#### Herein are the minimum requirements that shall be incorporated into the manufacturing process for Aluminum High Pressure Die Castings. This Process Specific Statement of Requirements (Process SOR) is in addition to and not intended to replace any requirements as outlined in the GM Supplier Quality SOR (GM 1927-03).

The GM Supplier Quality SOR (CG4338) includes a reference to compliance with CQI-27: Castings System Assessment. Any item which is mandatory in this Process SOR is also mandatory for GM in CQI-27.

The required tasks indicated below are based on experience, best practices, and lessons learned to improve part quality. They are applicable to all Tiered casting suppliers in the supply chain. Any deviations requested for mandatory items are to be detailed in *CG3404 M7 Technical Issues List* found in eSOR Appendix M7, and reviewed and approved by the appropriate General Motors Product Engineering Technical Specialists prior to sourcing*.*

In the event of any conflicting wording between this document and any similar document received from General Motors Product Engineering, the wording in the Product Engineering document shall prevail.

*Note:* “Shall” in this document is mandatory. “Should” is highly recommended.

It is intentional that this document is NOT GM Confidential.

**Table of Contents**

|  |  |
| --- | --- |
| 1. General Description | 1 |
| 2. Casting Process Requirements | 2 |
| 3. Supplier Acknowledgement | 10 |
| Appendix A – Revision History | 11 |

1. **General Description**

This Process Document is for a wide variety of aluminum high pressure die castings which are used in automotive applications. They may be purchased as raw castings, pre-machined components, or as part of finished assemblies. The high pressure die casting process may include different types of cast machine equipment such as cold chamber, hot chamber, squeeze cast.

The primary focus of this Process Document is on the raw casting. If further machining and assembly work is required, that work content would be covered by other SOR's.

This Process Document is not a procedure for how to make a casting. It is not a Control Plan. It is most similar to a PFMEA. It is a consolidation of Lessons Learned. It is Process content typical of foundries which have very good quality metrics.

The supplier’s piece price and tooling cost must include Full Compliance with this Process Document.

A Bidder is not required to have Full Compliance with this Document in order to quote, but must have a reasonably high compliance in order to pass a Technical Review. If awarded a contract, Full Compliance with this Document must be implemented before PPAP. APQP will track the Supplier’s progress.

1. **Casting Process Requirements**

**2.1 Design and Tooling**

* + 1. Casting tooling design begins with a review of the Finite Element Analyses (FEA). The Design Responsible party must disclose to the foundry any features on the casting which would have an Extreme Load Maximum Stress greater than 50% of the Yield Strength of the alloy. Yield Strength as used in this discussion is the x-bar (mean value) minus 3s (three sigma) statistical calculation from tensile bars pulled at the casting source. The foundry must take these features into account when designing the tooling and the process. Tooling: at any features in the FEA with Extreme Load Maximum Stresses over 50% of the Yield Strength of the alloy, the casting simulation should avoid hot spots, air entrapment, multiple metal fronts converging.  Process: any features in the FEA with Extreme Load Maximum Stresses over 50% of the Yield Strength of the alloy must be considered when establishing product audits such as wall thickness, microstructure, hardness, x-ray, crack inspections.
    2. If there are any features on the casting which would have an Extreme Load Maximum Stress greater than 75% of the Yield Strength of the alloy, then Limit Testing at Extreme Load conditions is appropriate. The foundry may not be responsible for this testing, however, the foundry is responsible to provide worst-case parts for this testing. Customer Product Engineering will define the worst-case conditions, such as internal porosity, for Limit Testing.
    3. If there are any features on the casting which would have an Extreme Load Maximum Stress greater than 75% of the Yield Strength of the alloy, Customer Product Engineering may restrict shipment of castings for serial production only to the extent of what was provided for Limit Testing. This may be tighter than stated Product Engineering acceptance criteria if the worst-case parts provided were not at the extremes of the permissible acceptance criteria. In other words, if it was not Limit Tested, it cannot be shipped. This is a decision to be made by GM Product Engineering.
    4. Due to the complexity and pressure tightness requirements of many die castings, single cavity dies are required. If a supplier predicts a multi-cavity die will work, the proposal must be approved by GM Product Engineering before a quote is submitted.
    5. The supplier must use solidification modeling software such as MagmaSoft, AnyCasting, ProCast, or similar software approved by GM on the casting prior to tooling construction and prototype part submission. Results must be reviewed with the GM DRE and/or casting engineer.
    6. It is strongly recommended that the solidification modeling software be capable of modeling jet cooling. It is strongly recommended that the solidification modeling software be capable of modeling squeeze pins.
    7. Overflows must be located where simulations show the last places to fill.
    8. All dies must be vented to atmosphere. All dies must have at least one chill vent.
    9. The die cavity steel must meet GM Spec HPDC-G-2. Typical alloys are ADC3, H11, H13, 8407.
    10. The holding blocks (frames) must be made from steel. Typical alloys are P20, 4140, 8620.
    11. Die steel must be heat treated in accordance with NADCA #207-2006 or similar procedure.
    12. The tool builder must color check the die matching in a spotting press.
    13. With GM Product Engineering prior approval, the supplier can utilize “soft tools” to produce beta and gamma samples if production tooling is not available when the parts are required. These castings may be used by General Motors for product validation tests, key engine builds, and machine tool runoffs. The castings must be produced with the production intent melting and metal handling process.
    14. Abrasive systems (such as shot blast and hand grinding) are not permitted for cleaning dies. Non-abrasive systems (such as dry ice, glass bead, high pressure water, solvent washing, and ultrasonic) are required.
    15. Tooling design must allow all raw casting locators (datum surfaces) to be on one piece of the die steel (such as all on the moveable side, or, all on the fixed side). This is for dimensional control purposes.
    16. Raw casting locators (datum surfaces) must not be removed by post-processing or finish machining.
    17. If the supplier creates the raw casting drawing, that drawing must be approved by GM Product Engineering. If a supplier is creating the tolerances between raw casting features and any other Drawing / Math Model, then GM Product Engineering must review and approve those tolerances.
    18. Supplier shall have a programmable Coordinate Measuring Machine (CMM) on site. The CMM must be run in an automatic mode. The CMM is considered the “gage of record” for dimensional measurements.
    19. The source shall maintain a CMM hit point map/drawing showing all CMM hit points that are agreed upon between the supplier and GM.
    20. The X-Y-Z datum surfaces used on the machined components should be the same X-Y-Z datum surfaces as the raw castings whenever possible. This is for dimensional purposes. Other surfaces may be used for machining and assembly.
    21. The raw casting datums must be included in all CMM hit point programs. The intent is to be able to dimensionally check the casting at any stage of manufacture in order to know if the raw casting was To Print. This expressly includes being able to check a finish machined component to determine if the raw casting was To Print.
    22. Scanning of castings may be required. The scanning may be out-sourced. Scan reports must include a screen shot showing which surface features were used to align the scan to the 3D Math Model; and what is the distance, D, of those scanned surface features to each of the same features in the 3D Math Model.
    23. Results must be shared with GM Product Engineering and the responsible Supplier Quality Engineer.
    24. Replacement inserts (new steel) requires PPAP approval and possible SPCR (Supplier Process Change Request) submission with possible PTR (Production Trial Run) requirements.
    25. All tooling repair (welding, grinding, machining, insert replacement) requires dimensional verification (internal approval) prior to re-instituting the tool for production volumes. Supplier must consult with the appropriate Supplier Quality Engineer for potential PPAP requirements.
  1. **Molten Metal**
     1. It is required to use ASTM E716 disk book molds for chemistry samples.
     2. There must be a Spectrometer on-site for final chemistry control.
     3. The Spectrometer must have certified Master Calibration Standards which cover the range of each chemistry element being controlled. Sufficient Calibration Masters must be on site in order to audit each element being controlled in direct comparison with a Calibration Master.
     4. A procedure must be posted near the Spectrometer which clearly defines the tolerance range of the Master Calibration Standards.
     5. For any mandatory elements, control limits must be reduced by the tolerance allowed on the Master Calibration Standards.
     6. The Iron:Manganese ratio must be calculated and controlled. A common target is 2:1
     7. The Sludge Factor must be measured and controlled below 2.0, preferably below 1.8. SF = %Fe + 2X %Mn + 3X %Cr.
     8. All metal must be rotary degassed at least once before casting.
     9. Degassing in a central melter and autoladle transferring to cast machine holders is unacceptable. These autoladle transfer processes will not be Approved.
     10. Degassing must be in a transfer ladle or in a holder at the cast machine. The design of the degassing unit must have a baffle plate.
     11. The use of cast machines with integral melter/holders is strongly discouraged. It is often difficult to meet requirements for metal cleanliness and degassing. A minimum requirement is a baffled chamber with a rotary degassing unit running continuously.
     12. After rotary degassing, a vacuum gas sample must be taken in order to determine the specific gravity. Calculate specific gravity of sample using weight in air vs. weight in water method. The specific gravity must be within 0.10 of the theoretical maximum based on the chemistry of the alloy. For many alloys, the theoretical maximum is around 2.70.
     13. There should be a low frequency audit to measure the oxide content of the metal going into the shot sleeve using Porous Disk Filter Analysis (PoDFA). PoDFA can be outsourced. Future metal cleanliness requirements may be based on PoDFA.
     14. The temperature of metal being delivered to a cast machine holding furnace must be checked. The temperature must be within +/- 25°C of the cast machine holding furnace setpoint. The intent is to prevent “shocking” the metal temperature at the cast machine holder.
     15. Holding furnaces at the cast machines must be capable of controlling metal temperature at the metal extraction point (Dip Well) to within +/- 5°C.
     16. The cast machine holding furnace thermocouple must trigger an alarm if out of range.
     17. Charging ingot or scrap into the cast machine holding furnace and running production out of it at the same time is prohibited.
  2. **Hypereutectic Silicon Alloys such as 390 and ADC14**
     1. The silicon particle size in the castings must be below 50 microns.
     2. Phosphorus must be greater than 0.005
     3. Iron must be less than 0.80
     4. The depth of the surface Silicon Depletion zone must be measured and controlled.
  3. **Cast in Place Inserts**
     1. GM Product Engineering must approve the source for the inserts.
     2. The insert source must implement Full Compliance with the applicable Process SOR before PPAP. For example, an iron bearing cap casting source must implement Full Compliance with the GM Iron Casting Process SOR before PPAP.
     3. Inserts must be pre-heated immediately prior to injecting aluminum into the die.
     4. The inserts must be dry. The volatiles content on the inserts must be audited, measured, and recorded.
     5. The inserts must be properly stored clean and dry.
     6. There must be a regular audit to section the castings to inspect the bonding of the insert with the aluminum. Audit results must be documented.
     7. Machined castings must be dye penetrant audited to inspect for cracks around the inserts. Audit results must be documented.
  4. **Pouring**
     1. Ladles must be made of or coated with an insulating material.
     2. Automatic pouring of molten metal into the mold is required. Manual pouring is not allowed.
     3. Ladles must be free of skull (aluminum oxide film) before entering the dip well.
     4. Ladle design must have a dam (hole in the back) to hold back the dross.
     5. Dipwells must be frequently skimmed to minimize the dross accumulation.
     6. Metal ladles should be on heat at their home position.
     7. Launders from pressure pour dosing furnaces must be designed and maintained such that metal does not buildup in them.
     8. When pressure pour dosing furnaces are used, an inert gas or dry air may be used to pressurize the chamber. If air is used, the dew point must be less than -40º C, preferably below -80º C.
     9. Equipment computer programs or mechanical limits for pouring and cycle times must be protected from non-authorized changes so that only authorized personnel can change the program or settings.
  5. **Cast Machines**
     1. The minimum die cast machine size must be determined using projected area/shot force calculations such as North American Die Casting Association (NADCA) PQ² software or other similar calculation methods.
     2. Strongly prefer metal pressures are over 10,000 psi = 700 kg/cm2 = 700 bar = 68.5 MPa. To meet common Product Engineering requirements for material properties, internal porosity, and leakage, the pressure is usually about 80 MPa.
     3. Cast machines must have real time closed loop shot end control capability for shot speeds and pressures.
     4. Cast machine must have real time closed loop monitoring which is either tied into the extractor/robot control or creates an alarm when key parameters are beyond control limits.
     5. The entire shot curve must be monitored, not just discrete points.
     6. For machine tonnages over 1800T, ABAQUS software or similar software is strongly recommended for analyzing die / machine distortion.
     7. Machines with automatic tie bar adjustment are preferred.
     8. The fill percentage in the shot sleeve must be at least 50%.
     9. The foundry must correlate the number of start-up shots with the finish machined / thoroughly inspected part quality.  The number of parts to scrap is not based on the first good part, it is based on the last bad part.  There can be some overlap of good and bad as the die heats up.  Must assure that none of the bad parts are shipped.  Foundries with water cooled dies, who understand the correlation concept well, are usually scrapping the first 15 to 30 shots. Foundries with oil cooled / heated dies, who understand the correlation concept well, are usually scrapping the first 3 to 5 shots.
     10. Thermocouples in the molds are recommended. The temperature should be continuously displayed. Temperature should be monitored with set points and tolerances. There should be an alarm to indicate when the temperature is out of range. Automatic temperature adjustment is preferred.
     11. Flow meters are required on all mold water / oil lines.
     12. Water, air, oil lines must be hooked up as designed. A well written Work Instruction with photos must be checked during every set-up. Error proofed or color-coded lines are required.
     13. Internal mold water lines must be checked for water flow rate during maintenance. A qualitative inspection for flow is unacceptable; a quantitative measure of the flow rate is required. The intent is to maintain the tooling with the flow rate used in the design simulations.
     14. If external cooling is utilized, spray flow rates and location must be audited and measured.
     15. Die temperature must be base-lined and audited to detect changes in thermal system. Infrared Cameras, lasers or touch probes can be used.
     16. Metal temperature inside the shot sleeve must be audited.
     17. Plunger tip lubricants must be dispensed onto the plunger tip outside of the shot sleeve. Dispensing plunger tip lubricants inside the shot sleeve is not allowed.
     18. In order to meet porosity specifications, it is critical for the die cavity to be totally dry when the shot is made. This must be taken into account when designing the die and selecting the spraying method.
     19. Spray heads must be programmable or dedicated to the die.
     20. Spray heads requiring operator adjustment of flexible tubing are not allowed. Any copper tubing must be securely clamped such that the spray pattern is fixed.
     21. Manual spraying is allowed.
     22. It is recommended to sample new dies with manual spray only. Assure the die is completely dry. Inspections for porosity in the castings can be compared with the simulation modeling. After a baseline is established with manual spray, it is recommended to sample the dies with the auto sprayer (if an auto sprayer is intended to be used in production) followed by a manual blow off. Compare with the baseline. There should be no deterioration in the porosity results. If the results are as good as the baseline, then sample the die with fully automatic spray and blow off. Compare with the baseline. The intent is to assure that the automation is actually getting the die cavity totally dry.
     23. There must be a physical audit for the actual spray quantity per cycle.
     24. Extraction tools must be designed to utilize the biscuit or gating for clamping without touching the final casting product.
     25. Automatic extraction is preferred. Automatic extractors should be programmed to scrap castings when parameters, such as biscuit size, are out of range.
  6. **Heat Treating**
     1. Any heat treating must be before machining.
     2. Heat treating may be outsourced.
     3. Any liquid quench must have automatic temperature control and agitation. Equipment must be capable to control quenching medium to within ­± 5º C. Must be over 80C.
     4. The delay from solution heat treat into a quenchant must not exceed 30 seconds.
     5. Heat treating must be in full compliance with CQI-9: Special Process: Heat Treat System Assessment (HTSA), published by AIAG.
  7. **Machining**
     1. Machining may include features which are finish machined or which leave stock on the surface that will be machined at the customer’s plant.
     2. Any tapped blind holes must utilize “through tool coolant” tools to eliminate retained chips in the blind holes.
     3. Error-proofing in-line is required if similar looking part numbers go through the same machine line.
     4. Error-proofing is required before final packaging if similar looking part numbers are in production in the same facility.
     5. Scheduling production of similar looking part numbers on different production shifts is not error-proofing.
     6. It is strongly recommended to have systems in place to control casting temperature during machining to within +/-10º C if pre-machining the product, and within ±2º C if finish machining any features, to reduce dimensional fluctuations due to changes in ambient temperature.
     7. Production fixtures must use hydraulic or pneumatic clamping during the machining operations. Manual clamping is not allowed.
     8. All surfaces must be free of any corrosion, including white rust. Any salvage operation to remove white rust including use of Evapo-Rust® or Rust Veto® must be approved by GM Product Engineering.
     9. Equipment must be available on-site for retained material inspection (also known as millipore testing)
  8. **Gages**
     1. All surfaces of fixtures and gages which touch the part must be made from hard tool steel.
     2. The tips of all clamps on fixtures and gages must be built with replaceable tips.
     3. All features on fixtures and gages which measure a dimensional aspect of the part must be built within +/- 5-micron accuracy. This is the dimensional accuracy of the fixture and gage; not the dimensional accuracy of the part.
     4. The gage plan must be reviewed and agreed upon with GM Product Engineering. The plan may include in-line gage equipment for 100% check of critical dimensions as identified on SOR and/or part drawing.
     5. Functional gaging with mating parts may be required.
     6. Brackets and Mounts often require 100% gaging in a fixture which checks all mounting hole locations in the same setup.
  9. **Leak Testing**
     1. Some castings may require leak testing.
     2. Castings must be thoroughly dried before going into an air decay leak test. An in-line drier is often necessary.
     3. Casting cavities must be leak tested separately in order to assure there are no cross-channel leaks.
     4. Air decay / mass flow controllers must have automatic temperature measurement and adjustment.
     5. Leak Masters must have leak rates within +/- 10% of the maximum permissible leak rate of the part.
     6. A Zero Leak Master is required. Impregnate the Master. Verify in water dunk that is has zero bubbles.
     7. Air decay / mass flow cannot measure Zero leakage. This technology does not exist for Zero leak applications.
     8. The measured leak rate for the Zero Leak Master must be recorded and plotted. Customer air decay / mass flow limits must be reduced by the observed +/- variation of the Zero Leak Master.
     9. A certified orifice may be used as the Leak Master and as the Zero Leak Master.
     10. Air decay must pass Gage R&R below 10% at maximum leak specification. The supplier shall have a water dunk tank on site for determining the location of leaks on castings as shipped to the customer AND for fully machined castings returned from the customer.
     11. Water dunk must use water temperature at least 20C. 100% water dunk, zero bubbles, is common for components with a Zero leak requirement. Preferred water dunk parameters are 5 bar air pressure, minimum 15 seconds without a bubble.
     12. Some castings may require 100% flow testing. If flow testing is required, this must be automated equipment. Using round balls or probes is not acceptable.
     13. Air decay test equipment and flow test equipment must automatically stamp good parts while the part is still in the test fixture.
     14. Impregnation is not allowed unless expressly approved by Product Engineering. Product engineering must approve the sealant (resin) to be used. Product engineering must approve the impregnation source which would perform the impregnation. Impregnation must be in full compliance with the GM SOR for Impregnation of Castings.
  10. **Inspections and Testing**
      1. Supplier must have inspection tools available on site to evaluate blocked passages. These may include boroscope, endoscope, and fiber optics.
      2. A metallograph image analyzer on-site is required. A microscope is not sufficient. The image analyzer must be capable of measuring any Product Engineering requirements such as Area Fraction porosity, secondary dendritic arm spacing (SDAS), silicon particle size.
      3. Reference photographs must be readily available at the metallograph for all microstructure requirements.
      4. There must be a regular audit for sectioning raw castings to check wall thicknesses.
      5. If the supplier is responsible for machining, there must be a regular audit to section machined castings through features such as blind holes.
      6. The supplier must have dye penetrant (color check) available on site. Fluorescent Particle Inspection (FPI) may be required on site. There must be a regular audit to dye penetrant check (color check) or fluorescent particle inspect (FPI) sliced sections for cracks at any features in the FEA with Extreme Load Maximum Stresses over 50% of the Yield Strength of the alloy.
      7. There must be on-site capability to cut and NaOH etch castings for internal inspections. (NaOH is sodium hydroxide, also called caustic soda.)
      8. The supplier shall have X-ray capability on-site. There must be certified Masters at the X-ray for determining the sensitivity and resolution of the images.
      9. Under no circumstances can the internal porosity exceed ASTM E505 Level 2 using the 1/8” series of reference photos regardless of actual section size.
      10. At any features of the casting which would have an FEA Extreme Load Maximum Stress greater than 50% of the Yield Strength of the alloy the internal porosity must not exceed ASTM E505 Level 1 using the 1/8” series of reference photos regardless of actual section size.
      11. The supplier shall have Scanning Electron Microscope (SEM) capability available. The SEM does not have to be on-site. However, the location and access to it must be reasonable for defect analyses.
      12. The supplier is responsible for any residual stress testing required in the Product SOR. Residual stress testing may be outsourced.
      13. The supplier is responsible for any fatigue testing required in the Product SOR. Fatigue testing may be outsourced.
      14. All mechanical property testing must be performed on-site. The properties to be measured are ultimate tensile strength, yield strength, and percent elongation. An extensometer must be attached to the test specimen for determining the Yield Strength.
      15. The supplier is required to perform mechanical property testing. Mechanical properties are often required from test bars cut from actual castings in an area designated on the engineering drawing or in the part quality document. These are mean minus three sigma requirements, not mean. The test bar location in the casting will be dimensioned from casting features.
      16. If the dimensions of a casting do not allow an industry standard size bar to be cut out, then a substitute must be used. Separately cast tensile bars are common. The use of a substitute must be approved by GM Product Engineering.
      17. Hardness testing must be in-house.
      18. The supplier must have certified Master blocks for auditing the calibration of the hardness tester.
      19. The tolerance range for the Master must not exceed +/- 3%.
      20. Customer hardness limits must be reduced by the +/- tolerance allowed on the Master Hardness blocks.
      21. Unless Product Engineering specifies otherwise, Brinell hardness test uses a 500Kg load, 10mm diameter indenter, and 30 second dwell time.
  11. **Repairs**
      1. GM Product Engineering must approve any salvage repair procedures. Casting repairs, such as welding, epoxy, Devcon, straightening, and impregnation, are not permitted, unless approved by GM Product Engineering.
      2. If repairs are allowed by GM Product Engineering, procedures must be completed and approved by GM Product Engineering before repairs can be used.
      3. If straightening is allowed, it requires a fixtured, automated process. Manual methods are not allowed

1. **SUPPLIER Acknowledgement of CG5305 Aluminum High Pressure Die Castings SOR REQUIREMENTS**

The casting source must acknowledge they have read and understand this document. Please complete this page and submit it as part of the technical review. If you do not complete this form, you will not obtain technical approval.

Full name of the foundry: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Specific address of the foundry: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Foundry Representative Name: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Foundry Representative Title (function):\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

Date: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

**Appendix A** – Revision History

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| **Rev** | **Date** | **Remark** | **Responsible** | **Approver** | **Approving Organization** |
|  |  | Initial transfer onto CG Template by Document Owner – Thomas Boone | Thomas Boone | Scott E Miller | Supplier Quality |
| A | 01/11/2018 | Initial upload of document to GDM | Thomas Boone | Scott E Miller | Supplier Quality |