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CQI-27

Special Process: Casting System Assessment

2nd Edition



Insight. Expertise. Results.



ABOUT AIAG

Purpose Statement

Founded in 1982, AIAG is a globally recognized organization where OEMs and suppliers unite to address and resolve issues affecting the worldwide automotive supply chain. AIAG's goals are to reduce cost and complexity through collaboration; improve product quality, health, safety and the environment; and optimize speed to market throughout the supply chain.

AIAG Organization

AIAG is made up of a board of directors, an executive director, executives on loan from member companies, associate directors, a full-time staff, and volunteers serving on project teams. Directors, department managers, and program managers plan, direct and coordinate the association's activities under the direction of the executive director.

AIAG Projects

Volunteer committees focus on business processes or supporting technologies and methodologies. They conduct research and develop, publish, and provide training on standards, conventions, standard business practices, white papers, and guidelines in the areas of automatic identification, CAD/CAM, EDI/electronic commerce, continuous quality improvement, health focus, materials and project management, occupational health & safety, returnable containers and packaging systems, transportation/customs and truck & heavy equipment.

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FOREWORD

Automotive Industry Action Group (AIAG) committees are made up of volunteers from member companies in the automotive industry. The work of preparing process audits is done by AIAG technical committees. This edition is a collaborative work of OEM, Tier 1 suppliers, and Casting suppliers.

The main task of technical committees is to prepare Automotive Standards and System Requirements. Draft documents adopted by the technical committees are circulated to the Steering Committee and industry experts for review and consensus approval. Publication of the documents requires approval by the Quality Steering Committee.

The 2nd Edition has many enhancements over the 1st Edition. Tables with similar requirements have been consolidated. More content has been added. Unclear wording from the 1st Edition has been revised. Greater emphasis has been placed on content generally regarded as mandatory. Any deviations must be authorized by documentation from customer Product Engineering. The objective is to have robust processes which minimize the risk of casting defects in automotive applications.

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INTRODUCTION

General

The work of preparing CQI-27 Special Process: Casting System Assessment was carried out through the AIAG Casting Work Group. These casting requirements are complementary to customer and product standards.

The Casting System Assessment can be used to assess an organization's ability to meet the requirements in this assessment, as well as customer, regulatory, and the organization's own requirements. The Casting System Assessment can also be used between an organization and its suppliers.

Process Approach

The Casting System Assessment supports the automotive process approach as described in IATF 16949.

Casting System Assessment Goals

The goal of the Casting System Assessment is the development of a robust casting process by eliminating common root causes of casting defects.

The Casting System Assessment, coupled with an internationally recognized quality management system and applicable customer-specific requirements, defines the fundamental requirements for casting processes.

The Casting System Assessment is intended to provide a common audit for automotive casting suppliers.

Assessment Process

Ongoing assessments shall be conducted annually, unless otherwise specified by the customer, to reexamine the continuing compliance with the Casting System Assessment. Each assessment shall include a review of the organization's systems using the Casting System Assessment. The assessment shall use the process approach to auditing/assessing as identified by the requirements of IATF 16949.

Customers may require the casting supplier to complete a new self-assessment at any time when the casting source is installing new processes, developing new commodities, or any other significant change to their business in order to assure that they are planning for Full Compliance with CQI-27. Casting sources should contact their customers for clarification of assessment frequency.

Assessor Qualifications

Assessor(s) should have the following specific experience to conduct the Casting System Assessment:

1. Assessor should be an experienced quality management system (QMS) internal auditor (for example, IATF 16949, ISO 9001).
2. Assessor should possess casting process knowledge. Evidence shall include a minimum of 5 years' experience in casting processes.
3. Assessor should possess knowledge of and be familiar with the application of automotive quality concepts including statistical process control, measurement systems analysis, part approval, failure mode and effects analysis, and advanced quality planning.

NOTE: If more than one assessor is required to meet the above qualifications, the lead assessor shall be the person meeting the requirements in #1.

Other Requirements

The organization shall keep records as evidence of compliance to the requirements identified in the Casting System Assessment, as well as all appropriate action plans to address any unsatisfactory ratings. These records shall be readily available for review by any customer requiring compliance to the requirements within this document.

Some customers may require that the supplier's piece price and tooling cost must include full compliance with CQI-27. Suppliers should discuss this with potential customers for clarification. A potential supplier is not required to have full compliance with CQI-27 in order to quote, but must have a reasonably high compliance in order to pass a Technical Review with customer Product Engineering. If awarded a contract, full compliance with CQI-27 must be implemented before PPAP. APQP will track the supplier's progress.

There are multiple items throughout the CQI-27 Tables which are stated as mandatory "unless customer Product Engineering" agrees to some deviation. The intent is that the customer decides if a deviation will be permitted. The item is not discretionary for the casting source. In many customer organizations, the responsibility to review the request for a deviation belongs to Product Engineering. Product Engineering may involve other functional groups in their organization for input before reaching a decision. The appropriate technical resources must evaluate if a deviation is permissible. The communication with the supplier is documented through Product Engineering.

1 SCOPE

1.1 General

This document specifies process requirements for casting suppliers, who need to:

- demonstrate ability to consistently provide product that meets customer and applicable regulatory requirements, and
- enhance customer satisfaction through the effective application of the system, including processes for continual improvement of the system.

The Casting System Assessment is applicable to sites where customer-specified parts for production and/or service are processed throughout the automotive supply chain.

1.2 Application

All requirements of the Casting System Assessment are generic and are intended to be applicable to all organizations performing the casting operations addressed in this document, regardless of type, size, and product.

Ten Process Tables have been developed and the appropriate table(s) is to be referenced during the assessment. The Process Tables are specific to casting processes as noted below:

Process Table A	Grey iron, ductile iron, compacted graphite iron, and steel castings.
Sand Casting (Iron/Steel)	There is a wide variety of molding processes including green sand, air set bonded sands, shell molding, stacking molding, precision sand core packages.
Process Table B	Ductile iron, grey iron, and steel castings (except Centrifugal Liners which has its own Table). The process ranges from highly automated cells to labor intensive process flows.
Centrifugal Castings	
Process Table C	Grey iron Centrifugal Cast Cylinder Liners used in Cylinder Blocks for automotive applications. The liners may be pressed-in-place (PIP) or cast-in-place (CIP). It ranges from highly automated cells to labor intensive process flows.
Centrifugal Liners	
Process Table D	Castings from processes commonly called investment casting, lost wax, or precision mold. It ranges from highly automated cells to labor intensive process flows. A wide variety of cast irons and steel alloys.
Investment Castings (Iron/Steel)	
Process Table E	The semi-permanent mold process may include different types of cast machine equipment such as: gravity die casting, tilt pour, rotary, and low pressure die cast.
Aluminum SPM Cylinder Heads	
Process Table F	There is a wide variety of molding processes including green sand, air set bonded sands, shell molding, stacking molding, precision sand core packages.
Aluminum Sand Castings	

Process Table G	Aluminum semi-permanent mold and permanent mold castings (except Cylinder Heads which has its own Table). Includes pistons, aluminum alloy wheels. Cast processes include different types of equipment such as: gravity die casting, tilt pour, rotary, low pressure die cast, and pressure counter pressure.
Aluminum Metal Mold	
Process Table H	This Table is for conventional high pressure die casting, horizontal and vertical squeeze casting, semi-solid, and similar variants of die casting.
Aluminum High Pressure Die Cast	
Process Table I	This Table is for conventional high pressure die casting, horizontal and vertical squeeze casting, and similar variants of die casting.
Magnesium High Pressure Die Cast	
Process Table J	This Table is for cold chamber and hot chamber high pressure die casting of zinc alloys.
Zinc High Pressure Die Cast	

2 THE CASTING SYSTEM ASSESSMENT PROCEDURE

2.1 Instructions for Completing the Cover Sheet

1. **Facility Name:** Complete name of the foundry being assessed.
The foundry may have several buildings or physical locations in the same general area. The description must be clear about the physical locations being assessed.
2. **Address:** The complete address of the foundry being assessed.
3. **Phone Number:** The phone number of the foundry, including Country Code. If there is no common phone number for the foundry, the phone number of the Operations Manager, Quality Manager, or Sales Manager shall be used.
4. **Website:** The internet website of the foundry.
5. **Date of Assessment:** Enter the date(s) of the assessment. Use a format which will avoid confusion. Example: May 3 – 4, 2018.
6. **Date of Previous Assessment:** List the date of the previous Special Process: Casting System Assessment of this foundry.
7. **Type(s) of Casting at this Foundry:** Place a checkmark to designate all casting process(es) performed at this foundry. This information determines the appropriate Process Table that shall be used during the assessment. Processes not listed on the cover sheet are not part of the Casting System Assessment.
8. **Date of Re-assessment (if necessary):** If “Non-Conforming” findings were observed from the original assessment, then the foundry shall address each item with implementation of the corresponding corrective action(s). The date of the re-assessment shall be given here, and the appropriate item(s) from the Process Tables, in the original assessment, shall be modified to reflect that the evidence, relating to the implementation of the corrective action(s), has been observed. Also, the number of “Non-Conforming” findings shall be modified as appropriate.
9. **Personnel Contacted:** List the name(s), title(s), phone number(s), and email address(es), if available, of the principal participants from the foundry’s organization.
10. **Auditors/Assessors:** List the name(s), Company(ies), phone number(s) and email address(es), if available, of the auditor(s).
11. **Number of Conforming / Non-Conforming / Not Applicable Findings:** Enter the number of each finding observed during the assessment.

Cover Sheet

CQI-27 Special Process: Casting System Assessment				
Complete Foundry Name:				
Complete Address:				
Phone Number:				
Website:				
Date of Assessment:				
Date of Previous Assessment(s):				
Date of Re-Assessment (if necessary):				
Foundry Personnel Contacted:				
Name:	Title:	Phone:	Email:	
Auditors/Assessors:				
Name:	Company:	Phone:	Email:	
Types of Casting Processes at this Foundry:		Number of Conforming Findings	Number of Non-Conforming Findings	Number of Not Applicable Findings
Process Table A				
Sand Casting (Iron/Steel)				
Process Table B				
Centrifugal Castings				
Process Table C				
Centrifugal Liners				
Process Table D				
Investment Castings (Iron/Steel)				
Process Table E				
Aluminum SPM Cylinder Heads				
Process Table F				
Aluminum Sand Castings				
Process Table G				
Aluminum Metal Mold				
Process Table H				
Aluminum High Pressure Die Cast				
Process Table I				
Magnesium High Pressure Die Cast				
Process Table J				
Zinc High Pressure Die Cast				

2.2 Instructions for Completing the Casting System Assessment

The assessor shall assess the Foundry's compliance to all applicable Process Tables by comparing the evidence presented by the foundry to the requirements listed in the "Minimum Requirement" columns.

1. Complete the Casting System Assessment, including all applicable Process Tables to determine the level of compliance.
2. Address each Non-Conforming item and determine corrective action, including root cause analysis and implementation of the corresponding corrective action(s). The corrective action(s) should be completed within 90 days. Records of the corrective action, including verification, shall be maintained.
3. Number of Process Table items identified as non-conforming in the Comments/Observation column to be reported.
4. Assessments shall be conducted annually.

NOTE 1: In the Process Tables, the words "must" and "shall" indicate mandatory requirements and the term "such as" indicates that any suggestions given are for guidance only. "Should" indicates strongly recommended.

NOTE 2: If an item is not applicable to the foundry, then the assessor shall write "N/A" in the Conforming / Non-Conforming / Not Applicable column, and write a brief reason why it is not applicable in the "Observations/Comments about Actual Condition" column.

If the observed evidence is in compliance to the item, the assessor shall note the evidence in the "Observations/Comments about Actual Condition" column and write Conforming in the Conforming / Non-Conforming / Not Applicable column.

If the observed evidence is not in compliance to the item, then the assessor shall note the non-compliance in the "Observations/Comments about Actual Condition" column and write Non-Conforming in the Conforming / Non-Conforming / Not Applicable column.

If the assessor is not able to answer a question at the time of the audit, the assessor shall note the missing information in the "Observations/Comments about Actual Condition" column and write Non-Conforming in the Conforming / Non-Conforming / Not Applicable column.

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5. Molding /Pouring/Casting Operation.....	A 13
6. Casing Cleaning and Finishing	A 15
7. Casting Inspection and Testing	A 16
8. Material Properties.....	A 18
9. Leak Testing	A 20

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PROCESS TABLES.

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PROCESS TABLE A - Sand Castings (Iron/Steel)

All requirements given below are subordinate to customer specific requirements.

When performing the CQI-27 Casting Assessment the auditor shall verify foundry is conforming to customer requirements; including a customer approved Control Plan defining the agreed upon inspection testing and frequencies. *If minimum requirements are not met, provide supporting records to justify actual conditions.

What is the scope covered by this audit? The entire foundry? A specific product line? A specific part number? Other?

Describe the scope of the audit:

Item	Category/Process Step	Requirement	Observations / Comments about Actual Condition	Conforming / Non-Conforming / Not Applicable
1.0	Casting Design and Tooling			
	Casting Process	This Process Table is for grey iron, ductile iron, compacted graphite iron, and steel castings used in automotive applications. There is a wide variety of molding processes including green sand, air set bonded sands, shell molding, stacking molding, precision sand core packages.		
A1.1	Design Software	1. Casting plant must be compliant to customer specific software requirements. 2. Casting plant must have and maintain customer specific requirements for math data transfer for the tooling and for part Drawings / Models.		
A1.2	Casting Simulation	1. The casting plant must use solidification modeling software such as MagmaSoft, AnyCasting, ProCast, EKK, FLOW-3D or similar software approved by the customer Product Engineering on the casting as part of the design process for the gating and feeding system prior to tooling construction and prototype part submission. Simulation must include both fill and solidification analysis. 2. Results must be reviewed with the Customer Product Engineering. 3. At any high stress features in the FEA, the simulation should avoid hot spots, air entrapment, multiple metal fronts converging.		
A1.3	FEA Analysis - Part One	1. The design responsible party must complete an FEA (Finite Element Analysis) for the casting. The ultimate tensile strength, yield strength, and percent elongation used in the FEA must be over the lower limit of engineering requirement for the specified alloy for similar applications. 2. The foundry should know the specific features of the casting where maximum stresses exceed 50% of the Yield Strength. For purposes of this assessment, the expression "high stress" refers to any feature exceeding 50% of the Yield Strength. 3. 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. 4. Any high stress features identified in the FEA must be evaluated when casting simulations are reviewed, and when establishing product audits such as wall thickness, microstructure, hardness, x-ray, crack inspections.		

PROCESS TABLE A - Sand Castings (Iron/Steel)

All requirements given below are subordinate to customer specific requirements.
When performing the CQI-27 Casting Assessment the auditor shall verify foundry is conforming to customer requirements; including a customer approved Control Plan defining the agreed upon inspection testing and frequencies. *If minimum requirements are not met, provide supporting records to justify actual conditions.

What is the scope covered by this audit? The entire foundry? A specific product line? A specific part number? Other?

Describe the scope of the audit:

Item	Category/Process Step	Requirement	Observations / Comments about Actual Condition	Conforming / Non-Conforming / Not Applicable
A1.4	FEA Analysis - Part Two	5. 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. 6. 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 customer Product Engineering.		
A1.5	Casting Datum	1. If the casting plant creates the raw casting drawing, that drawing must be approved and released per the customer Product Engineering requirements. 2. If the casting plant creates the tolerance limits between the raw casting drawing and any other drawing, those tolerance limits must be approved by the customer Product Engineering. 3. Whenever possible, the X-Y-Z datum surfaces used on the machined components should be the same X-Y-Z datum surfaces as the raw castings. This is for dimensional control purposes and minimizing datum shifts between the casting and machined surfaces (one of the causal factors related to thin-wall conditions). 4. Tooling design must allow all raw casting locators (datum surfaces) to be on one piece of the tooling steel. This is for dimensional control purposes. Customer Product Engineering approval is required for any deviation from this concept. 5. The raw casting datum surfaces must not be removed by any post-processing or machining unless customer Product Engineering has approved it.		
A1.6	Casting Tool Material	1. All production core boxes and molding patterns must be made from steel alloys unless customer Product Engineering approves alternate material. 2. With customer Product Engineering prior approval, the supplier can utilize "soft tools" to produce prototype samples if production tooling is not available when the parts are required. These sample castings may be used for activity such as product validation tests, assembly builds, and machine tool runoffs. The castings must be produced with the production intent melting and metal handling process.		

PROCESS TABLE A - Sand Castings (Iron/Steel)				
All requirements given below are subordinate to customer specific requirements. When performing the CQI-27 Casting Assessment the auditor shall verify foundry is conforming to customer requirements; including a customer approved Control Plan defining the agreed upon inspection testing and frequencies. *If minimum requirements are not met, provide supporting records to justify actual conditions.				
What is the scope covered by this audit? The entire foundry? A specific product line? A specific part number? Other?				
Describe the scope of the audit:				
Item	Category/Process Step	Requirement	Observations / Comments about Actual Condition	Conforming / Non-Conforming / Not Applicable
A1.7	Core Box Design	Core boxes must be designed such that filing on the locating surfaces of core prints is not allowed. Avoid blow tubes, vents, parting lines on the locating surfaces.		
A1.8	Core Box Vents	Slotted contoured vents are required to be used on casting cavity surfaces of core tooling cavities unless customer Product Engineering approves alternate construction.		
A1.9	Tooling Maintenance	1. The life of the tooling is tracked based on number of cycles. 2. There is an itemized list of regular maintenance items completed at pre-defined frequencies. 3. Checksheet to track completion of regular maintenance. 4. Abrasive systems (such as shot blast and hand grinding) not permitted for cleaning tooling. Non-abrasive systems (such as dry ice, high pressure water blast, solvent washing and ultrasonic) are required.		
A1.10	Tool Changes	1. Replacement inserts (new steel), where there is a customer specific requirement, a PPAP approval may be required. Customer specific requirements may require a process change request submission with possible production trial run requirements. 2. All tooling repair (welding, grinding, machining, insert replacement) requires dimensional verification (internal approval) prior to re-instituting the tool for production volumes. 3. The supplier complies with all customer requirements related to which PPAP requirements are needed when tooling is corrected.		

PROCESS TABLE A - Sand Castings (Iron/Steel)

All requirements given below are subordinate to customer specific requirements.
When performing the CQI-27 Casting Assessment the auditor shall verify foundry is conforming to customer requirements; including a customer approved Control Plan defining the agreed upon inspection testing and frequencies. *If minimum requirements are not met, provide supporting records to justify actual conditions.

What is the scope covered by this audit? The entire foundry? A specific product line? A specific part number? Other?

Describe the scope of the audit:

Item	Category/Process Step	Requirement	Observations / Comments about Actual Condition	Conforming / Non-Conforming / Not Applicable
A1.11	Casting Traceability	1. All castings produced must be identified with customer branding requirements, casting plant logo (as applicable), casting part number, cavity number, and cast date in designated locations per customer requirements. 2. In some applications, traceability to both casting machine and/or measured process parameters specific to the casting may be required. Identification must be accurate and readily visible on non-machined surfaces, and must not interfere with parting lines, appearance, function, processing or assembly.		
A1.12	Fixtures and Gages	1. Gage and fixture plan must be reviewed and approved by customer. (May include in-line gage equipment for 100% check of critical dimensions as identified on part specification and/or part drawing.). 2. 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. Customer approval is required for any other accuracy such as 10% or less of part working tolerance. 3. All surfaces of fixtures and gages which touch the part must be made from hard tool steel unless customer Product Engineering approves other materials. 4. The tips of all clamps on fixtures and gages must be built with replaceable tips unless customer Product Engineering approves a different design. 5. Production fixtures must use hydraulic or pneumatic clamping during the machining operations. Manual clamping is not allowed. 6. Variable gages must pass Gage R&R per AIAG or similar standard. 7. All fixtures and gages must be certified periodically either by in-house if capable or by third party.		
2.0	Metal Control			
A2.1	Incoming/Returned Material Storage	Raw /Returned materials must be stored without mixing them in marked storage areas by type.		
A2.2	Charging Materials and Alloy Additions	Charge materials and alloys going into melting furnaces must be weighed first.		

PROCESS TABLE A - Sand Castings (Iron/Steel)				
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A2.3	Metal Chemistry	1. Chemistry must be controlled at each key point in the process (melting, holding, and pouring). 2. There must be a spectrometer on site for chemistry control. Industry Standards, such as ASTM E1999, must be followed for sampling, verification, standardization and calibration. 3. There must be a Gas Combustion C/S analyzer on site. Gas combustion shall be the method for controlling carbon unless customer Product Engineering approves another measurement method. 4. Gas combustion (carbon/sulfur analyzer such as LECO or similar) does not have to be used for 100% of the measurements if carbon limits are not mandatory in the customer part number specific requirements. The spectrometer can be used as long as it is crosschecked daily against the gas combustion. Results of the crosscheck must be documented. The spectrometer carbon must crosscheck within +/- 0.05 of the value from gas combustion, preferably within +/- 0.03. If carbon limits are mandatory in the customer part number specific requirements, then gas combustion must be used to verify all carbon analyses prior to shipment for each heat produced. 5. 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. 6. A procedure must be posted near the spectrometer which clearly defines the permissible tolerance range of the Master calibration Standards. 7. There must be control limits for all key elements of the material grade including carbon equivalent (typically C + 1/3Si) and customer defined elements. 8. For ductile iron and compacted graphite iron, there must be a minimum limit for sulfur. Preferably over 0.006%. 9. Recommend 0.0012% maximum Boron for cast irons.		

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A2.4	Chemistry	For any elements with customer specified mandatory limits, these limits must be reduced by the tolerance permitted on the Master calibration Standards.		
A2.5	Chemistry	For cast iron, a Thermal Arrest unit, also known as a CE Meter, must be used on the melt deck for in-process checks unless customer Product Engineering approves that it is not required.		
A2.6	Metal Temperature	1. Immersion is the preferred method for temperature checks at each metal holding location with upper and lower control limits. 2. Holding furnaces must be capable of controlling metal temperature at the metal extraction point to +/-10°C.		
A2.7	Cast Iron Inoculation	1. All metal must be post-inoculated. This could be in the ladle, in-stream, or in the mold. 2. Post-inoculation based on weight is preferred. If the post-inoculation addition is based on volume or timers, there must be a regular audit to verify the weight.		
A2.8	Carbon Raiser	The carbon raiser used as an addition to electric melting furnaces shall be less than 0.3% volatiles content unless customer Product Engineering approves a higher limit. Volatiles content can be provided on Material Certification from supplier of the carbon raiser. Petroleum Coke by-products and industrial graphite scraps with high volatiles content can cause porosity in castings. This volatiles requirement does not apply to organic charcoal carbon raisers such as charred coconut hulls.		

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3.0	Magnesium Treatment	Section 3.0 is for Ductile Iron and Compacted Graphite Iron		
A3.1	Treatment Ladle	1. Forms or molds must be used to build or repair the treatment ladle. The dimension of the reaction chamber must be verified after the build or repair. 2. For open top sandwich and wiring process treatment ladles, the recommended internal height to diameter ratio is 2:1 or greater. 3. The treatment ladle shall never be poured with any other irons other than the ductile iron.		
A3.2	Weighing System	All the materials, such as magnesium alloy, cover material, inoculate, and other alloys, must be weighed before they are added to the treatment ladle.		
A3.3	Metal Weight	For compacted graphite iron, the iron to be poured must be weighed in order to adjust the vermiculizer addition. For ductile iron, some customers may require the iron to be weighed.		
A3.4	Magnesium (alloy) Addition	Magnesium Treatment materials must be added to the treatment ladle as late as possible prior to tap out to avoid the burn (oxidation) of the magnesium alloy.		
A3.5	Alloy/ Cover Material Addition	If cover material is used, clean steel plates/punching are preferred. The materials must be added in proper order and location in the treatment ladle.		
A3.6	Treatment Ladle Temperature	There must be documented instruction/process to assure adequate pre-heating of the treatment ladle prior to tap out.		
A3.7	Treatment Temperature	Tap out temperature must be monitored and controlled within an established range and the record must be documented.		

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A3.8	Magnesium Treatment Filling	There must be a system to avoid the direct pouring over the material chamber of the treatment ladle.		
A3.9	Slagging	The slag must be completely removed from the treatment ladles before transferring to holders or pouring into molds.		
A3.10	Magnesium Reaction Time	The nodularizing reaction time may be required by customer to be measured and documented.		
A3.11	Chemistry Control	The chemistry must be checked for each treatment ladle after nodularizing. For nitrogen covered pressure auto-pour process, the chemistry must be checked before each addition of new treated iron.		
A3.12	Cored Wire Magnesium Treatment	1. An automatic feeding system is required for straightening the wire and for controlling the feeding speed. 2. It is recommended that the guiding tube is perpendicular to the bath for vertical feeding. 3. The wire supplier must be ISO or similarly certified.		
A3.13	Fade Time	There must be a maximum time limit from nodularization treatment to last mold poured. There must be a timer alarm which is clearly visible or audible located where it is obvious to the workers at the cast line.		

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4.0	Cores (Cold Box, Hot Box and Shell)			
A4.1	Outsourced Cores	Cores may be purchased, or blown in-house. If they are purchased, core supplier must be in full compliance with this Process Table.		
A4.2	Cold Box	1. The compressed air supply for cold box blowers must have a dew point at atmospheric pressure below -40°C. 2. Cold box core boxes must be designed with tamping pins in areas of casting surfaces. 3. Cold box cores must be stored in an environment below 35°C and below 40% humidity unless customer Product Engineering approves higher limits. Special rooms with temperature and humidity control may be necessary in order to comply with this requirement. Foundries with many large cores may have trouble to comply with this requirement due to the storage area necessary; they must coat (dip/paint) the cores within two hours after they are blown and must pour them off with 48 hours of being blown. 4. Cold box mix recipe should be verified by measured weight of resins. 5. Weight of mixed core sand should be minimized; 6 to 10 blows typical, not to exceed one hour of mixed sand.		
A4.3	Hot Box	1. The compressed air supply for hot box blowers must have a dew point at atmospheric pressure below -40° C. 2. Hot box core boxes must have internal thermocouples. The temperatures must be displayed. There must be an alarm if the temperature is out of range. Automatic temperature adjustment is required unless customer Product Engineering approves another adjustment method. 3. Hot box cores must be stored in an environment below 35C and below 40% humidity unless customer Product Engineering approves higher limits. Special rooms with temperature and humidity control may be necessary in order to comply with this requirement. Foundries with many large cores may have trouble to comply with this requirement due to the storage area necessary; they must coat (dip/paint) the cores within two hours after they are blown and must pour them off with 48 hours of being blown. 4. Hot box mix recipe should be verified by measured weight of resins. 5. Weight of mixed core sand should be minimized; 6 to 10 blows typical, not to exceed one hour of mixed sand.		

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A4.4	Shell Core	Shell core boxes must have internal thermocouples. The temperatures must be displayed. There must be an alarm if the temperature is out of range. Automatic temperature adjustment is required unless customer Product Engineering approves another adjustment method.		
A4.5	Core Repair	Repair of cores requires customer approval for this practice. If allowed, the repairs must be done in the core department, not at the mold line.		
A4.6	Cured Core Check	There must be a regular audit to cut open cores to check to see if they are properly cured hard to the center.		
A4.7	Core Coating	1. If any cores are wet coated, they must be oven dried prior to use. Coating / painting / dipping / spraying any liquids onto the cores is permitted as long as the cores get baked dry. Includes water base, alcohol base, oil base, kerosene base, methylated spirits, or any other liquid. This includes flammable coatings; burning them is not sufficient. 2. The Baume or viscosity of coatings must be measured and controlled. 3. Coating tanks must have continuous mixing and filtering.		
A4.8	Core Coating	The use of graphite coatings is discouraged. They are a common cause of inclusions.		
A4.9	Chaplet/Spacer	Any chaplets, spacers, or chills used must be completely clean and dry.		
A4.10	Core Preparation	Filing on cores at the cast machines is not allowed. Cores and core assemblies must be thoroughly blown off from all sides before they are set into molds.		

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A4.11	Core Assembly	1. Cores must be thoroughly blown off from all sides before they are used to make core assemblies. 2. Core assemblies must be gaged. 3. Cores and core assemblies must be inspected for damage or breakage before delivery to the cast machines. 4. Inspection criteria must be clearly defined and displayed. Core defects and their location should be documented. 5. Use of automated or manual assist setters are preferred for assembled core packs. 6. For cylinder blocks, the cylinder bore core package must be set into the mold by a fixture which locates off of the flask pins and bushings. Manual placement of the cylinder bore cores is not allowed. The fixture can be moved to the mold line manually, usually by operators and a hoist. An automated fixture is strongly preferred.		
A4.12	Core Storage	1. Cores must not be stacked touching each other. Adequate storage racks must be provided to place cores in single layers. 2. Racks, containers, trays, may need foam padding or similar as appropriate to protect cores from damage during movement or handling.		
A4.13	Core Inventory	1. During regular production, the core inventory must not exceed 48 hours, preferably less than 24 hours. Customer approval required for more than 48 hours core inventory as a regular practice. 2. Cold box cores must have 2 hours minimum wait time after being blown before placing in molds.		

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5.0	Molding/Pouring/Casting Operation			
A5.1	Start-Up Process	Define work instructions or procedure for pre-heating ladles, pour boxes, stopper rods, transfer ladles.		
A5.2	Metal Transfer	Molten metal from the melting furnaces may be tapped directly to go to the cast line, or it may be transferred to intermediate holders. If intermediate holders are used, they must have heating capability to maintain temperature.		
A5.3	Filter	Filters are required to be used in all molds unless customer Product Engineering approves production without filters. Filters are preferably foam (sponge) type 30 ppi.		
A5.4	Auto Pouring	1. If auto pouring holders are used, they must have heat unless customer Product Engineering approves production without heat. 2. Auto pouring holders must be capable of controlling metal temperature at the metal extraction point to +/-10°C. 3. Auto holders and tilting auto ladles must have an infrared measurement sensor to check the temperature of the metal stream for each mold poured unless customer Product Engineering approves an alternative method of temperature control. The sensor must alarm when the temperature is out of range.		
A5.5	Metal Pouring	1. Automatic pouring of molten metal into the mold is required unless customer Product Engineering approves manual pouring. 2. Pouring ladles should be on heat when not in use.		
A5.6	Ladle Construction	If manual ladle or auto ladle pouring, the ladles must have a teapot spout construction in order to hold slag back.		
A5.7	Batch Pour System	Immersion temperature audit from each ladle or pour box to confirm that all molds were poured within specified temperature range.		
A5.8	Metal Quality	Charging raw materials or scrap into the auto pouring holders or ladles and running production out of them at the same time is prohibited.		
A5.9	Alloying	Alloying into the auto pouring holders or ladles is allowed, but must be minimized in order to prevent defects such as inclusions.		
A5.10	Mold Traceability	1.The molds must have traceability to each ladle / heat of metal poured. The location for the first mold and last mold per ladle / heat must be easily identifiable. 2. Cast lines with multiple cooling lines must track each mold from each ladle / heat of metal poured. Strongly prefer all molds from the same ladle / heat to be sequential in the same cooling line.		

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A5.11	Machine Settings	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.		
A5.12	Control Limits	Cast machine should have real time closed loop monitoring which is either tied into the shakeout control or creates an alarm when key parameters are beyond control limits. Castings that are outside the control limits must be segregated for additional inspections.		
A5.13	Nodularity Control for ductile iron and compacted graphite iron	1. The last iron poured from a ladle / heat must be nodularity checked before the first mold poured from that same ladle / heat reaches shakeout. 2. Unless customer Product Engineering approves an alternative method, these nodularity checks at the cast line must be from a microstructure inspection; they must not be based on any ultrasonic correlation with a sample specimen. The AFS standard coupon is preferred. 3. The cast line and shakeout must be built such that suspect low nodularity scrap can be reliably separated from the rest of production. There should be a switch before the shakeout where an operator can Stop/Start the cast line. Any suspect castings must be isolated for further testing and evaluation. 4. Suspect low nodularity scrap is not allowed to go through a rotating drum unless customer Product Engineering approves this practice. It must be diverted ahead of the drum. 5. The intent of the nodularity controls is that suspect bad iron is never mixed with good iron.		
A5.14	Sand Lab	1. There must be an on-site sand lab equipped for checking both molding sand and core sand. 2. The sand lab must be capable of making audits for common parameters such as Sieve analysis, loss on ignition (LOI), core strength tests, compactability, moisture, % volatiles, methylene blue test for active clay, compression, permeability.		
A5.15	Sulfur in the Sand	For ductile iron and compacted graphite iron, there must be a regular audit to measure the sulfur content of the molding sand in order to prevent degenerated graphite at the casting surface. The sulfur in the molding sand must not exceed 0.15% unless customer Product Engineering approves a higher limit.		

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A5.16	Sand Temperature	The sand system must have sufficient cooling systems and controls to keep the temperature of the molding sand going into the molds below specified temperature per the control plan. It is preferred not to exceed 40C sand temperature at the mold line.		
A5.17	Shakeout Time	1. The cast line must provide a long enough time to assure castings have cooled to a black color at shakeout. If castings are above 727°C at shake out, customer may require residual stresses to be measured on a casting at the shortest shakeout time to assure cracking is not an issue. A metallographic examination may also be required to be assessed as machinability may be a concern. Results of these measurements and shakeout process must be reviewed and approved by customer Product Engineering. 2. The shakeout method must not crack the castings. For cylinder blocks, rotary drums are not allowed.		
6.0	Casting Cleaning and Finishing			
A6.1	De-gating	Wedge cutter is preferred for de-gating. Casting must not be damaged during de-gating operation. If hammer is used for de-gate, the hammering locations shall be specified to prevent the casting to be hit by hammer.		
A6.2	Shot Blast	1. Must have Preventative Maintenance plan. 2. Must have table condition for each individual shot blast machine including shot time, application ampere, discharge pressure. 3. Must define when and how to replenish shots due to worn and lost. 4. Must define how to handle the dropped/ stuck/re-working castings. 5. Must have standard to qualify shot blast finished part per customer specification.		
A6.3	Trimming/Grinding Operation	1. Must have documented check-list and work instruction to verify that the trim-press/grinding machine works properly and parts meet customer specification/tolerance for burrs, parting lines, gates and riser contacts. 2. If auto-trimming is used, it is preferred to have workpiece set trouble detection device (interlock). When a trouble is detected, the equipment is stopped automatically.		

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7.0	Casting Inspection and Testing			
A7.1	Retained Material or Cleanliness Requirement	Equipment must be available onsite to properly administer retained material inspection per customer requirements.		
A7.2	Dimensional Inspection - Part One	1. As a minimum, the casting plant shall have a programmable Coordinate Measuring Machine (CMM) on site. The CMM must be run in an automatic mode. Where possible, the application of point cloud/laser scanning inspection technology is preferred. When used in combination with point cloud scanning technology, the CMM is considered the "gage of record" for dimensional measurements because of precision associated with the points measured. 2. The casting plant shall maintain a CMM hit point map/drawing showing all CMM hit points that are agreed upon between the casting plant and the customer. (Point Cloud Inspection/laser scanning can be used in place of CMM inspection if agreed upon with customer Product Engineering). 3. The raw casting datums must be included in all CMM hitpoint 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.		
A7.3	Dimensional Inspection - Part Two	4. The CMM program must include checking the flatness of each individual raw casting datum surface if the datum pad is intended to be a flat surface. Preferably less than 0.250mm. 5. Point cloud/laser scanning inspection must use the part-design datum construction to align the measurement data. Unless otherwise specified by the customer, "best-fit" data alignment is not allowed. 6. The casting plant is responsible for comparing the scan with the 3D Math Model. In all cases the Point Cloud/laser scan must be aligned to the math model using the X-Y-Z raw casting datum surfaces. Results must be shared with customer Product Engineering and the responsible APQP Quality Engineer. 7. 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. The scan report must clearly state which version of the 3D Math Model was used. 8. Point Cloud/laser scanning Inspection is recommended for prototype parts and PPAP parts as defined by the customer specific requirements. The scanning may be out-sourced.		

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A7.4	Casting Tolerance	Cast tolerances apply to castings which have not been painted, plated, or coated. There should be Casting dimensional data/layouts for castings which have not been painted, plated, or coated.		
A7.5	Wall Thickness	1. There must be regular audits to section raw castings for wall thickness verification; including any high stress features in the FEA. If the supplier is responsible for any machining, there must be regular audits to section machined castings for wall thickness verification. 2. For cylinder blocks, the supplier must have on-site a portable ultrasonic device for checking bore wall thickness.		
A7.6	Nodularity Verification	For ductile iron and compacted graphite iron, the supplier is responsible for the correlation of Ultrasonic Velocity or Resonant Frequency Testing to % nodularity to define limits for acceptance at the test location for each part number. Customer may require 100% ultrasonic checking for some applications.		
A7.7	Internal Integrity	1. The supplier must be capable of conducting internal Integrity inspection using non-destructive testing method (x-ray) or destructive testing (sectioning) per customer requirements; including any high stress features in the FEA. 2. The supplier shall have X-ray capability available. X-ray does not have to be on-site. However, the location and access to it must be reasonable for development purposes.		

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A7.8	Internal Passages	Supplier is responsible to acquire proper non-destructive inspection tools to evaluate for blocked passages. This may include boroscopes, endoscopes, probes, fiber optics, flow meters, or X-ray.		
A7.9	Surface Integrity (Crack Detection)	The supplier must be capable of conducting surface integrity testing using non-destructive testing techniques (magnetic particle inspection, resonance testing, eddy current) per customer requirements; including any high stress features in the FEA.		
A7.10	Repairs	1. Customer must approve any salvage repair procedures. Casting repairs, such as welding, epoxy, Devcon, and impregnation, are not permitted, unless approved by customer Product Engineering. 2. If repairs are allowed, repair method and procedures must be approved by Customer Product Engineering. 3. If straightening is allowed, a customer Product Engineering approved method is required, normally with a fixtured, automated process. Manual methods should not be used.		
8.0	Material Properties			
A8.1	Laboratory Location	1. The supplier shall have a metallurgical lab located on-site with capabilities to analyze chemistries, hardness, microstructure, % nodularity, area fraction porosity, and any other features specified by customer Product Engineering. 2. 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.		
A8.2	Material Property Testing	1. Material property testing must be defined per customer design records. 2. Mechanical properties testing must be on site unless customer Product Engineering approves another location. 3. Mechanical property testing must include ultimate tensile strength, yield strength, and percent elongation. Yield Strength must be measured with an extensometer attached to the specimen unless customer Product Engineering agrees to some other method. 4. If retest or replacement is necessary must be with agreement of the customer Product Engineering. 5. Testing begins with prototypes and continues through regular production.		
A8.3	Mechanical Property	The casting source must prepare test bars from a location approved by customer Product Engineering. For example, these might be cut from a casting or from a separately cast bar. 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. The test bar location in the casting will be dimensioned from casting features.		

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A8.4	Microstructure Analysis	1. Metallurgical examination is to be done by the supplier prior to any component testing to insure microstructure meets engineering drawing specifications. 2. A metallograph image analyzer is required on-site unless customer Product Engineering approves some other method of measuring features in the images. 3. Reference photographs must be readily available at the metallograph for all microstructure requirements. 4. Microstructure audits must include any high stress features in the FEA.		
A8.5	Hardness Testing	1. Hardness testing is to be done on-site per ASTM E10/ISO 6506. Supplier must have certified Master blocks on-site for auditing the calibration of the hardness tester. 2. The Tolerance range for the Master block must be posted on the hardness tester. 3. The Tolerance range for the Master must not exceed +/- 3%. 4. The customer specified hardness range must be reduced by the tolerance allowed on the hardness Master block. 5. Unless Product Engineering specifies otherwise, Brinell hardness test using a 3000Kg load, 10 mm diameter indenter, and 10 - 15 second dwell time. 6. Hardness to be measured at a specified location from customer Product Engineering. 7. If hardness readings are out of specification, all castings in the Lot shall be hardness tested with any out-of-specification castings rejected.		
A8.6	Heat Treatment	1. Heat treating must be before machining unless customer Product Engineering agrees to heat treat after machining. Heat treating may be in-house or outsourced. Heat treating must be in compliance with CQI-9: Special Process: Heat Treat System Assessment (HTSA), published by AIAG. 2. Austempered Ductile Iron often has some pre-machining before heat treatment. Features to be pre-machined must be approved by customer Product Engineering.		
A8.7	Residual Stress Testing	The supplier is responsible for any residual stress testing requirements unless Customer Product Engineering agrees that the supplier is not responsible for it. Testing may be outsourced. Customer Product Engineering must approve the source which conducts the testing.		
A8.9	Fatigue Testing	The supplier is responsible for any fatigue testing requirements unless Customer Product Engineering agrees that the supplier is not responsible for it. Testing may be outsourced. Customer Product Engineering must approve the source which conducts the testing.		

PROCESS TABLE A - Sand Castings (Iron/Steel)

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9.0	Leak Testing			
A9.1	Leak Test Requirement	1. Some castings may require leak testing. Leak rate specification must be defined on the customer Product Engineering document. 2. Acceptable methods for leak testing are: air under water, sniffers, pressure decay, mass flow. 3. Pressure decay / mass flow cannot measure Zero leakage. Zero leakage applications must use air under water or helium particle counters (sniffers). 4. Pressure decay / mass flow must pass Gage R&R below 10% at the maximum leak specification. 5. Pressure decay / mass flow cannot pass Gage R&R at very low leak rate specifications. These very low leak rate applications must also use air under water or sniffers.		
A9.2	Leak Test Process	1. Castings must be thoroughly dried before going into pressure decay / mass flow. An in-line drier is preferred. 2. Casting cavities must be leak tested separately in order to assure there are no cross channel leaks. 3. Pressure decay / mass flow controllers must have automatic temperature measurement and adjustment. 4. Leak Masters must have leak rates within +/- 10% of the maximum permissible leak rate of the part. 5. A Zero Leak Master is required for pressure decay / mass flow. A Zero Leak Master is an Impregnated casting. Verify in water dunk that is has zero bubbles. 6. Each day that the pressure decay / mass flow is used, the measured leak rate for the Zero Leak Master and for the Max Leak Master must be recorded and plotted. 7. Customer maximum leak rate limits must be reduced by the observed Bias and Variation of the measurement system (such as the +/- variation of the Zero Leak Master). 8. A certified orifice may be used as the Leak Master and/or as the Zero Leak Master if customer Product Engineering approves. 9. Pressure decay / mass flow test equipment must automatically stamp good parts while the part is still in the test fixture.		

PROCESS TABLE A - Sand Castings (Iron/Steel)

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A9.3	Water Dunk Capability	1. The supplier shall have water dunk capability on site for determining the location of leaks on castings as shipped to the customer AND for fully machined castings returned from the customer. 2. Water dunk must use water temperature at least 20°C. 3. 100% water dunk, zero bubbles, is common for components with a Zero Leak requirement. Typical water dunk parameters are 5 bar air pressure, minimum 15 seconds without a bubble. Air pressure and minimum time must be approved by customer Product Engineering.		
A9.4	Impregnation	1. Impregnation is not allowed unless expressly approved by customer Product Engineering. Approval must be documented per Customer specific policy, such as on the part print. 2. Customer Product Engineering must approve the sealant (resin) to be used. 3. Customer Product Engineering must approve the impregnation source which would perform the impregnation. 4. Impregnation must be in full compliance with any customer specific Statement Of Requirements for Impregnation of Castings.		
A9.5	Flow Testing	1. Some castings may require flow testing. Flow rate specification must be defined on the customer Product Engineering document. 2. Flow testing must use automated air flow equipment. Using round balls or probes is not acceptable unless approved by customer Product Engineering. 3. Flow test equipment must automatically stamp good parts while the part is still in the test fixture.		
A9.6	Error-Proofing	1. Error-proofing is required before final packaging if similar looking part numbers are in production in the same facility. 2. Scheduling production of similar looking part numbers on different production shifts is not error-proofing.		

PROCESS TABLE B - Centrifugal Castings

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1.0	Casting Design and Tooling			
	Casting Process	This Process Table is for ductile iron, grey iron, and steel castings (except Centrifugal Liners which has its own Table). Variations of centrifugal casting are used to produce many automotive components. The process ranges from highly automated cells to labor intensive process flows.		
B1.1	Design Software	1. Casting plant must be compliant to customer specific software requirements. 2. Casting plant must have and maintain customer specific requirements for math data transfer for the tooling and for part Drawings / Models.		
B1.2	FEA Analysis - Part One	1. The design responsible party must complete an FEA (Finite Element Analysis) for the casting. The ultimate tensile strength, yield strength, and percent elongation used in the FEA must be over the lower limit of engineering requirement for the specified alloy for similar applications. 2. The foundry should know the specific features of the casting where maximum stresses exceed 50% of the Yield Strength. For purposes of this assessment, the expression "high stress" refers to any feature exceeding 50% of the Yield Strength. 3. 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. 4. Any high stress features identified in the FEA must be evaluated when casting simulations are reviewed, and when establishing product audits such as wall thickness, microstructure, hardness, x-ray, crack inspections.		

PROCESS TABLE B - Centrifugal Castings

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B1.3	FEA Analysis - Part Two	5. 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. 6. 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 customer Product Engineering.		
B1.4	Casting Simulation	1. The casting plant should use solidification modeling software such as MagmaSoft, AnyCasting, ProCast, EKK, FLOW-3D or similar software approved by customer on the tube prior to tooling construction and prototype part submission. 2. Results must be reviewed with the Customer Product Engineering.		
B1.5	Casting Datum	The surfaces to be used as datums for dimensional purposes must be reviewed and approved by customer Product Engineering.		
B1.6	Tube Mold Material	1. All production molds must be made from steel alloys unless customer Product Engineering approves alternate material. 2. With customer Product Engineering prior approval, the supplier can utilize "soft tools" to produce prototype samples if production tooling is not available when the parts are required. These sample castings may be used for activity such as product validation tests, assembly builds, and machine tool runoffs. The castings must be produced with the production intent melting and metal handling process.		

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B1.7	Tooling Maintenance	1. The life of the molds is tracked based on number of cycles. 2. There is an itemized list of regular maintenance items completed at pre-defined frequencies. 3. Checklist to track completion of regular maintenance. 4. Abrasive systems (such as shot blast and hand grinding) not permitted for cleaning tooling. Non-abrasive systems (such as dry ice, high pressure water blast, solvent washing and ultrasonic) are required.		
B1.8	Tool Changes	1. Replacement inserts (new steel), where there is a customer specific requirement, a PPAP approval may be required. Customer specific requirements may require a process change request submission with possible production trial run requirements. 2. All tooling repair (welding, grinding, machining, insert replacement) requires dimensional verification (internal approval) prior to re-instituting the tool for production volumes. 3. The supplier complies with all customer requirements related to which PPAP requirements are needed when tooling is corrected.		
B1.9	Casting Traceability	1. For piston rings, all rings produced must be identified with customer branding requirements, casting plant logo (as applicable), casting part number, and cast date in designated locations per customer requirements. 2. In some applications, traceability to both casting machine and/or measured process parameters specific to the casting may be required. Identification must be accurate and readily visible on non-machined surfaces, and must not interfere with parting lines, appearance, function, processing or assembly.		
B1.10	Fixtures and Gages	1. Gage and fixture plan must be reviewed and approved by customer. (May include in-line gage equipment for 100% check of critical dimensions as identified on part specification and/or part drawing.). 2. 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. Customer approval is required for any other accuracy such as 10% or less of part working tolerance. 3. All surfaces of fixtures and gages which touch the part must be made from hard tool steel unless customer Product Engineering approves other materials. 4. The tips of all clamps on fixtures and gages must be built with replaceable tips unless customer Product Engineering approves a different design. 5. Production fixtures must use hydraulic or pneumatic clamping during the machining operations. Manual clamping is not allowed. 6. Variable gages must pass Gage R&R per AIAG or similar standard. 7. All fixtures and gages must be certified periodically either by in-house if capable or by third party.		

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2.0	Metal Control			
B2.1	Incoming/Returned Material Storage	Raw /Returned materials must be stored without mixing them in marked storage bins by type.		
B2.2	Charging Materials and Alloy Additions	Individual charge materials going into melting furnaces must be weighed first.		
B2.3	Metal Chemistry	1. Chemistry must be controlled at each key point in the process (melting, holding, and pouring). 2. There must be a spectrometer on site for chemistry control. Industry Standards, such as ASTM E1999, must be followed for sampling, verification, standardization and calibration. 3. There must be a Gas Combustion C/S analyzer on site. Gas combustion shall be the method for controlling carbon unless customer Product Engineering approves another measurement method. 4. Gas combustion (carbon/sulfur analyzer such as LECO or similar) does not have to be used for 100% of the measurements if carbon limits are not mandatory in the customer part number specific requirements. The spectrometer can be used as long as it is crosschecked daily against the gas combustion. Results of the crosscheck must be documented. The spectrometer carbon must crosscheck within +/- 0.05 of the value from gas combustion, preferably within +/- 0.03. If carbon limits are mandatory in the customer part number specific requirements, then gas combustion must be used to verify all carbon analyses prior to shipment for each heat produced. 5. 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. 6. A procedure must be posted near the spectrometer which clearly defines the permissible tolerance range of the Master calibration Standards. 7. There must be control limits for all key elements of the material grade including carbon equivalent (typically C + 1/3Si) and customer defined elements. 8. For piston rings, titanium should be controlled below 0.015%. 9. For ductile iron, there must be a minimum limit for sulfur. Preferably over 0.006%. 10. Recommend 0.0012% maximum Boron for cast irons.		

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Documents

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PROCESS TABLE B - Centrifugal Castings

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B2.4	Chemistry	For any mandatory elements, control limits must be reduced by the tolerance allowed on the Master Calibration Standards.		
B2.5	Chemistry	A Thermal Arrest unit, also known as a CE Meter, must be used on the melt deck for in-process checks unless customer Product Engineering approves that it is not required.		
B2.6	Metal Temperature	1. Immersion is the preferred method for temperature checks at each metal holding location with upper and lower control limits. 2. Holding furnaces must be capable of controlling metal temperature at the metal extraction point to +/-10°C.		
B2.7	Inoculation	1. All metal must be post-inoculated. This could be in the ladle, in-stream, or in the mold. 2. Post-inoculation based on weight is preferred. If the post-inoculation addition is based on volume or timers, there must be a regular audit to verify the weight.		
B2.8	Carbon Raiser	The carbon raiser used as an addition to electric melting furnaces shall be less than 0.3% volatiles content unless customer Product Engineering approves a higher limit. Volatiles content can be provided on Material Certification from supplier of the carbon raiser. Petroleum Coke by-products and industrial graphite scraps with high volatiles content can cause porosity in castings. This volatiles requirement does not apply to organic charcoal carbon raisers such as charred coconut hulls.		

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3.0	Magnesium Treatment	This section for Ductile Iron		
B3.1	Treatment Ladle	1. Forms or molds must be used to build or repair the treatment ladle. The dimension of the reaction chamber must be verified after the build or repair. 2. For open top sandwich and wiring process treatment ladles, the recommended internal height to diameter ratio is 2:1 or greater. 3. The treatment ladle shall never be poured with any other irons other than the ductile iron.		
B3.2	Weighing System	1. All the materials, such as magnesium alloy, cover material, inoculate, and other alloys, must be weighed before they are added to the treatment ladle. 2. A system should also be in place for weighing the molten iron poured into the treatment ladle. Some customers may require the iron to be weighed.		
B3.3	Magnesium (Alloy) Addition	Magnesium Treatment materials must be added to the treatment ladle as late as possible prior to tap out to avoid the burn (oxidation) of the magnesium alloy.		
B3.4	Alloy/ Cover Material Addition	If cover material is used, clean steel plates/punching are preferred. The materials must be added in proper order and location in the treatment ladle.		
B3.5	Treatment Ladle Temperature	There must be documented instruction/process to assure adequate pre-heating of the treatment ladle prior to tap out.		
B3.6	Treatment Temperature	Tap out temperature must be monitored and controlled within an established range and the record must be documented.		
B3.7	Magnesium Treatment Filling	There must be a system to avoid the direct pouring over the material chamber of the treatment ladle.		
B3.8	Slagging	The slag must be completely removed from the treatment ladles before transferring to holders or pouring into molds.		
B3.9	Magnesium Reaction Time	The nodularizing reaction time may be required by customer to be measured and documented.		
B3.10	Chemistry Control	The chemistry must be checked for each treatment ladle after nodularizing. For nitrogen covered pressure auto-pour process, the chemistry must be checked before each addition of new treated iron.		
B3.11	Cored Wire Magnesium Treatment	1. An automatic feeding system is required for straightening the wire and for controlling the feeding speed. 2. It is recommended that the guiding tube is perpendicular to the bath for vertical feeding. 3. The wire supplier must be ISO or similarly certified.		

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4.0	Metal Control			
B4.1	Equipment	The centrifugal casting machines are commonly called spinners. Metal at the spinners may be in a ladle or in a holder.		
B4.2	Start-Up Process	Define work instructions or procedure for pre-heating ladles, pour boxes, stopper rods, transfer ladles.		
B4.3	Metal Transfer	Molten metal from the melting furnaces may be tapped directly to go to the cast line, or it may be transferred to intermediate holders. If intermediate holders are used, they must have heating capability to maintain temperature.		
B4.4	Auto Pouring	1. If auto pouring holders are used, they must have heat unless customer Product Engineering approves production without heat. 2. Auto pouring holders must be capable of controlling metal temperature at the metal extraction point to +/-10°C. 3. Auto holders and tilting auto ladles must have an infrared measurement sensor to check the temperature of the metal stream for each mold poured unless customer Product Engineering approves an alternative method of temperature control. The sensor must alarm when the temperature is out of range.		
B4.5	Metal Pouring	1. Automatic pouring of molten metal into the mold is required unless customer Product Engineering approves manual pouring. Manual pouring into a tilt pour basin is allowed; the tilting action must be automated. 2. Pouring ladles should be on heat when not in use.		
B4.6	Batch Pour System	Immersion temperature audit from each ladle or pour box to confirm that all molds were poured within specified temperature range.		
B4.7	Metal Quality	Charging raw materials or scrap into the auto pouring holders or ladles and running production out of them at the same time is prohibited.		
B4.8	Alloying	Alloying into the spinner holding furnaces or ladles is allowed, but must be minimized in order to prevent defects such as inclusions.		
B4.9	Machine Settings	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.		
B4.10	Control Limits	Spinners should 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. Tubes that are outside the control limits must be segregated for additional inspections.		

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5.0	Spinners			
B5.1	Process	Centrifugal casting is to be used to produce the raw tubes.		
B5.2	Pre-Heat	Automated spinner cells must have a mold preheat station.		
B5.3	Process	Spinners may be manual or automatic.		
B5.4	Cleaning	An automated reciprocator must be used to clean the inside diameter of the mold before each cycle.		
B5.5	Coating	An automated reciprocator must be used to apply the coating spray. Nozzle arrangement must assure uniform coating application. Appropriate maintenance required to keep the nozzles open.		
B5.6	Coating	The coating spray volume must be measured and controlled.		
B5.7	Coating	The coating spray Baume (viscosity) must be measured and controlled.		
B5.8	Coating	The coating spray tank must have continuous agitation.		
B5.9	Coating	The temperature of the coating in the spray tank must be measured and controlled. Preferably below 45°C.		
B5.10	Coating	The mold coating spray should be applied with PLC control. PLC alarms when parameters such as volume, pressure, time, temperature are out of range.		
B5.11	Coating	The coating thickness inside the molds must be audited and controlled.		
B5.12	Cooling	The water cooling cycle must be PLC controlled.		
B5.13	RPMS	The spinner RPMS must be PLC controlled. There must be an alarm if out of range.		

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6.0	Pouring			
B6.1	Ladle Construction	If manual ladle or auto ladle pouring, the ladles must have a teapot spout construction in order to hold slag back.		
B6.2	Ladle Pre-Heat	If manual ladle or auto ladle pouring, the ladles must be on heat when not in use.		
B6.3	Inoculation	All metal must be post-inoculated.		
B6.4	Inoculation	Post-inoculation based on weight is preferred. If the post-inoculation addition is based on volume or timers, there must be a regular audit to verify the weight.		
B6.5	De-Slagging	The ladles must be slagged off before every pour.		
B6.6	Pour Weight	The pour weight must be measured and controlled.		
B6.7	Temperature	The temperature of all molds must be checked at the pour station right before pouring.		
B6.8	Temperature	If the temperature of the mold is too cold, an alarm must sound and the tube must be scrapped. Tubes from cold molds must be identified and scrapped after extraction.		
B6.9	Fade Time	For ductile iron, there must be a maximum time limit from nodularization treatment to last mold poured. There must be a timer alarm which is clearly visible or audible located where it is obvious to the workers at the cast line.		
B6.10	Tube Traceability	The tubes being cast must have traceability to each ladle / heat of metal poured. The location for the first tube and last tube per ladle / heat must be easily identifiable. For ductile iron, this is critical in case of suspect low nodularity scrap.		
B6.11	Nodularity Control for ductile iron	1. The last iron poured from a ladle / heat must be nodularity checked without delay. 2. Unless customer Product Engineering approves an alternative method, these nodularity checks at the cast line must be from a microstructure inspection; they must not be based on any ultrasonic correlation with a sample specimen. The AFS standard coupon is preferred. 3. The cast line must be built such that suspect low nodularity scrap tubes can be reliably separated from the rest of production. Any suspect tubes must be isolated for further testing and evaluation. 4. The intent of the nodularity controls is that suspect bad iron tubes are never mixed with good iron tubes.		

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7.0	Extraction			
B7.1	Traceability	After extraction, all tubes must be individually marked for traceability to each ladle / heat of metal poured. For ductile iron, this is critical in case of suspect low nodularity scrap.		
B7.2	Scrap	The spinner cell must be built such that scrap tubes can easily be removed from the cell right after extraction. For ductile iron, this is critical in case of suspect low nodularity scrap.		
B7.3	Dimensional	There must be control limits for the raw tube inside diameter and outside diameter.		
B7.4	Dimensional	There must be an audit to section raw tubes for wall thickness checks.		
8.0	Processing and Inspections			
B8.1	Shot Blast	Shot blasting must be in-house.		
B8.2	Crack Inspection	Magnetic Particle Inspection must be available on site. The early production ramp up may require 100% magnetic particle inspection.		
B8.3	Crack Inspection	Dye penetrant inspection must be available on site.		
B8.4	Crack Inspection	Ultrasonic inspection must be available on site.		
B8.5	Cleanliness	For piston rings, the volatiles content of rings being shipped must be audited, measured, and controlled.		
B8.6	Traceability	Unless otherwise noted on part print, all pallet boxes or containers must have customer part number and have traceability information on a sticker attached to the container. The traceability label must contain a code which when provided to the supplier will allow the supplier to provide the following information: 1. Date of casting 2. Spinner number 3. Chemical composition 4. Operator number 5. Casting machine number 6. Casting lot number 7. Machining equipment used 8. Machining operator number		

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B8.7	Repairs	1. Unless expressly Approved by customer Product Engineering, no repairs are allowed. This includes, but is not limited to: impregnation, welding, epoxy repair, heat treating. 2. If repairs are allowed by Customer Product Engineering, procedures need to be completed and approved by Product Engineering before repairs can be used.		
B8.8	Dimensional Inspection - Part One	1. As a minimum, the casting plant shall have a programmable Coordinate Measuring Machine (CMM) on site. The CMM must be run in an automatic mode. Where possible, the application of point cloud/laser scanning inspection technology is preferred. When used in combination with point cloud scanning technology, the CMM is considered the "gage of record" for dimensional measurements because of precision associated with the points measured. 2. The casting plant shall maintain a CMM hit point map/drawing showing all CMM hit points that are agreed upon between the casting plant and the customer. (Point Cloud Inspection/laser scanning can be used in place of CMM inspection if agreed upon with customer Product Engineering).		
B8.9	Dimensional Inspection - Part Two	3. The CMM program must include checking the flatness of each individual raw casting datum surface if the datum pad is intended to be a flat surface. Preferably less than 0.250mm. 4. Point cloud/laser scanning inspection must use the part-design datum construction to align the measurement data. Unless otherwise specified by the customer, "best-fit" data alignment is not allowed. 5. The casting plant is responsible for comparing the scan with the 3D Math Model. In all cases the Point Cloud/laser scan must be aligned to the math model using the X-Y-Z raw casting datum surfaces. Results must be shared with customer Product Engineering and the responsible APQP Quality Engineer. 6. 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. The scan report must clearly state which version of the 3D Math Model was used. 7. Point Cloud/laser scanning Inspection is recommended for prototype parts and PPAP parts as defined by the customer specific requirements. The scanning may be out-sourced.		
B8.10	Dimensional	For piston rings, rings must be stabilized at 21°C, +/- 1° for CMM dimensional inspection purposes.		
B8.11	Wall Thickness	There must be regular audits to section raw castings for wall thickness verification; including any high stress features in the FEA. If the supplier is responsible for any machining, there must be regular audits to section machined castings for wall thickness verification.		

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*If minimum requirements are not met, provide supporting records to justify actual conditions.

What is the scope covered by this audit? The entire foundry? A specific product line? A specific part number? Other?

Describe the scope of the audit:

Item	Category/Process Step	Requirement	Observations / Comments about Actual Condition	Conforming / Non-Conforming / Not Applicable
B8.12	Nodularity Verification	For ductile iron, the supplier is responsible for the correlation of Ultrasonic Velocity or Resonant Frequency Testing to %nodularity to define limits for acceptance at the test location for each part number. Customer may require 100% ultrasonic checking for some applications.		
B8.13	Internal Integrity	1. The supplier must be capable of conducting internal Integrity inspection using non-destructive testing method (x-ray) or destructive testing (sectioning) per customer requirements; including any high stress features in the FEA. 2. The supplier shall have X-ray capability available. X-ray does not have to be on-site. However, the location and access to it must be reasonable for development purposes.		
9.0	Material Properties			
B9.1	Laboratory Location	1. The supplier shall have a metallurgical lab located on-site with capabilities to analyze chemistries, hardness, microstructure, % nodularity, area fraction porosity, and any other features specified by customer Product Engineering. 2. 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.		
B9.2	Material Property Testing	1. Material property testing must be defined per customer design records. 2. Mechanical properties testing must be on site unless customer Product Engineering approves another location. 3. Mechanical property testing must include ultimate tensile strength, yield strength, and percent elongation. Yield Strength must be measured with an extensometer attached to the specimen unless customer Product Engineering agrees to some other method. 4. If retest or replacement is necessary must be with agreement of the customer Product Engineering. 5. Testing begins with prototypes and continues through regular production.		
B9.3	Mechanical Property	The casting source must prepare test bars from a location approved by customer Product Engineering. For example, these might be cut from a tube or from a separately cast bar. Mechanical properties are often required from test bars cut from tubes in an area designated on the engineering drawing or in the part quality document.		

PROCESS TABLE B - Centrifugal Castings

All requirements given below are subordinate to customer specific requirements.

When performing the CQI-27 Casting Assessment the auditor shall verify foundry is conforming to customer requirements; including a customer approved Control Plan defining the agreed upon inspection testing and frequencies.

*If minimum requirements are not met, provide supporting records to justify actual conditions.

What is the scope covered by this audit? The entire foundry? A specific product line? A specific part number? Other?

Describe the scope of the audit:

Item	Category/Process Step	Requirement	Observations / Comments about Actual Condition	Conforming / Non-Conforming / Not Applicable
B9.4	Microstructure Analysis	Metallurgical examination is to be done by the supplier prior to any testing to insure microstructure meets engineering drawing specification. 1. A metallograph image analyzer is required on-site unless customer Product Engineering approves some other method of measuring features in the images. 2. For piston rings, the designated location for microstructure audits is the Outside Diameter wearing surface. 3. Reference photographs must be readily available at the metallograph for all microstructure requirements. 4. Microstructure audits must include any high stress features in the FEA.		
B9.5	Hardness Testing	1. Hardness testing is to be done on-site per ASTM E10/ISO 6506. Supplier must have certified Master blocks on-site for auditing the calibration of the hardness tester. 2. The Tolerance range for the Master block must be posted on the hardness tester. 3. The Tolerance range for the Master must not exceed +/- 3%. 4. The customer specified hardness range must be reduced by the tolerance allowed on the hardness Master block. 5. Unless Product Engineering specifies otherwise, Brinell hardness test raw tubes using a 3000Kg load, 10 mm diameter indenter, and 10 - 15 second dwell time. 6. Hardness to be measured at a specified location from customer Product Engineering. 7.If hardness readings are out of specification, all tubes in the Lot shall be hardness tested with any out-of-specification tubes rejected. 8. Machined parts to be hardness tested per customer Product Engineering requirements.		
B9.6	Heat Treatment	1. Heat treating must be before machining unless customer Product Engineering agrees to heat treat after machining. Heat treating may be in-house or outsourced. Heat treating must be in compliance with CQI-9: Special Process: Heat Treat System Assessment (HTSA), published by AIAG. 2. Austempered Ductile Iron often has some pre-machining before heat treatment. Features to be pre-machined must be approved by customer Product Engineering.		
B9.7	Residual Stress Testing	The supplier is responsible for any residual stress testing requirements unless Customer Product Engineering agrees that the supplier is not responsible for it. Testing may be outsourced. Customer Product Engineering must approve the source which conducts the testing.		
B9.8	Fatigue Testing	The supplier is responsible for any fatigue testing requirements unless Customer Product Engineering agrees that the supplier is not responsible for it. Testing may be outsourced. Customer Product Engineering must approve the source which conducts the testing.		