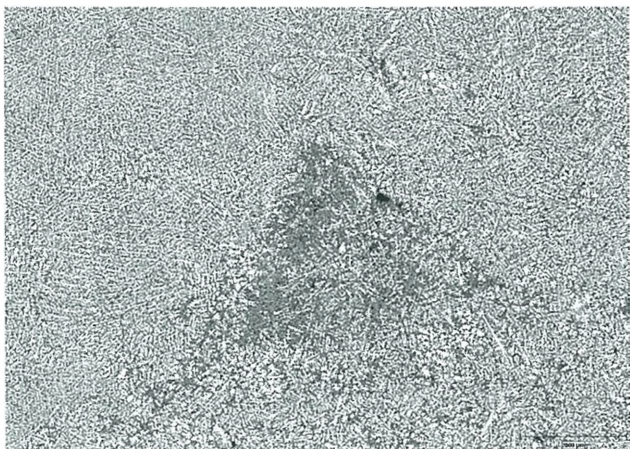


Fig. LF-13a. Micrograph showing the microstructure of a misrun in 356 aluminum, caused by three converging metal fronts. Different cooling rates create a segregated microstructure with a higher concentration of eutectic silicon.

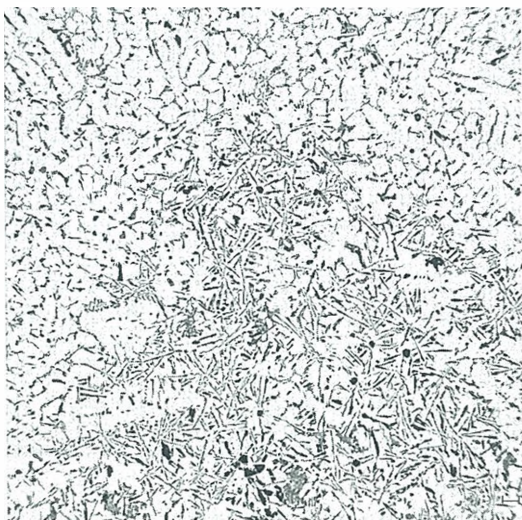


Fig.LF 13b. Higher magnification of Fig. LF-13a

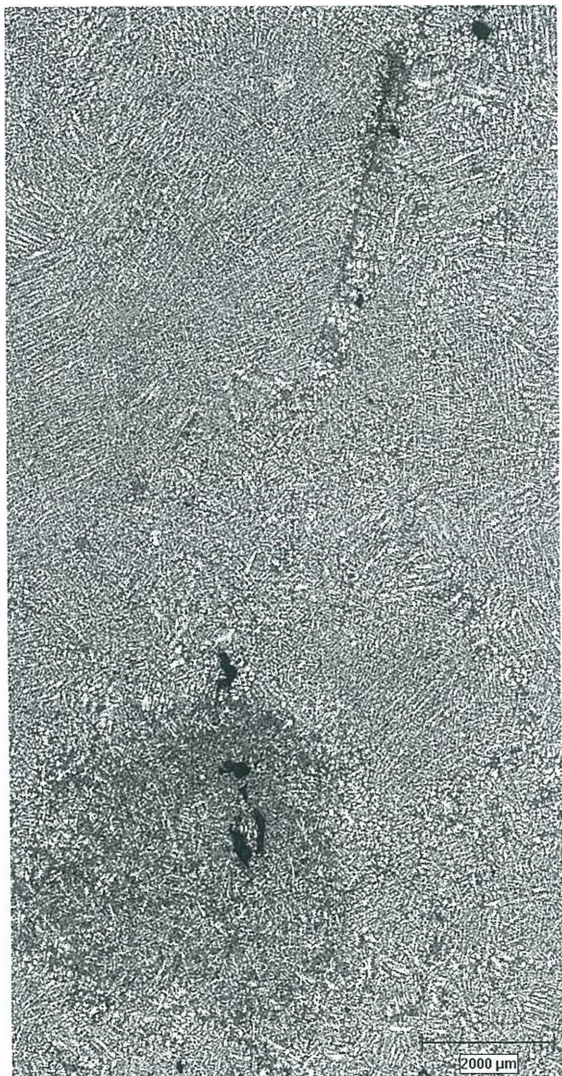


Fig. LF-14a. Microstructure of misrun in 356 caused by three converging metal fronts, with subsequent micro-voids created by foam decomposition products.



Fig. LF-14b. Higher magnification of Fig. LF-14a.

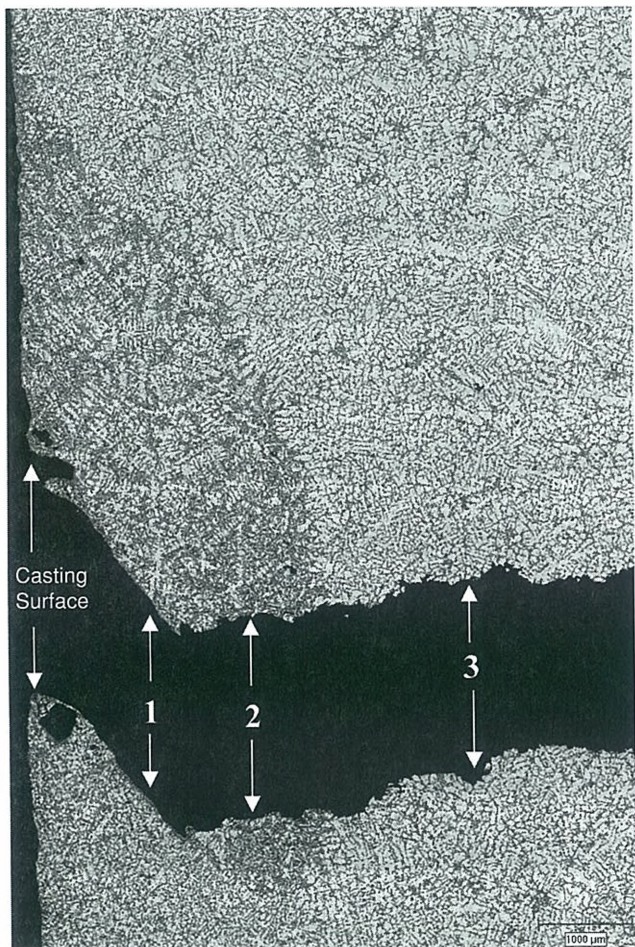


Fig. LF-15. Micrograph showing microstructure of misrun in 356 caused by two metal fronts converging at an edge—(1) oxide film fracture surface, (2) misrun microstructure and (3) matrix microstructure typical of 356.



Fig. LF-16. Misrun.

Glue Joints

Many lost foam patterns readied for casting are assembled by gluing. The adhesive used has a higher density than the foam pattern itself, and hence requires more metal energy during the casting process to degrade it. Glue material is more "chilling" and will generate more heat loss, which may lead to irregular metal flow and a possible defect as foam decomposition evolution and escape is altered. Change in solidification rate can create segregation in the casting microstructure.



Fig. LF-17. Microstructural segregation at a glue joint in A356 aluminum.

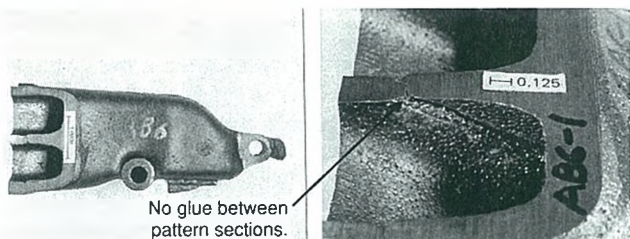


Fig. LF-18. Glue-line defect resulting from insufficient gluing between pattern pieces

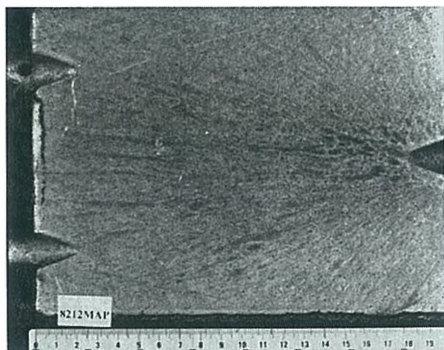


Fig. LF-19a. X-ray view of effect of glue joint on metal quality; poured without glue joint.

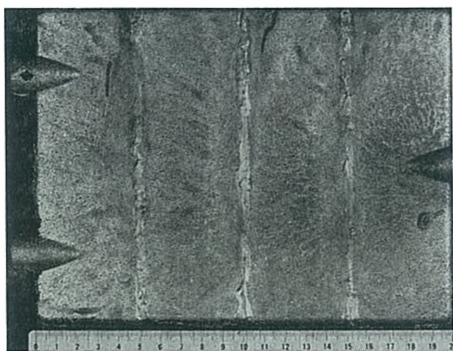


Fig. LF-19b. X-ray view of effect of glue joint on metal quality; poured with glue joint.

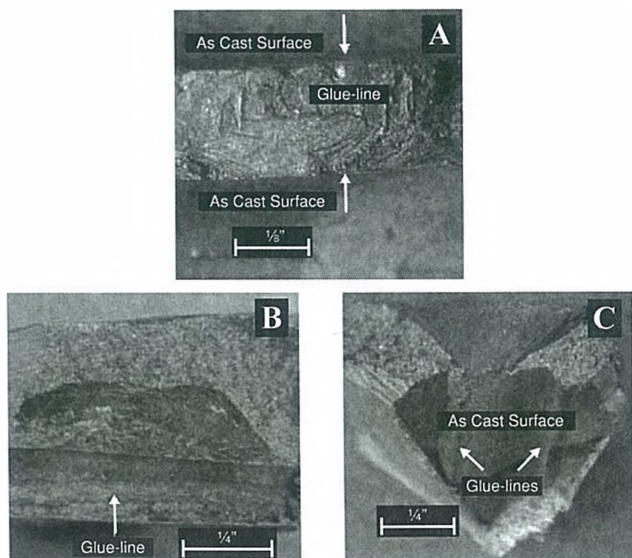


Fig. LF-20a, b and c. Examples of glue-line defects (folds).

Gas Related

Gas related porosity can originate from hydrogen in the melt and subsequent evolution during solidification, but also results from pattern decomposition and inability for complete venting.

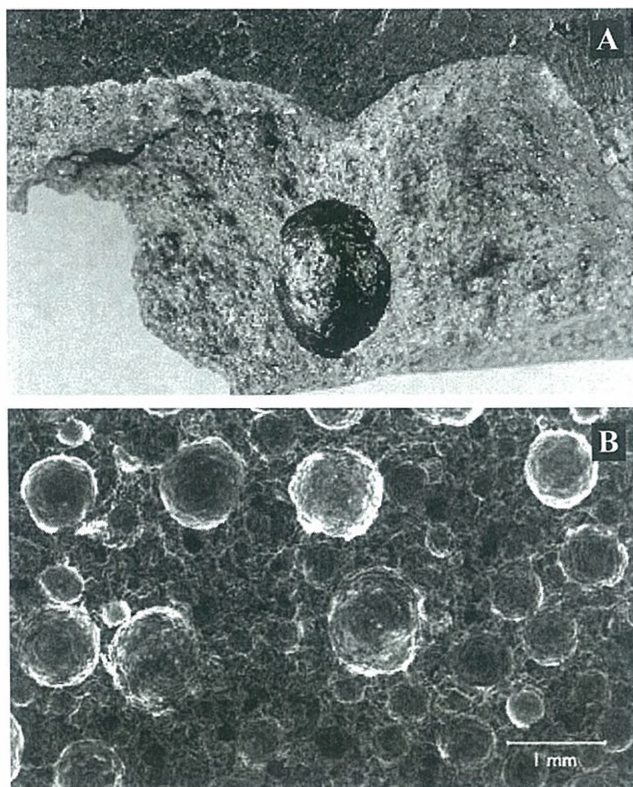


Fig. LF-21a and b. Examples of porosity in an aluminum lost foam casting.

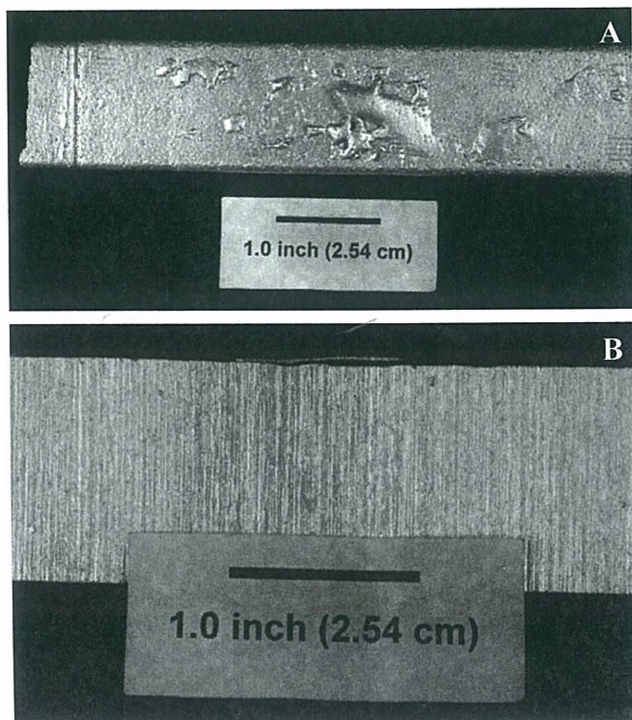


Fig. LF-22a and b. Examples of surface blisters on lost foam castings.

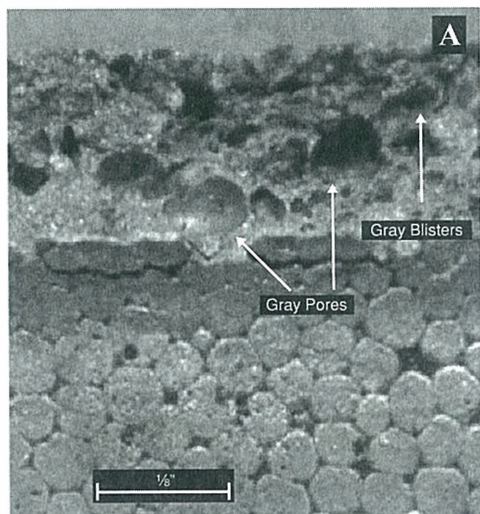


Fig. LF-23a. Blisters and internal pores found under cope.

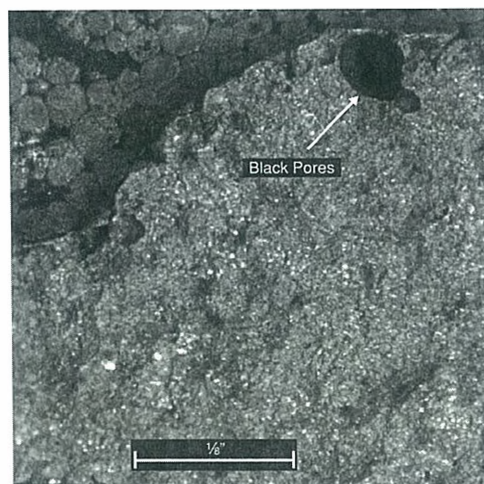


Fig. LF-23b. Blisters and internal pores found under up-facing surfaces

II. Coating/Sand Defects

Coating inclusions may arise from breakdown of the coating itself during the casting process, but also from irregularities in coating slurry and application to the pattern assembly; inadequate bead fusion and/or glue joint integrity permitting coating material penetration; or mishandling of the finished assembly ready for casting. Thus spalling or flaking of the coating surface may occur. A sand defect may occur, such as burn-on or burn-in, when the sand filling and compaction is incomplete; when the pattern coating is too thin; the metal temperature is too high and/or the metal velocity in a particular section of the casting is too great.

Coating permeability, coupled with foam pattern integrity and metal velocity, is critical to allow for controlled removal of foam pyrolysis degradation products to avoid defect formation.

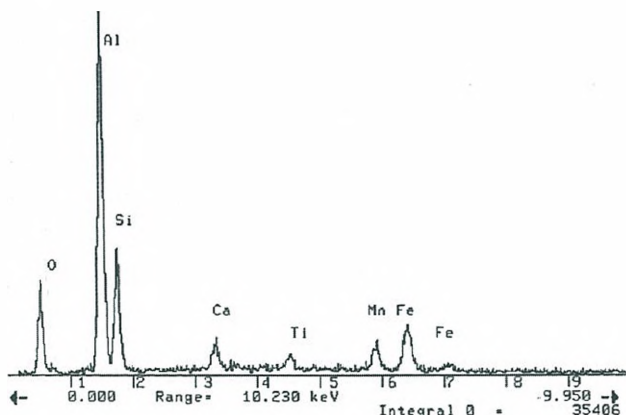


Fig. LF-24. SEM photo of coating inclusion.

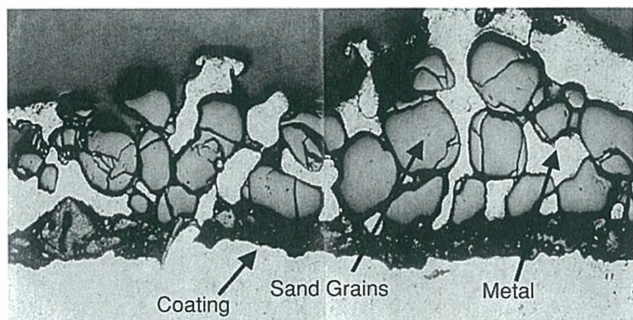


Fig. LF-25. Micrograph exhibiting burn-on (metal penetration) in lost foam casting.

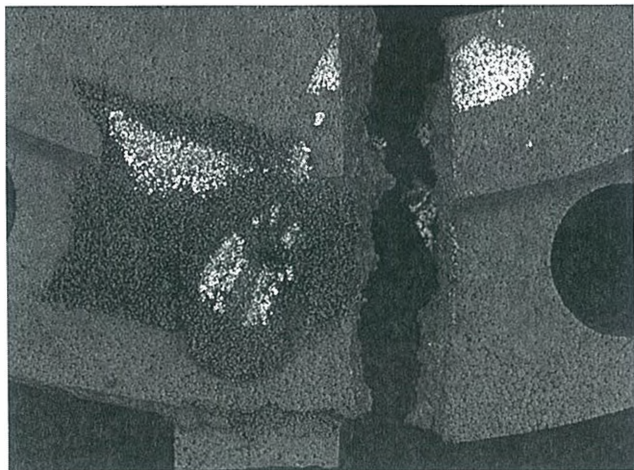


Fig. LF-26. Metal penetration found at the gate on the drag surface of the casting.

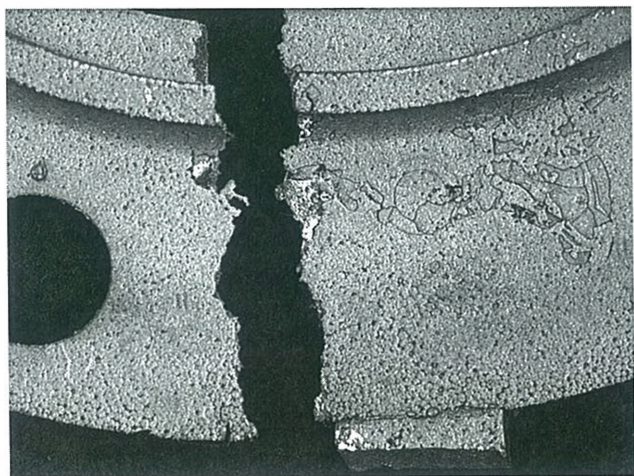


Fig. LF-27. Surface imperfection associated with metal penetration shown in Fig. LF-26



Fig. LF-28. Surface undulations on the casting resulting from entrapment of liquid-EPS at the metal-coating-mold interface.

APPENDIX

International Defect Codes, Names and Corresponding Chapter(s)

International Defect Code	Defect Name	Chapter where mention or example
B112-GI	Blowholes next to Inserts/Chills	N/A
B111-GI	Blowholes, Pinholes	7,8
B112-GI	Blowholes next to Inserts/Chills	1,2,3
B111-GI	Blowholes, Pinholes	1,2,3,4
C111-GI	Breakage	1
E221-GI	Broken Casting	1,2
A226-GI	Broken or Crushed Core	1
D131-GI	Buckle	1,5
D222-GI	Burn In	1,7
D221-GI	Burn On	1,7
F233-GI	Casting Distortion	2
G211-GI	Chill	1,2
D224-GI	Coating Failure	2,3,5
C331-GI	Cold Chill or Insert	N/A
G112-GI	Cold Shot	3
C311-GI	Cold Shut or Cold Lap	1,3,4,5,7,
D112-GI	Cope Defect, Elephant Skin	N/A
D232-GI	Cope Erosion Scab	1,3,5
A121-GI	Cope Raised, Raised Mold	N/A
B213-GI	Core Shrink	N/A

B212-GI	Corner or Fillet Shrinkage	N/A
A225-GI	Corner Scab	N/A
A213-GI	Crush	1,2
B124-GI	Dispersed Shrinkage	1,2
B122-GI	Draws	N/A
A212-GI	Erosion, Cut or Wash	1,2,3
A114-GI	Fillet Scab	N/A
A115-GI	Fillet Vein	N/A
D114-GI	Flow Marks	2,3,7
D133-GI	Flow Marks, Crow's Feet	N/A
G144-GI	Hard Spots	1,3
C121-GI	Hot Cracking	1,2,3
C221-GI	Hot Tearing	1,2,3
B221-GI	Internal Shrinkage	1,2,3
G262-GI	Kish Graphite Inclusions	N/A
G223-GI	Localized Hard Spots/Chilled Areas	N/A
G143-GI	Lustrous Carbon Films	N/A
D223-GI	Metal Penetration	1,5,6
G111-GI	Metallic Inclusions	2,3
E111-GI	Misrun	1-7
A224-GI	Mold Drop	1
B211-GI	Open or External Shrinkage	1,2
D134-GI	Orange Peel, Alligator Skin	N/A
E122-GI	Poured Short	1,2
D211-GI	Push Up, Clamp Off	N/A
F223-GI	Ram Off, Ram Away	N/A
D132-GI	Rat Tail	1,5
D121-GI	Rough Casting Surface	2,3,7
E123-GI	Runout	2
A122-GI	Sag or Strain	1
G131-GI	Sand Inclusions	1,3
D231-GI	Scab, Expansion Scab	1,2
F221-GI	Shift	1,2
F222-GI	Shifted Core	1,2
D141-GI	Sink Marks, Draw, Suck In	3
B113-GI	Slag Blowholes	N/A

D142-GI	Slag Inclusions	N/A
G121-GI	Slag Inclusions, Dross, Cerioxide	N/A
A221-GI	Sticker	1,3
D111-GI	Surface Folds	3,7
B123-GI	Surface Pinholes	1-7
A211-GI	Swells	1
G221-GI	Type C Graphite	N/A
G222-GI	Unacceptable Skin	N/A
A112-GI	Veining or Finning	5
F234-GI	Warped Casting	N/A
F	Off Dimension	N/A
B	Gas Voids with MnS	N/A
B	Gas Voids Lined with Graphite	N/A
B	Gas Voids Lined with Oxide	N/A
G	Micro-voids Lined with Steadite	N/A
G	Tellurium Wash Migration	N/A
G	Carbide/Inverse Chill	N/A
G	Carbide-Intercellular Primary	N/A
G	Carbide Intercellular alloy	N/A
G	Widmanstätten Graphite	N/A

