Quality Assurance

SECTION 7

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Quality Assurance

Frequently Asked Questions (FAQ)

1) Is there information available about porosity in a die casting?
   See pages 7-12 through 7-17 starting at Porosity.
2) What process variables affect the quality of die castings?
   See page 7-11, Process Variables.
3) Where can information on die casting defects be found?
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4) When should CP or CPK be used?
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6) What are some typical images of porosity and/or breakout at parting lines?
   See pages 7-12 through 7-17, Porosity.
7) Can x-ray be used to view porosity?
   See page 7-16.

Introduction

Continuing advances in die cast processing and control technologies allow the specifier of die castings today to achieve very high levels of precision.

However, custom production requirements that are beyond readily manageable process capabilities can increase costs. It is therefore essential that the user of die castings discuss process capabilities with the die caster early to keep costs in line with expectations.

This section deals with the control of the variables in die casting production to achieve the specifications presented in the earlier Engineering and Design Sections. It is the aim of this section to clarify terminology and establish the criteria necessary to maintain acceptable product quality under normal die casting practice.

Communications by means of purchase orders, part drawings, CAD/CAM databases, corporate standards, manufacturing specifications, die casting industry standards and guidelines should all be used to clarify the job content. Working together to clearly define areas in doubt will obviously result in optimum service at lowest costs.

1 Balancing Process Capabilities With Product Requirements

The best opportunity to reduce costs and enhance quality lies in carefully specifying those characteristics that are clearly needed in the product, i.e., distinguishing between critical and less critical features. When the functional requirements have been clearly defined, the die caster can determine, in advance, the precise processing steps necessary to achieve them.

1.1 The Engineering/Quality Team

Developing the optimum set of product requirements consistent with process capabilities is best accomplished by forming a cross-functional engineering and quality team involving all parties who are concerned with the success of the product.

Often called a "concurrent engineering" or "simultaneous engineering" team, it should include representatives of design engineering, manufacturing engineering (from both the die caster and customer), quality assurance and marketing.[1]

If a formal cross-functional engineering team is not set up, an informal team of key personnel from both the customer and the die caster should be formed to meet several times during the product development process to address important questions.

1.2 Standard vs. Precision Tolerances

The die casting process can offer very high casting precision, as discussed under "Standard" and "Precision" Tolerances in "Engineering and Design," Section 4A. Precision Tolerance levels should be specified only when product requirements justify the additional production steps that may be required. Otherwise industry Standard Tolerances should be used.

It is always advantageous, in terms of faster delivery and lower production costs, to avoid unnecessarily stringent tolerances and specifications.

1.3 Simulation

The term "Lean" is used to describe a manufacturing process. Lean is continually striving for perfection, continually declining costs, zero defects, zero inventories, and an increase in business. There are five major principles used in "Lean Thinking!"

- **Value**: Only the ultimate customer can determine value!
- **Value Stream**: All the actions and services required to bring a specific casting to market.
- **Flow**: Flow is a continuum from the order desk to the shipping dock. No stopping or storing!
- **Pull**: The customer can pull the product from the caster because of the quick turnaround time. Pulling is like turning on a switch for the desired product.
- **Perfection**: There is no end to the process of reducing effort, time, space, cost, and mistakes.

Lean employs five principles, but we will use two of those principles to highlight our improvement for Product Integrity. Value Stream is one of those concepts: "All the actions and services required to bring a specific casting or family of castings to market in a logical, timely sequence that promotes perfection. Perfection is an overriding principle for our premise of improvement: "Make sure we know exactly what the customer wants."

Recent software tools such as CAD/CAM, shot monitors, and simulation programs all assist the industry in achieving perfection. Often times these tools are not used at all or are used out of the proper sequence for achieving perfection. As technology in software improves, the industry must use the advantages offered for a profitable timesaving. When NADCA metal flow principles are properly employed it increases the probability for sample castings to be approved. When a shot monitor is employed the engineering department can easily determine machine capabilities and create a realistic PQ^2 analysis. When vacuum metal flow simulation software is used the runners, gating, vents, overflows and vacuum vents can all be properly placed for minimal defect metal flow. It may take several simulation iterations to ensure the runners and gate placement creates the desired metal flow pattern.

There are many automated features on the die cast machine, trim dies, and subsequent machining operations. If the mold is not producing an acceptable casting the speed created is not in the Perfection Mode of Lean Thinking.

For example, the following steps are used for a typical metal flow simulation:

- Engineering will create a 3-D model of the casting with runners and gates connected and export the file in an STL format for the simulation. A PQ^2 analysis will yield the desired fill time and optimum gate area. The gate depth and location can be determined for the simulation.
- A fast simulation, in the initial design stage can be made to ensure the position of inlets will yield the desired perfection. This is a critical stage to ensure the holder and mold will be oriented for machining. The neglect of this sequence in the value stream may result in welding and refashioning runners & gates, resulting in a time and material loss. If the gates have to be moved the result may result in a shortage of tool steel for the new gates. Emphasis must be placed on the proper sequence to avoid mistakes, rework and ultimate delays in the delivery of the mold. Perfection is a must at this step in the value stream.

Critical questions to ask at this critical stage are:

- Does the inlet gate satisfy the feeding of each cavity?
- Is the last place to fill well defined? (Figure 7-1)
- Are the overflows and/or vacuum lines in the last place to fill?
- Are there areas that may be porous or not filling properly? (Figure 7-2)
- Does it seem the gates are placed correctly? (Figure 7-3)
- Has a PQ^2 analysis determined gate size and filling speed? (Figure 7-4)
- Has the casting been checked for square corners or areas of difficult fill? (Figures 7-5a & 7-5b)
- Will major changes have to be made to ensure perfection?
- If the simulation determines a change, the recommendations are put into a new model and STL for another iteration. If it seems the gate is adequate or a slight change is needed the mold can be aggressively machined. A fine, more accurate simulation can verify all the data.

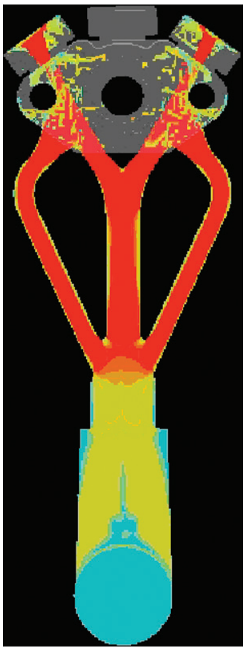


Figure 7-1: This is an example of the overflows filling first instead of being the last place to fill. An initial fast simulation will detect such undesirable characteristics.

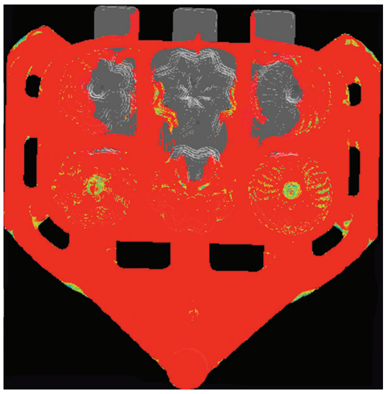


Figure 7-2: This simulation shows the end and top overflows are of no value. The cavity areas encircled are filled with porosity. The scrap rate was 75%. A new gate/runner with confirming simulations yielded a 1.5% scrap rate. The simulation will save hours of rework and lost time.

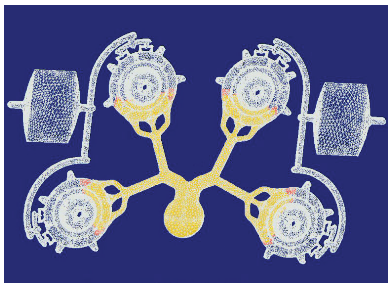


Figure 7-3: The metal flow in the outer runners is well past the two inner runner/gates. Gate placement must ensure the maximum use of available gate area. The angle of metal entry must be within metal flow capabilities per NADCA standards. Seeing the flow enhances the needed changes for proper fill.

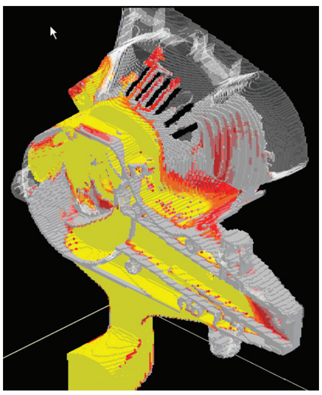


Figure 7-4: This simulation is depicting a velocity that is too slow, the metal flow is freezing before the final fill. A PQ^2 analysis will render a proper gate and metal flow velocity to ensure a complete fill. Simulations show very accurately the filling characteristics.

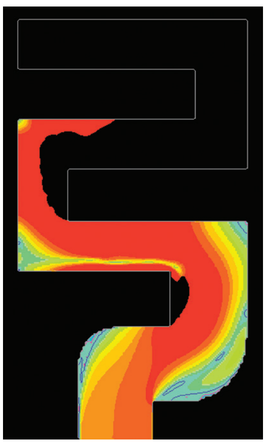


Figure 7-5a: Square corners in a runner or casting result in porosity. pockets.

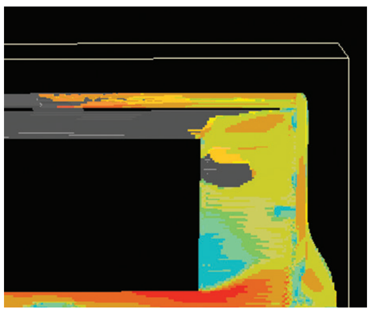


Figure 7-5b: A zinc cosmetic casting that has square corner metal flow that results in unacceptable porosity. A visual defect!

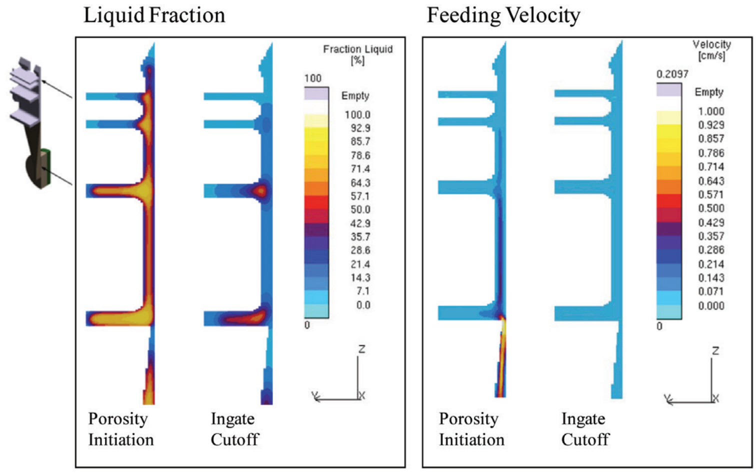


Figure 7-6: Simulations of liquid fraction (left) and feeding velocity (right) at porosity initiation and ingate cutoff for a ribbed casting configuration.

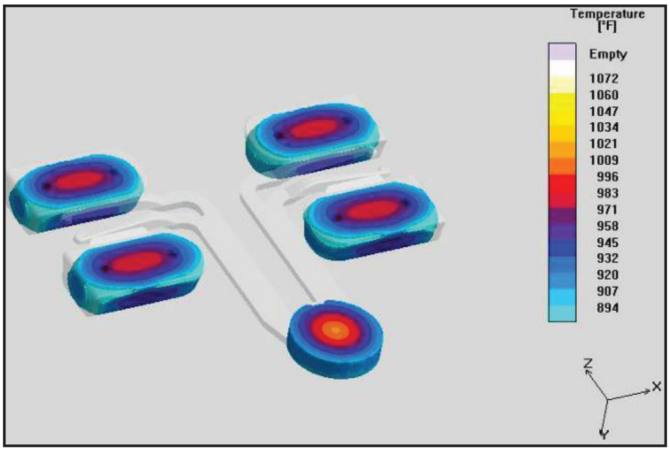


Figure 7-7: Thermal simulation showing the temperature gradient at a given point in time of castings in a 4-cavity die.

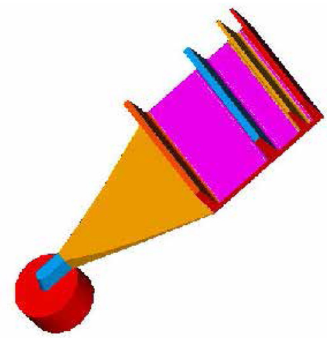


Figure 7-8: The selected part for simulation.

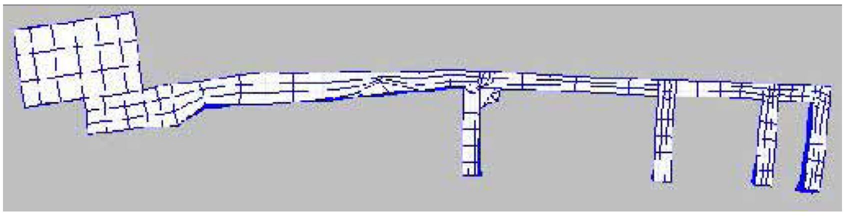


Figure 7-9: An example of distortion modeling, 20x magnification factor.

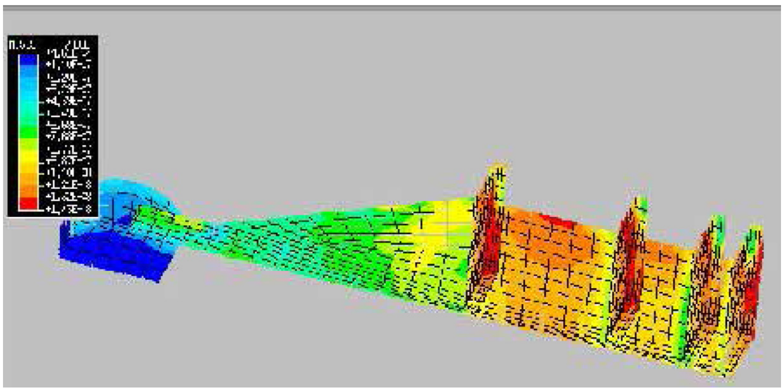


Figure 7-10: An example of residual stress prediction at time of ejection using elastic-plastic analysis.

Simulations can be used to optimize heat flow, determine the location of cooling lines and cooling requirements. Simulations can also be used to predict die distortion, casting ejection temperatures and dimensional capability, last place to fill, and areas of poor fill or non-fill, and pockets of porosity. They also indicate where the overflows should be placed as indicated by the last area of the casting to fill.

A time and cost saving for the entire supply chain is to have accurate information for the mold-maker to complete the mold building. Time and price increase when the project is delayed because of minute changes or uncertainty of design. The customer, caster, and mold maker must all be informed of the part design and specific areas of special concern. All questions must be answered so every party can be aggressive in executing their expertise. Then the project can mature in an orderly and speedy fashion.

FAQ Concerning Simulation:

What is the value or benefit of a simulation?

The simulation will give an accurate, graphic depiction of the filling process and will verify the suggested gating profile. Many times a runner and gate are cut only to find the results are not in the perfection mode of desirability. The simulation must be done prior to cutting steel.

Are the simulation results easy to understand or read?

It requires a skilled engineer or experienced person to explain the results. Any computer literate individual can create the simulation, but experience is required to understand the results.

Is the simulation cost effective?

If a caster or mold maker owns the software it can and should be used on virtually every project. There are also consultants who will be cost effective in conducting a simulation. The process saves countless hours of die changes, welding and machining of gates to enhance flow. The relative small cost of the simulation saves time, money and increases the availability for increased business. The true reward for a proper value stream sequence is realized when the project goes into production as a result of careful planning and timely execution. All the members of the value stream make a profit and have capacity for increased business.

Finite Element and Finite Difference Methods

Both finite element and finite difference methods are used to numerically solve the partial differential equations that describe physical phenomena including heat transfer, fluid flow, stress, displacement, distortion and others. Both techniques require discretizing the object or spatial domain of analysis into a grid of nodes and applying numerical techniques to solve the problem of interest at these nodes. The main differences in the methods arise from differences in the solution techniques used.

Finite difference uses a grid of points, almost always uniform, and the derivatives present in the differential equations are approximated by differences constructed using neighboring points, hence the name. The problem is thereby reduced to a set of simultaneous equations that are solved iteratively. Because the grid is uniform, finite difference grids may not perfectly follow the surface of the object and may have a stair step like appearance. Newer grid generation procedures minimize these effects but not all finite difference-based programs support them.

Finite element also discretizes the space into a grid, but it is not necessarily uniform. Instead the spatial domain of the analysis is decomposed into discrete elements. The elements generally are polyhedra either with 6 rectangular sides and 8 corner nodes (brick elements) or four triangular sides and 4 corner nodes (tetrahedral elements). Accurate tetrahedral meshes are easily created by automatic meshing programs. Because of the meshing procedure FE meshes provide excellent surface fidelity.

Finite element methods solve the differential equations by using an approximate solution defined within the element in terms of the solution value at the nodes. Neighboring elements share nodes and the solution much match at these nodes leading to a set of simultaneous equations that must be solved consistent with specified boundary condition. Each element has so called fitting functions that are used to interpolate the solution within the elements and, because the element contains the approximate solution, different element types are required for each type of problem to be solved. That is, even with the same geometry and mesh, different elements are used for heat transfer and stress analysis for example. Finite elements will always have nodes at the corners and may have nodes at the center of each edge and at the center of the element depending on the element type and the solution approximation technique that is used. Even with the extra nodes, finite element meshes generally contain a smaller number of nodes than a finite difference grid for the same problem.

In principle either technique can be used to solve the differential equations of any of the common engineering problems although finite difference tends to the method of choice for fluid dynamics problems (such as metal flow analysis) and finite element for stress and deflection. Both methods handle heat flow equally well. For either type of system, there can be wide differences in the implementation of a particular type of solution across vendors. Also, for both special and general purpose packages, not all will have the ability to address nonlinearities such as contact and movement between components of the system (e.g., contact between the die and the machine platen or contact between the casting and cavity wall). The quality of the solution depends more on the quality of the implementation than on the method.

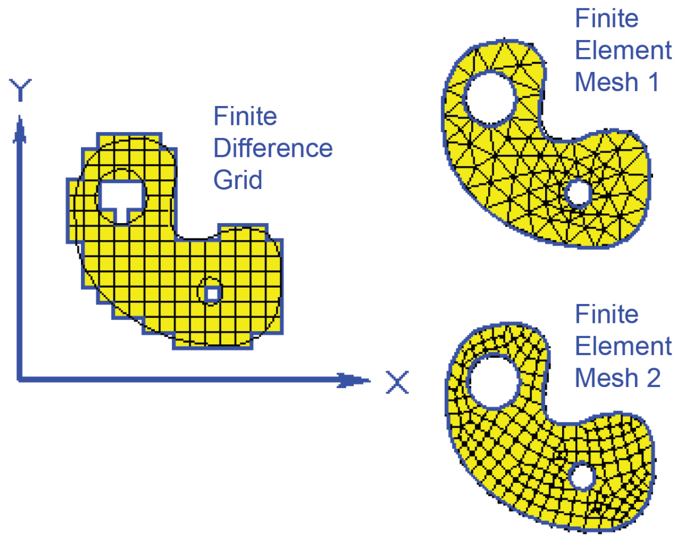


Figure 7-11 A: 2D illustration of the difference between finite difference and finite element meshes.

2 Defining Product Quality

The definition of product quality is fitness for end use. The definition will vary from design to design and usually varies for different areas of the same part.

The designer should expect to commit sufficient time and resources with the custom die caster, in the preliminary design stages before final drawings are completed, to determine what constitutes casting defects, and to precisely define acceptable product quality. This critical step will reduce rejections and rework, promote smooth operations between the die caster and the customer's design and procurement staff and increase successful results.

The checklists C-8-1 and C-8-2, which appear at the end of Commercial Practices, Section 8, should be used in specifying quality requirements.

It is rarely, if ever, practical to eliminate all casting discontinuities. Any attempt at total elimination will usually increase the cost of the casting unnecessarily.

There are two general types of discontinuities: internal and external. Internal defects can affect the structure of the casting, and may or may not be visible on the surface.

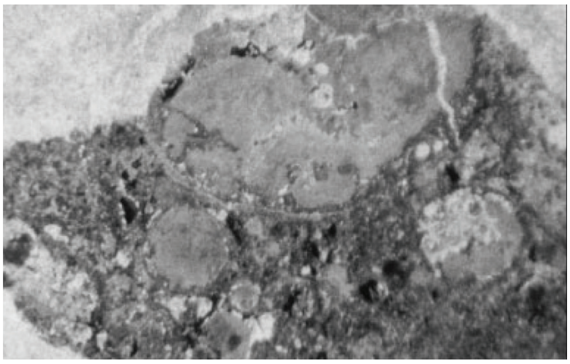


Figure 7-12: Magnified view of a non-metallic inclusion as an example of an internal defect other than porosity.

2.1 Internal Defects

Porosity is the most common type of internal defect (see page 7-14 Internal Porosity). In many cases internal porosity will have little or no effect on the overall strength and integrity of a casting.

Where pressure tightness for a gas or liquid application is not a requirement, a mechanical strength test (by a standard weight drop or torque wrench application) per an agreed upon sampling plan can be a cost-effective approach to quality assurance for casting strength.

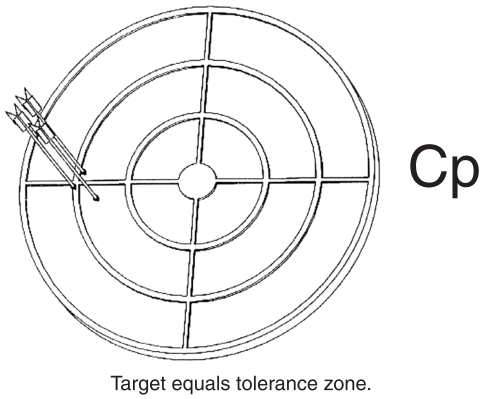


Figure 7-13: Cp is the raw capability index or in simpler terms = repeatability.

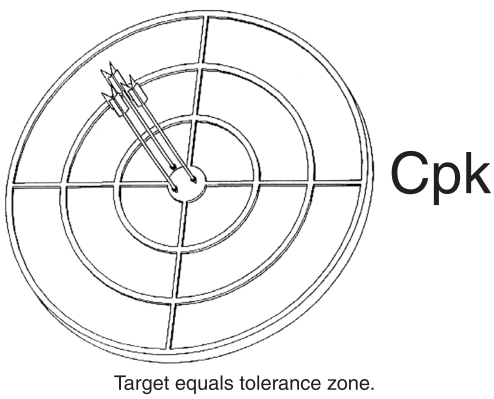


Figure 7-14: Cpk is the Total Process Capability or = accuracy and repeatability.

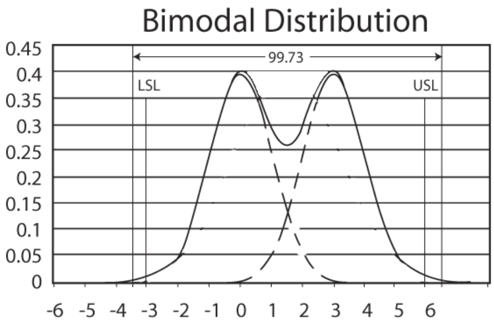


Figure 7-15: Cp can be applied to a bimodal distribution that allows for migration from one side of the tolerance range to the other. The higher the Cp number the more repeatable the process is.

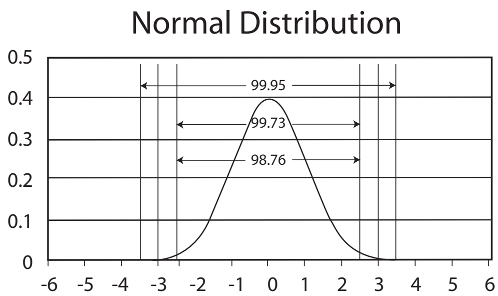


Figure 7-16: CPK indicates a normal distribution that allows within the distribution the maximum allowance of plus/minus tolerance that yields the greatest number of good parts in production. The higher the CPK number the more repeatable and accurate the process is.

2.2 External Defects

External, or surface defects, do not generally affect the structure of the casting. Surface defects are especially sensitive to the particular design of gates and runners in the die casting die. Calculated design parameters using proven metal flow design and process simulation techniques have been shown to be very effective.

The type and severity of external defect that can be accepted depends greatly on the type of final surface treatment to be applied. For example, a powder coating application deposits a relatively thick coat compared with painting systems, and will tolerate greater levels of surface roughness. Bright plating, such as chrome or brass, requires a very smooth surface finish.

Surface finish standards for die castings are normally developed on a part-by-part basis between the producer and the user.

It is important that the final finish acceptance standards developed be understood and agreed upon by all parties, with reference to a specific viewing standard such as "no objectionable imperfections, as specified, when viewed under normal lighting conditions at XX feet viewing distance." This can be addressed on checklist C-8-2, in Section 8, checklist item Q.

Reference sample standards should be retained by all parties after agreement on the acceptable standard.

Some common types of surface defects that may occur in production over time are cold shuts (knit lines), swirls (surface roughness), build-up (die lube or soldering accumulation) and heat checking (very small raised fins on parts). See Guideline G-6-6 Surface Finish, As-Cast on page 6-8 for more details.

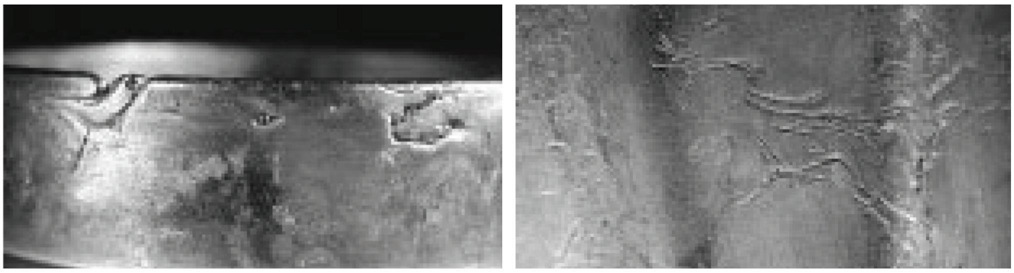


Figure 7-17: Examples of external defects.

Heat checking occurs during the life of a die when small cracks appear in the die due to thermal cycling. They sometimes cause concern on structural features because they appear, to the untrained eye, as cracks on a part. However, they do not affect the structural integrity of the casting, and are not generally objectionable on structural features that do not have cosmetic requirements.

Raised fins are routinely removed by surface blasting with shot or grit, or by vibratory finishing (which is normally the procedure used to prepare the surface for painting). How external defects are to be removed or eliminated depends on the type of surface finish required, whether painted, plated, or functional. The method to be used should always be discussed with the die caster. For more information on die casting defects see NADCA publication #E-515 Die Casting Defects – Causes and Solutions.

3 Drawings and Specifications

To insure uninterrupted production to specifications at the most economical level, it is important to supply all drawings and specifications to the die caster with the "Request for Quotation" (RFQ).

For correlation purposes, it is necessary that the drawings and specifications contain the following information:

01. Dimensions or areas that are of critical, major or minor importance, and the Acceptance Quality Level (AQL) or Parts-Per-Million (PPM) level to which they will be checked, including the dimensions for which the customer will be requesting control charts.

02. Datum locations to be used for machining or gaging and the areas to be used for special checking

03. The gaging procedures the customer intends to follow and the special gages that will be furnished.

04. Special requirements and the areas to which they pertain.

05. Coded surfaces on parts to be plated, painted, etc., designating classification of surfaces.

06. Indication as to where die trimmed edges are not acceptable and specification of degree of metal extension removal required (See "Metal Extension," G-6-5, in Section 6).

07. Indication of any engineering change level requirements by purchase orders and accompanying drawings.

08. Specification of those surfaces which may not be used for location of the ejector pins.

09. A list of generic print tolerances which will adequately describe all the non-critical areas on the print.

10. Clear description of all standards for approval or rejection.

Providing detailed and complete specifications at the time of the RFQ will benefit both the customer and the supplier. It will enable the die caster to submit more accurate, competitive quotes and help assure that the customer will receive quality die castings at the most economical level.

7

4 Gage, Measurement and Testing Equipment

Proper gaging equipment must be provided for effective measurement of product conformance. The customer is expected to furnish special-purpose gages which are required for inspection of specific die castings.

Special gaging requirements should be stated and the responsibility for maintenance of special gages should be established on the RFQ and on subsequent contracts between the die caster and customer. Gaging labor, when applicable, is included in the price quoted for the die casting.

When special gaging fixtures are necessary, they should be made in duplicate by the customer and one set furnished to the die caster. The customer should also furnish complete inspection methods and gage design information to the die caster at the time of the request for quotation. A gage and measurement instrument calibration system, with records maintained by the die caster, will assure consistent measurement control.

It is also suggested that gage Reproducibility and Repeatability (R & R) studies be done on all customer-supplied special gages. Further, it is recommended that all gaging sets be qualified by both the customer and die caster.

The responsibility for any preventative maintenance to be performed on customer-owned gaging should be made clear.

5 First Article Inspection Requirements (FAIR)

Whether the die caster or the customer is to perform the inspection of initial samples produced from a die casting die should be decided at the time the purchase order is issued.

When the inspection of initial samples is completed by the die caster, a report of the findings will be submitted to the customer. This is frequently referred to as a First Article Inspection Report (FAIR). Unless otherwise specified, first piece samples are supplied for dimensional check only. (Inspection of initial samples by the die caster may result in added cost.)

At the customer's request, the die caster will be responsible, after the inspection of initial samples, for correction of tooling for out-of-specification part dimensions before the start of production.

The customer should change the print for those dimensions for which tooling correction is not required in order to agree with the initial samples report. The general print tolerance will apply to the changed dimensions as noted, unless there is agreement to a new tolerance. Any automotive or other industry requirements such as preproduction approval pieces (PPAP) should also be known at the time of quoting. See figure 7-22 on an example PPAP flow chart.

In the event a print change will not be made, the customer should furnish an inspection report specifying those dimensions or tooling corrections which are not required. Any dimension not requested to be corrected or changed on the print is considered a valid dimension with normal tolerances, after the start of production, for the life of the tool.

The customer must acknowledge part acceptance by a formal letter before production is run. Such acknowledgment indicates either conformance to print or acceptance of a permanent deviation from specifications. The general print tolerances will apply to any deviations. Any die castings received by the customer which conform to the approved sample dimensions will be considered acceptable product.

If capability studies are to be done at the time of first-piece inspection, or in place of first piece inspection, this requirement should be specified at the time of the RFQ. Any automotive or other industry requirement such as Pre-Production Approval Process (PPAP) should be known at the time of quoting.

6 Statistical Quality Control

To assure uniform quality control standards acceptable sampling procedures and tables for inspection by attributes, such as ANSI/ASQC Z1.4, should be used.

Characteristics to be inspected for product conformity should be agreed upon by the customer and supplier prior to the first production run.

The classification of particular characteristics and AQL or PPM levels should be determined at the time the contract is negotiated. Classification of defects (critical, major, minor) should be in accordance with the latest revision of the acceptable sampling procedures to be utilized.

Normal inspection, as per ANSI/ASQC Z1.4 for instance, should be used.

Sampling plans to be used by the die caster will be left to the discretion of the individual die caster, recognizing, however, the responsibility to meet the agreed upon AQL or PPM levels.

6.1 SPC Procedures

Where the current revision of ANSI/ASQC Z1.4 is not desired or appropriate, a negotiated standard of sampling and acceptance should be established prior to die design, with early determination of SPC recording. Any requirement for process potential data or process capability studies should also be outlined at that time.

Dimensions and/or parameters requiring SPC data and Cp and Cpk values should be agreed upon by the customer and die caster prior to the first production run. This should include types of SPC charts, subgroup size, and sampling frequencies.

Determination must be made prior to production as to all specific SPC reporting requirements, data maintenance and its transmission. The die caster should be expected to point out to the customer the impact on Cpk values when cast die features are built on the "steel safe" or "wear safe" side of nominal, to allow the tooling maximum tool life and wear towards nominal dimensions.

6.2 Process Variables

There are five process variables that affect the quality of the die casting:

1. *Metal analysis*
2. *Metal temperature*
3. *Die temperature*
4. *Die lubricant characteristics*
5. *Die filling conditions*

In general, die casting is a setup-dominant process that exhibits variation of a serial, rather than random, nature. Of the five variables only No. 5, "die filling conditions," exhibits the "continuous drift" variation that the traditional X bar-R control charts were conceived to monitor.

Variables 2 and 3, metal and die temperature fluctuations, exhibit more of "cyclic drift" and are thus not well suited for periodic inspection associated with traditional SPC. A continuous monitoring system is better suited to measure the variability of temperature-related process variables. Monitoring within part variation will document significant temperature differences that can occur.

Variable 5, die filling conditions, consists of the elements of the shot profile that shot monitoring equipment can monitor and measure. Capability studies can be used to establish the range in the shot profile that the process will produce in casting production. More often than not, changes in the shot profile due to random, constant-cause conditions are minimal compared with the non-random conditions that are traceable to machine maintenance requirements.

Any special production requirements should be reviewed early with the die caster. Not all die casters may be able to apply SPC to machine parameters and may have to monitor the process, or the results of the process, through a less sophisticated method.

6.3 Capability

Capability studies have become increasingly more popular in the last several years. In the past, SPC and capability studies were tools used mainly by machine houses, but more and more die casters are being required to do them to qualify the die cast tooling. Capability studies can be very important in determining process ranges as well as helping to determine PPM levels. However, misuse of Cp vs. Cpk can take away much needed process variation and tool life in the die casting operation.

Due to the pressures used in the die cast process, several variables can come into play. These include parting line separation, mismatch at the parting line, core slide blow back and core slide shift or a combination of the above. Normally, dimensions that are affected by these conditions are built into the die cast die on the low side of the tolerance range. These dimensions should be considered as a plus side tolerance dimensions only.

In addition, the die cast process can be very abrasive on the die surface causing rapid tooling wear. Part features that are affected by this wear are normally built on the high side of the tolerance range. These dimensions should be considered as a minus side tolerance dimension only.

$$Cp = \frac{(USL-LSL)}{(6 \times \sigma)}$$

$$Cpk = \frac{(X-LSL)}{(3 \times \sigma)} \qquad Cpk = \frac{(USL-X)}{(3 \times \sigma)}$$

On as-cast features Cp should be used as the primary measurement if the dimension targeted is in tolerance and on the right side of the tolerance range. For example a cast hole dimensioned at 2.000 +/- 0.010 (50.8mm +/- 0.25mm) checks 2.008 with a Cp index of 6.0 and a Cpk of +0.85, should be considered a good dimension to yield maximum tool life and process repeatability.

On cored hole locations and machined features Cpk should be used as the primary measurement. For example a machined hole dimensioned at 2.000 +/- 0.010 (50.8mm +/- 0.25mm) checks 2.008 with a Cp index of 6.0 and a Cpk of +0.85, should be considered as bad and the size adjusted to get closer to 2.000.

6.4 PPM Levels

PPM goals and requirements are becoming increasingly popular in the procurement of die castings and die cast assemblies. Since the part complexity, customer requirements and level of processing contribute to the reject level, a threshold PPM level is not specified by NADCA.

Process capability studies may be used to assist in predicting PPM levels for specific castings, secondary processes, and/or assemblies. Ultimately, the PPM goal or requirement should be as agreed upon between the die caster and customer.

7 Porosity

It is usually necessary to address porosity when specifying die castings. While porosity specifications are very difficult to define generically, there are existing guidelines that provide a good starting point.

Solidification begins at the surface of die castings and progresses to the center generating two distinct zones in each wall section, as shown in Figure 7-18. The skin, which has finer grain structure, begins at each surface and extends inward to a typical thickness of .015 to .020 in. (.38 to .50 mm). This area is usually free of porosity compared to the center of the section. The porosity is located between the skins in the core. The finer grain structure and absence of porosity give the skin superior mechanical properties. Skin thickness of a die casting is relatively constant and is not a function of total wall thickness; therefore, thin-wall sections can actually be stronger and more consistent than thick sections. The removal of the skin to a depth greater than .020 in. (.50mm) by secondary processes, such as machining, increases the chance of exposing porosity in the core as can be seen in Figure 7-19. These important points are not widely recognized by designers.

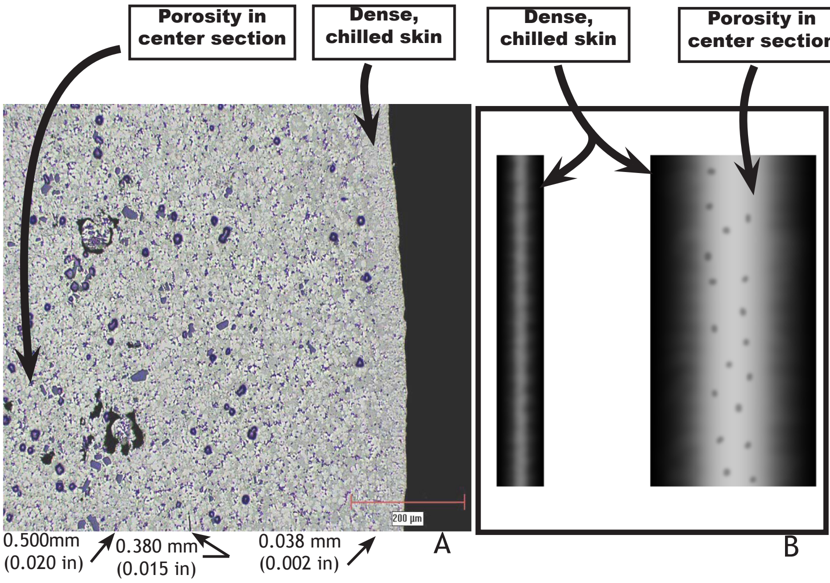


Figure 7-18: Skin Effect Due to rapid solidification in the die, a die castings outer skin has a dense, fine grained structure with a higher strength than underlying metal. According to Borland and Tsumagari (2007), the skin extends inward to a typical depth of 0.38 to 0.50mm (0.015 to 0.020"). The rapid solidification of the skin tends to drive porosity to the center of the section as portrayed here.

Exterior or surface porosity can be identified with the naked eye, magnification or with penetrant inspection methods.

The as-cast surface is more dense than the core, and hence, stock removal by machining should be minimized. The die caster should be aware of critical areas as porosity can be managed to large extent via gating, overflows, chills and various process parameters.

Castings can be inspected utilizing non-destructive inspection techniques NDT. When specified, reasonable detection levels should be employed. Non-destructive testing methods for internal porosity detection include ultrasound (UT), radiography/X-ray (film, real-time, ADR automatic defect recognition), eddy current (EC) and various weight techniques. Methods for external porosity detection include visible and fluorescent die penetrant (DPI).

If porosity is a major concern due to leakage/pressure tightness issues, the employment of a pressure test should be considered.

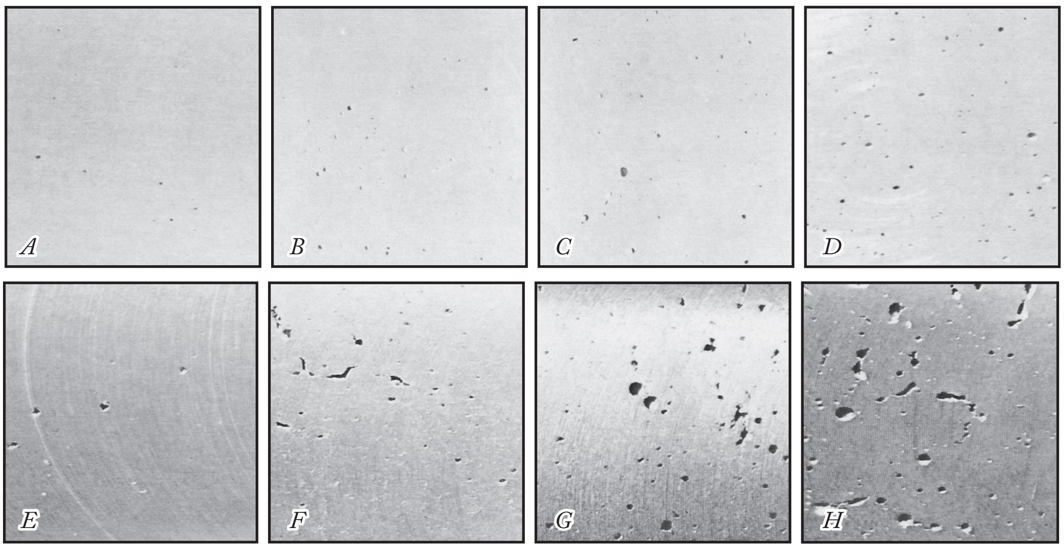


Figure 7-19: Various degrees of porosity exposed after machining.

7.1 Internal Porosity

Interior porosity can be detected by a range of techniques, including detection by fluoroscope, X-ray and ultrasonic procedures. Internal porosity can also be detected in the die casting plant through sectioning or simulated machining techniques, when the die caster is advised of the areas to be machined.

Part prints should call out the areas where only the lowest levels of pinpoint porosity can be tolerated, areas where additional porosity can be tolerated and areas where larger porosity will have no effect on the casting application.

Whether porosity levels are defined by "X-ray" or "sectioning" procedures, each party should retain a sample radiograph or part section that defines the minimum acceptance standard (see fig. 7-19).

It is important that the user not specify porosity limits that are more stringent than required for the application. It is also usually necessary to establish specific porosity standards independently for each component design. The specification of special porosity detection operations will increase the cost of the castings.

The type of porosity may be important in defining porosity standards. A small dispersion of smooth, round holes (salt and pepper generally less than 1mm in diameter), which are caused by release of disolved hydrogen or entrapped gas bubbles, may have a minimal effect on part strength and will not tend to cause leaks. Individual, non-grouped pores are generally less than 2mm in diameter. These types of gas porosity are those most commonly found in die casting. See figure 7-19A through 7-19E.

In critical areas of a casting. where porosity is a concern, the acceptable porosity is often specified in the following format:

1. *The maximum allowable size of individual porosity pores.*
2. *The minimum allowable spacing between pores.*
3. *The maximum allowable density of pores in a defined area (pores/distance2)*

For example a note based on this format may look like:
Porosity specification in crosshatched marked areas on print: 1mm maximum porosity pore size, 2mm minimum spacing between pores, maximum of 10 pores per $12mm^2$.

More jagged-shaped shrinkage porosity, caused by solidification, can cause more problems. This is typically a part design-related issue, and is caused by heavy sections in the casting. Shrink porosity can be interconnected and may result in leakers. The shrink porosity does not have to be visible to cause leakers and is often microscopic in nature. Shrinkage porosity, when exposed, can be larger than gas porosity. For instance, a typical specification for a large drilled and tapped boss is < 2 mm on the first three threads, < 5 mm on other threads. See figures 7-19F through 7-19H and 7-19C, as well, as subsection 7.

Minimizing porosity begins with up-front planning in the design of the part and die casting die and the management of heat in both the die and the castings. Sophisticated process control and monitoring equipment as well as simulation software is best utilized for castings with stringent porosity requirements.

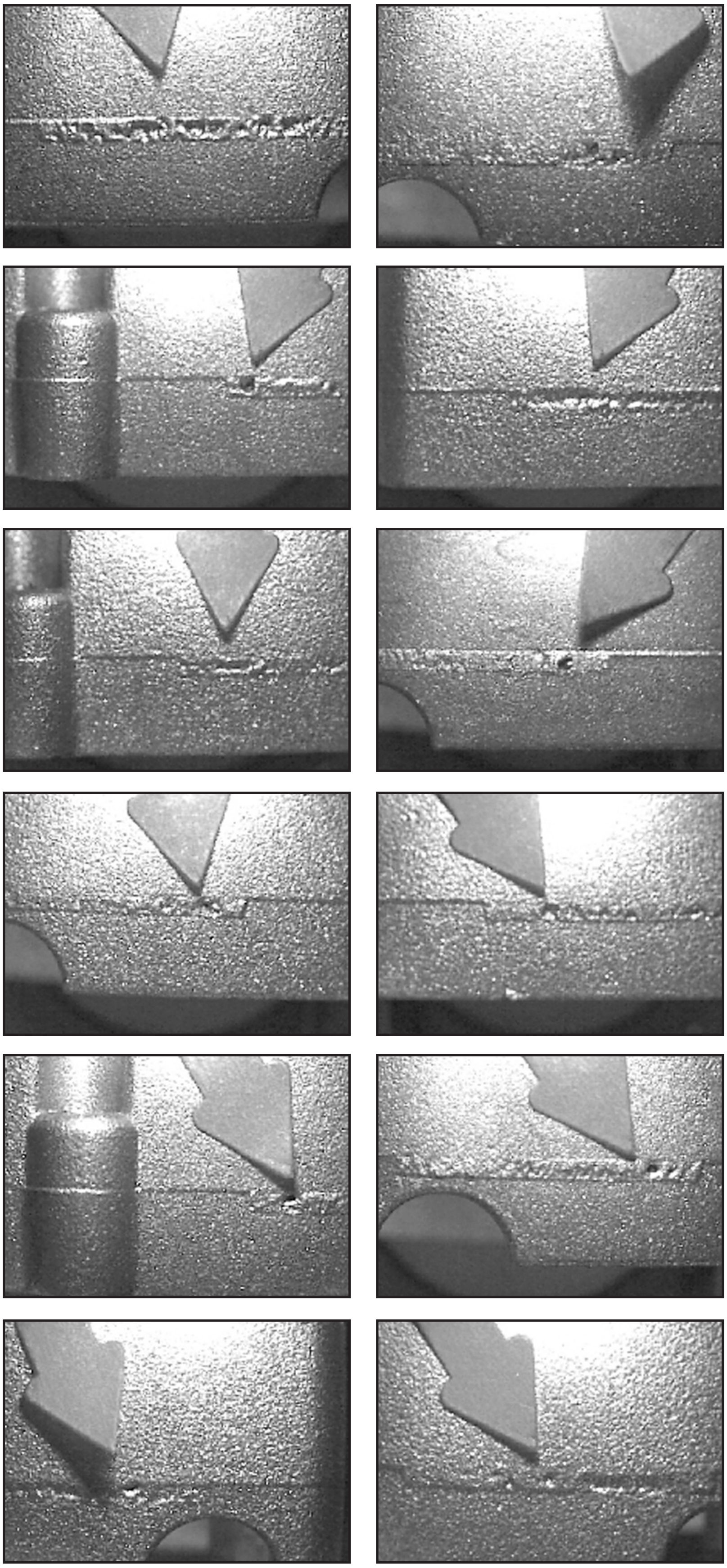
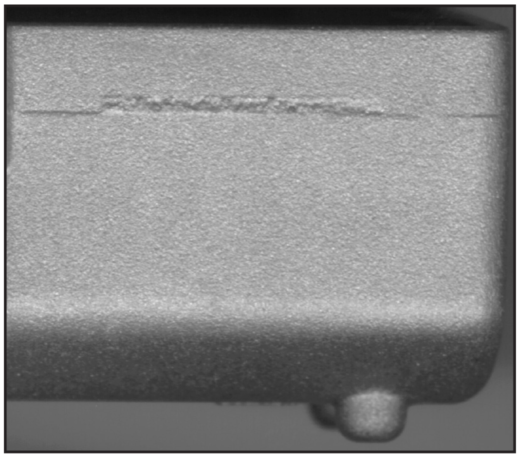
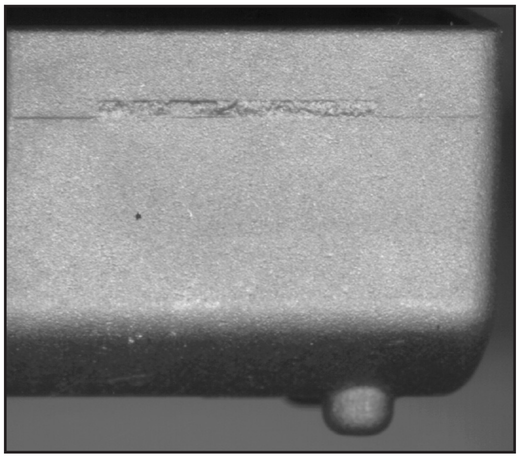


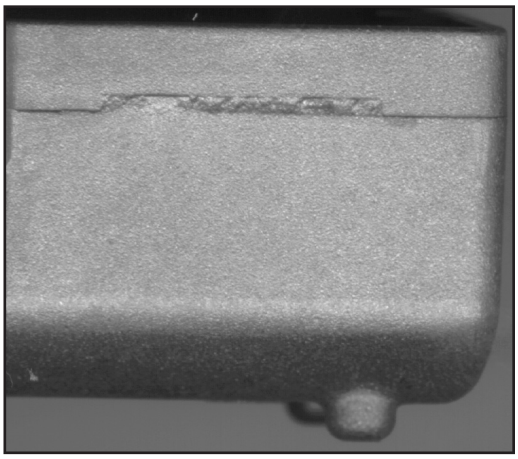
Figure 7-20A: Parting line porosity at various severity levels.



Minor



Moderate



Major

Figure 7-20B: Parting Line Break-Out placed into 3 groups.

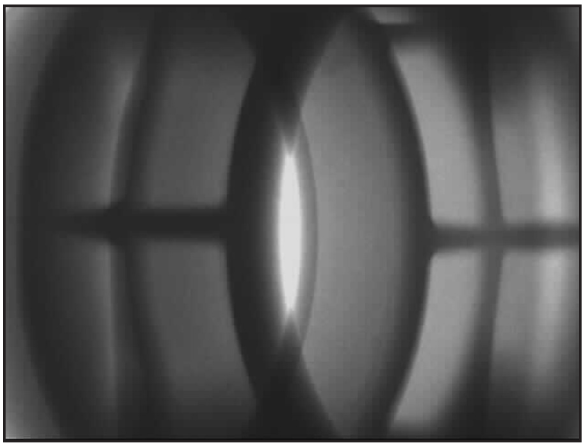


Figure 7-21A: Example radiograph of a casting with no visible porosity revealed by radiography. This level of soundness is achievable through consultation with your die caster and good part design, process design and process monitoring.

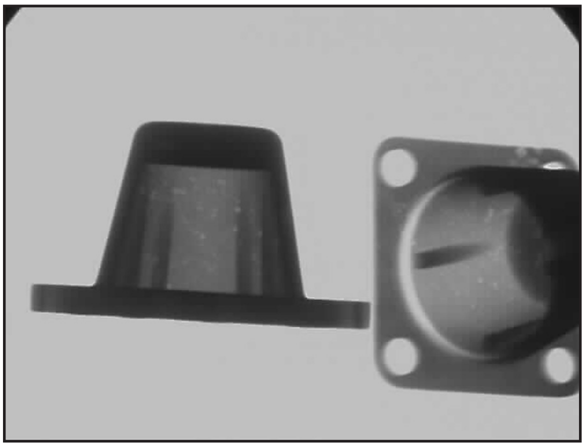


Figure 7-21B: Example radiograph of porosity that does not impact part form, fit or function. The user should be agreeable to accepting a specified amount of porosity in areas of the casting where it does not impact form, fit, or function.

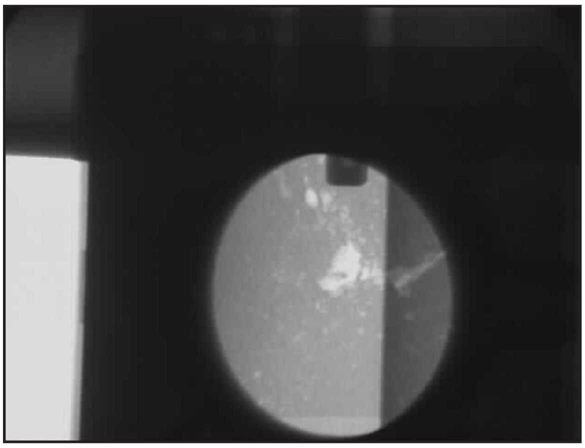


Figure 7-21C: Example radiograph of shrinkage in a thick cross-section.

If specific porosity will be detrimental to the use of the product being cast, the die caster must be informed of the areas that will require special control to reduce the incidence of such porosity. This information must be supplied in detail at the time of the RFQ, so that measures such as part design change requests, accountability for higher scrap or utilization of special processes, can be taken in advance of die design and construction.

Since zero porosity is virtually impossible to achieve in a die casting, the size, nature and location of permissible porosity should be identified by the customer, with the agreement of the die caster. The user should be agreeable to accepting a specified amount of porosity in areas of the casting where it does not impact form, fit or function. See figure 7-19.

Note: ASTM Nondestructive Testing Standard E505 provides reference radiographs for inspection of aluminum and magnesium die castings.

7.2 Parting-Line Porosity

It should be noted that some parting-line porosity may exist in some die castings. Whenever possible, castings should be designed to avoid parting lines on complex functional or cosmetic surfaces. Special measures will need to be taken when this cannot be done, such as adding changes in the parting line, adding a CAM-type movement or a hand-removal operation to blend surfaces. Parting line porosity should not be confused with parting line break-out (see figures 7-17A & B).

8 Pressure-Tight Castings

Pressure tightness (leakage) requirements for components add to die design and casting costs and should not be specified unless required for the application.

When a pressure-tight die casting is desired, the customer should specify at the time of quotation the pressure the die casting is expected to withstand and the relevant testing method to be employed.

Common leak testing methods for die castings include pressurized air bubble testing (to discover the location of the leak), gas pressure decay and mass flow testing (to determine the magnitude of the casting leakage in pressure loss or flow rate per unit time), and helium detection probe (when very low leak rates are required).

When the die casting is expected to withstand specified pressures, the die caster can offer pressure testing of a statistical sample of parts, 100% sampling or impregnating of parts to meet the pressure specification.

If machining of the pressure-tight die casting is required, it must be recognized that impregnation may be required after machining. The die caster should be advised of the specific areas to be machined in advance of the die design.

The die caster will not be responsible for machining, impregnating or testing costs if the machining is done by the customer. By mutual agreement, the die caster may accept for replacement or credit the die castings that have failed the pressure test after the machining and impregnation process.

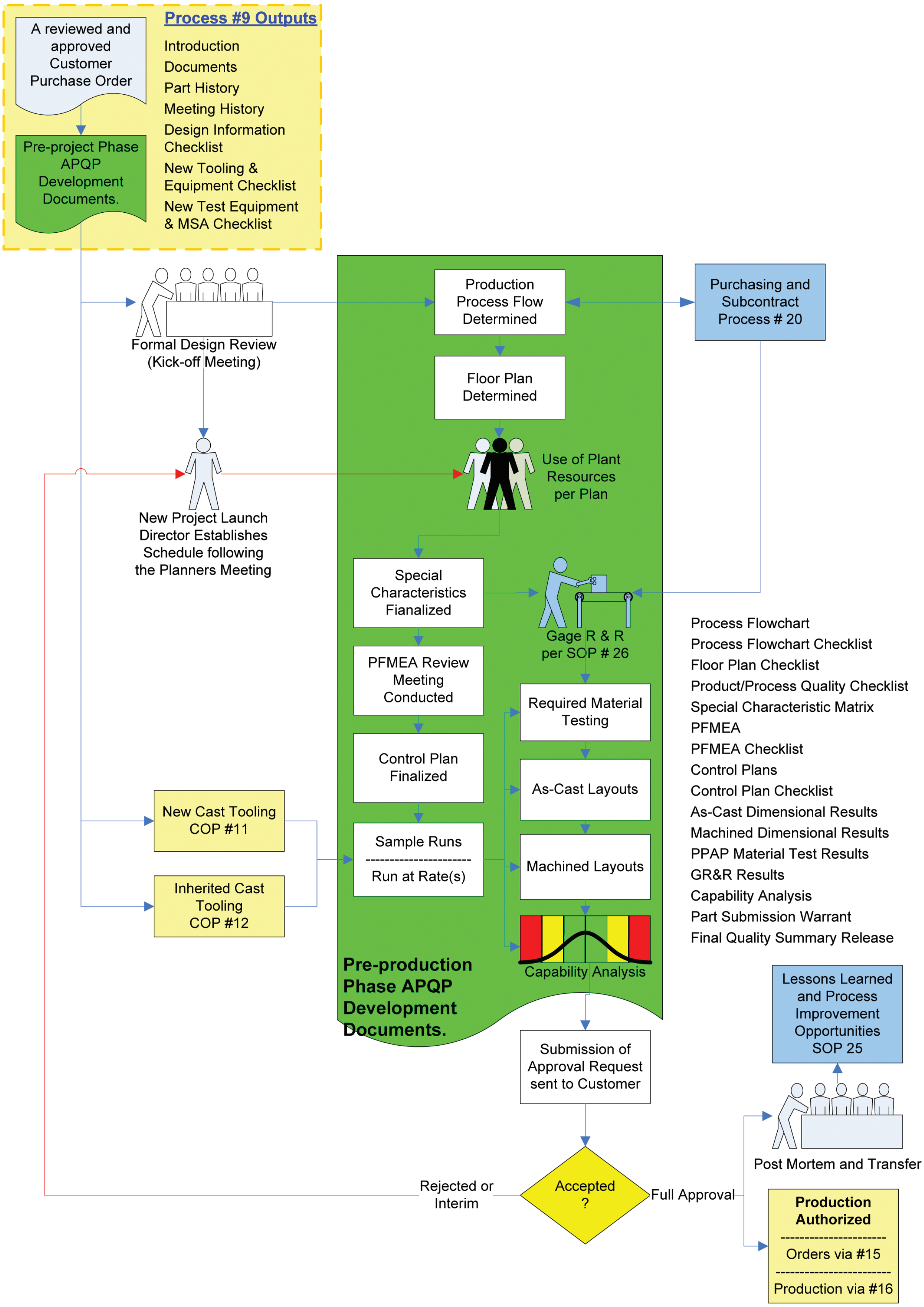


Figure 7-22: Example Advanced Product Quality Planning process flow chart.

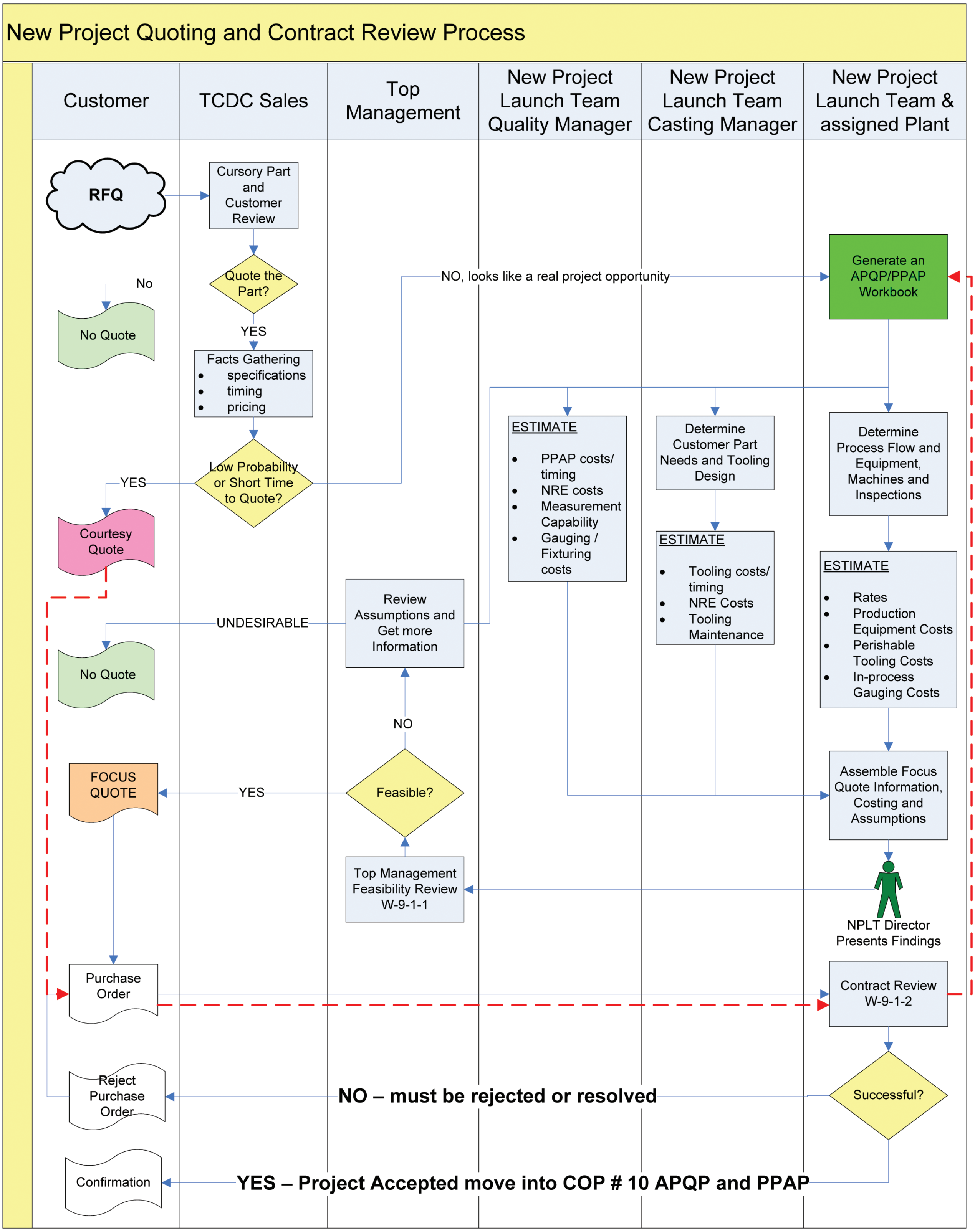


Figure 7-23: Example New Project process flow chart.

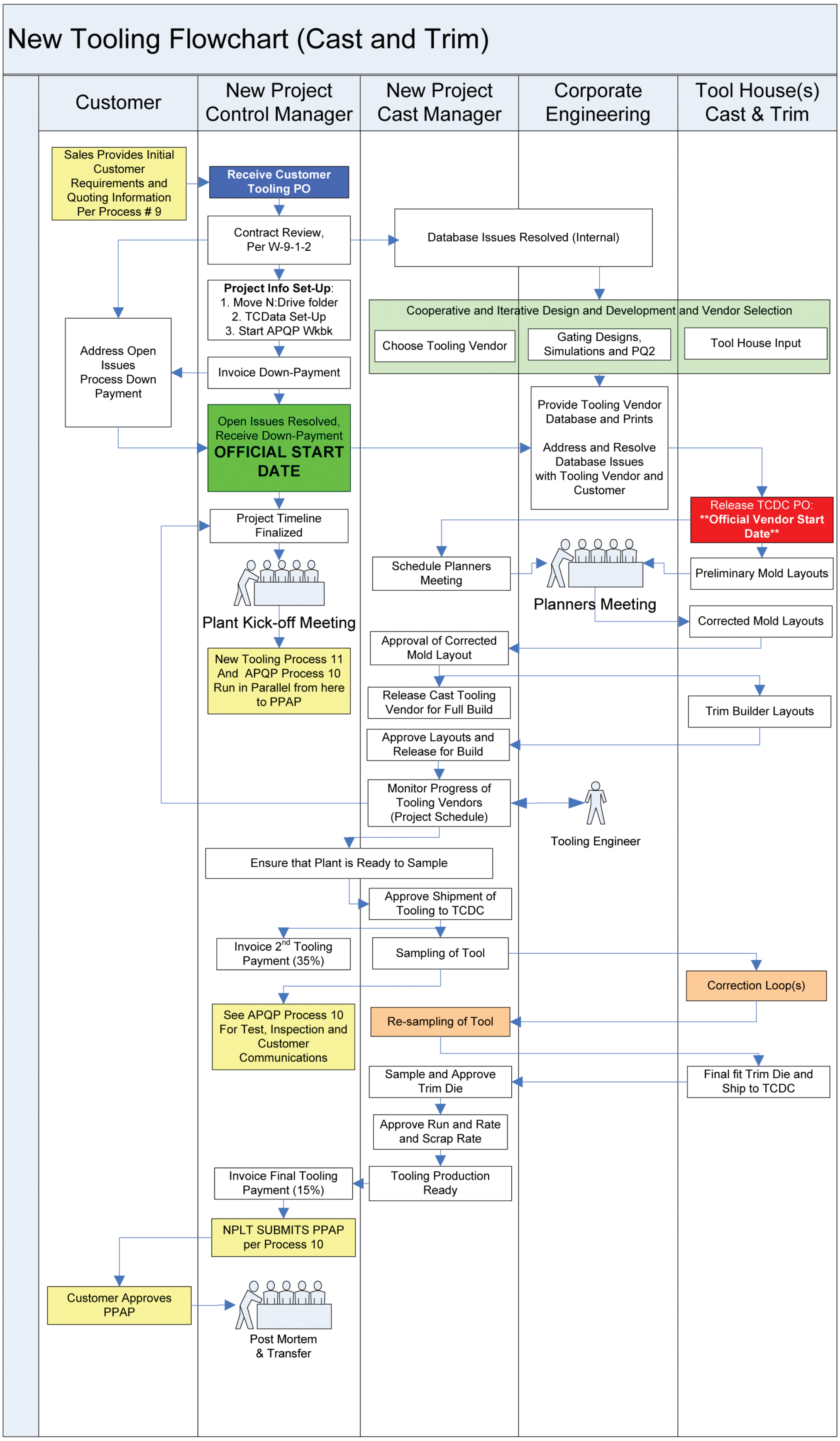


Figure 7-24: Example New Tooling processes flow chart.