# PrometheanFoam

Advanced Foam Metal Solutions for Industrial Applications

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**Industry:** Aluminum Foundry & Casting **Technology:** Ceramic-Coated Foam Metal Filtration

# Aluminum Foundry Yield Transformation

*A Case Study on Ceramic-Coated Foam Metal Filtration in Aluminum Casting Operations*

## Executive Summary

This case study presents the implementation of PrometheanFoam's ceramic-coated foam metal filtration technology in an aluminum foundry environment. The technology addressed critical quality issues associated with air entrapment and impurities in molten aluminum, transforming the client's yield rate from **78% to 96%** and generating annual savings of **$2.8 million** across production operations.

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### Transformative Results

- **Defect reduction:** 22% to 4% defective parts
- **Yield improvement:** 78% to 96% overall yield
- **Material savings:** 8% reduction in raw aluminum consumption
- **Annual cost savings:** $2.8M across production operations
- **Quality certification:** Zero customer rejections for 18+ months

| | |
|---|---|
| **96%**<br>Final Product Yield | **18%**<br>Yield Increase |
| **99.8%**<br>Impurity Removal | **800°C+**<br>Operating Temperature |

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# 1. The Aluminum Casting Challenge

## 1.1 Industry Background

Aluminum foundries face persistent challenges with molten metal quality that directly impact product performance, reliability, and cost structure:

- **Gas Porosity:** Hydrogen gas entrapment during solidification leads to structural weaknesses
- **Inclusions:** Oxide films, carbides, and intermetallic compounds degrade mechanical properties
- **Low Yield Rates:** Industry average yields range from 75-85% for precision castings
- **High Scrap Costs:** Rework and scrap handling represent significant financial burdens
- **Inconsistent Properties:** Variable impurity levels lead to unpredictable mechanical performance

## 1.2 The Client Profile

**Client:** Tier-1 Automotive Aluminum Component Supplier

**Production Scale:** 5,000+ tons annual aluminum casting capacity

**Primary Products:** Engine blocks, cylinder heads, transmission housings

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### Pre-Implementation Challenges

| Metric | Value | Industry Impact |
| --- | --- | --- |
| Overall Yield Rate | 78% ± 4% | 22% scrap rate translates to high material waste |
| Customer Rejections | 3.2% of shipments | Quality issues with OEM customers |
| X-Ray Inspection Failure | 15% of castings | Internal porosity and inclusions |
| Tensile Strength Variation | ± 12% from specification | Inconsistent mechanical properties |
| Annual Scrap Cost | $3.5 million | Direct material and processing losses |

## 1.3 Root Cause Analysis

Our technical team conducted a comprehensive analysis identifying key failure modes:

1. **Hydrogen Gas Absorption:** Molten aluminum absorbs hydrogen from moisture in the atmosphere
2. **Oxide Film Formation:** Surface oxidation during transfer and pouring
3. **Inclusion Entrapment:** Refractory particles and furnace lining contamination
4. **Turbulent Flow:** Improper gating design causing air entrapment

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Figure 1: Typical Defects in Aluminum Castings (Pre-Implementation)

*Figure 1: Common defects observed: (A) Gas porosity, (B) Oxide inclusions, (C) Shrinkage porosity, (D) Foreign material inclusions*

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# 2. The Solution: Ceramic-Coated Foam Metal Filtration

## 2.1 Technology Overview

We developed a multi-stage ceramic-coated foam metal filtration system specifically engineered for aluminum foundry applications:

| System Component | Traditional Solutions | PrometheanFoam Solution |
|---|---|---|
| **Filter Media** | Ceramic foam (80-90% alumina) | 316L Stainless Steel Foam with Ceramic Coating |
| **Porosity Gradient** | Single PPI density (typically 10-20 PPI) | Multi-stage: 30-60-90 PPI progression |
| **Temperature Resistance** | 700-800°C (limited thermal shock resistance) | 800°C continuous, 1000°C peak (excellent thermal shock) |
| **Mechanical Strength** | Brittle, prone to cracking | High ductility with ceramic surface |
| **Flow Characteristics** | High pressure drop (15-25 kPa) | Optimized flow with 8-12 kPa pressure drop |
| **Service Life** | 2-4 weeks typical | 8-12 weeks with proper maintenance |

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## 2.2 Technical Specifications

### Ceramic-Coated Foam Metal Filter Specifications

- **Base Material:** 316L Stainless Steel Foam
- **Ceramic Coating:** Alumina-Zirconia composite (80:20 ratio)
- **Coating Thickness:** 150-200 microns per side
- **PPI Progression:** 30 PPI (coarse) → 60 PPI (intermediate) → 90 PPI (fine)
- **Porosity:** 85-90% (maintained after coating)
- **Dimensions:** Standard 300mm × 300mm × 50mm (custom sizes available)
- **Maximum Operating Temperature:** 800°C continuous, 1000°C intermittent
- **Thermal Shock Resistance:** $\Delta T = 500°C$ (water quench test)
- **Hydrogen Removal Efficiency:** 85-90% reduction
- **Inclusion Removal:** >99.5% for particles >20 microns

## 2.3 Filtration Mechanism

The system employs a multi-stage filtration approach:

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### Three-Stage Filtration Process

1. **Stage 1 - Coarse Filtration (30 PPI):**
    - Removes large inclusions (>100 microns)
    - Reduces turbulence and initial hydrogen release
    - Pre-filters for subsequent stages
2. **Stage 2 - Intermediate Filtration (60 PPI):**
    - Captures medium-sized inclusions (20-100 microns)
    - Further hydrogen reduction through extended contact time
    - Oxide film breakup and capture
3. **Stage 3 - Fine Filtration (90 PPI):**
    - Removes fine particles (5-20 microns)
    - Final hydrogen reduction
    - Produces laminar flow into mold cavity

Figure 2: Multi-Stage Filtration System Design

*Figure 2: Schematic of the three-stage ceramic-coated foam metal filtration system showing progressive impurity removal*

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# 3. Implementation & Results

## 3.1 Pilot Program

The initial implementation was conducted on a single casting line over a 90-day period:

- **Duration:** 90 days (3 full production cycles)
- **Scope:** One high-volume casting line for engine blocks
- **Monitoring:** Daily metallurgical analysis, weekly X-ray inspection
- **Parameters Tracked:** Hydrogen content, inclusion counts, mechanical properties

## 3.2 Performance Results

| Quality Metric | Before Implementation | After Implementation | Improvement |
| --- | --- | --- | --- |
| Hydrogen Content (ml/100g Al) | 0.32 ± 0.08 | 0.05 ± 0.02 | 84% reduction |
| Inclusion Count (per cm²) | 42 ± 15 | 0.8 ± 0.5 | 98% reduction |
| X-Ray Porosity Rating | Level 3-4 (ASTM E505) | Level 1-2 (ASTM E505) | 2-level improvement |
| Tensile Strength (MPa) | 285 ± 35 | 310 ± 15 | 8.8% increase, 57% less variation |
| Yield Strength (MPa) | 240 ± 30 | 260 ± 10 | 8.3% increase, 67% less variation |
| Elongation (%) | 4.5 ± 1.5 | 6.2 ± 0.8 | 38% increase, 47% less variation |

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## 3.3 Production Yield Results

### Pilot Program Yield Analysis

| Yield Category | Before (%) | After (%) | Improvement (absolute) |
|---|---|---|---|
| First Pass Yield | 65.2 | 89.5 | +24.3% |
| Final Yield (with rework) | 78.4 | 96.1 | +17.7% |
| Customer Rejection Rate | 3.2 | 0.1 | -3.1% |
| Scrap Rate (total) | 21.6 | 3.9 | -17.7% |

## 3.4 Full-Scale Implementation

Following the successful pilot, the system was implemented across all 4 casting lines over 6 months:

**$2.8M**

Annual Savings

**15%**

Production Increase

**8%**

Raw Material Saving

**18 mos**

Zero Rejections

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# 4. Economic Analysis

## 4.1 Initial Investment

| Cost Component | Cost per Casting Line | Total (4 lines) | Notes |
|---|---|---|---|
| Filtration System Design | $15,000 | $60,000 | Custom engineering for each line |
| Filter Units (initial set) | $8,500 | $34,000 | Ceramic-coated foam metal filters |
| Installation & Commissioning | $6,000 | $24,000 | 2-day installation per line |
| Training & Documentation | $4,000 | $16,000 | Operator and maintenance training |
| **Total Initial Investment** | **$33,500** | **$134,000** | One-time capital expenditure |

## 4.2 Annual Operational Costs

| Operational Cost | Cost per Casting Line | Annual Total (4 lines) |
|---|---|---|
| Filter Replacement (every 10 weeks) | $3,400 | $13,600 |
| Preventive Maintenance | $1,200 | $4,800 |
| Quality Testing (enhanced) | $800 | $3,200 |
| **Total Annual Operational Cost** | **$5,400** | **$21,600** |

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## 4.3 Annual Savings & ROI

| Savings Category | Annual Savings per Line | Annual Total (4 lines) | Calculation Basis |
|---|---|---|---|
| Reduced Scrap & Rework | $385,000 | $1,540,000 | 17.7% yield improvement on $2.175M/line |
| Raw Material Savings | $174,000 | $696,000 | 8% reduction in aluminum consumption |
| Reduced Customer Returns | $85,000 | $340,000 | 3.1% reduction in rejection rate |
| Increased Production Capacity | $65,000 | $260,000 | 15% throughput increase |
| **Total Annual Savings** | **$709,000** | **$2,836,000** | Net of operational costs |

### Return on Investment Summary

**Payback Period:** 1.7 months

Calculation: $134,000 total investment ÷ $2,836,000 annual savings × 12 months = 0.57 months

**Annual ROI:** 2,016%

Calculation: ($2,836,000 annual savings ÷ $134,000 initial investment) × 100% = 2,116%

**3-Year Total Savings:** $8,374,000

Calculation: ($2,836,000 × 3 years) - $134,000 = $8,374,000

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# 5. Metallurgical Performance Improvements

## 5.1 Microstructural Analysis

### Key Microstructural Improvements

- **Grain Refinement:** Average grain size reduced from 120μm to 85μm
- **Porosity Reduction:** Total porosity decreased from 1.8% to 0.3%
- **Inclusion Size Distribution:**
  - >50μm inclusions: Reduced from 12/cm² to 0.1/cm²
  - 20-50μm inclusions: Reduced from 25/cm² to 0.5/cm²
  - <20μm inclusions: Reduced from 5/cm² to 0.2/cm²
- **Secondary Phase Distribution:** More uniform distribution of Si and Mg phases

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### 5.2 Mechanical Property Enhancement

| Mechanical Property | Before (Average ± SD) | After (Average ± SD) | Improvement | Industry Specification |
|---|---|---|---|---|
| Tensile Strength (MPa) | 285 ± 35 | 310 ± 15 | +25 MPa (8.8%) | ≥ 290 MPa |
| Yield Strength (MPa) | 240 ± 30 | 260 ± 10 | +20 MPa (8.3%) | ≥ 240 MPa |
| Elongation (%) | 4.5 ± 1.5 | 6.2 ± 0.8 | +1.7% (37.8%) | ≥ 3.0% |
| Fatigue Strength ($10^7$ cycles, MPa) | 95 ± 12 | 120 ± 8 | +25 MPa (26.3%) | ≥ 100 MPa |
| Impact Toughness (J) | 7.5 ± 2.0 | 10.2 ± 1.2 | +2.7 J (36.0%) | ≥ 6.0 J |

### 5.3 Hydrogen Content Analysis

Reduced hydrogen content has significant implications for product performance:

- **Before:** 0.32 ml/100g Al (typical for unfiltered aluminum)
- **After:** 0.05 ml/100g Al (superior to degassed aluminum at 0.10-0.15 ml/100g)
- **Industry Standard:** <0.15 ml/100g Al for critical automotive components

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Figure 3: Microstructural Comparison (Before vs After)

*Figure 3: Optical micrographs showing (Left) Unfiltered aluminum with porosity and inclusions, (Right) Filtered aluminum with clean microstructure*

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# 6. Implementation Guidelines

## 6.1 System Integration

### Integration Requirements

- **Location:** Between furnace and holding vessel, or holding vessel and casting station
- **Temperature Control:** Maintain 700-750°C at filter interface
- **Flow Rate:** 20-30 kg/min per filter unit (standard size)
- **Pre-heating:** Filters must be pre-heated to 500°C before use
- **Support Structure:** Stainless steel frame with ceramic insulation

## 6.2 Operational Protocol

1. **Start-up Procedure:**
    - Pre-heat filters to 500°C over 2 hours
    - Initial metal flow at reduced rate (10 kg/min)
    - Gradual ramp to full production rate over 15 minutes
2. **Production Monitoring:**
    - Continuous temperature monitoring at inlet and outlet
    - Pressure drop measurement (target: 8-12 kPa)
    - Visual inspection of filtered metal quality
3. **Shutdown Procedure:**
    - Reduce flow rate before stopping
    - Allow filters to cool in place
    - Remove for inspection and cleaning

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### 6.3 Maintenance Schedule

| Maintenance Activity | Frequency | Procedure | Expected Duration |
|---|---|---|---|
| Filter Inspection | Daily | Visual check for cracks, clogging, or damage | 5 minutes |
| Pressure Drop Check | Twice per shift | Measure differential pressure across filter | 2 minutes |
| Filter Cleaning | Every 2-3 weeks | High-pressure air or water jet cleaning | 30 minutes |
| Filter Replacement | Every 8-12 weeks | Swap out filter units per rotation schedule | 45 minutes |
| System Calibration | Quarterly | Temperature sensors and pressure gauges | 2 hours |

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# 7. Scalability & Applications

## 7.1 Different Aluminum Alloys

The technology has been validated across multiple aluminum alloy systems:

| Alloy Series | Typical Applications | Yield Improvement | Notes |
|---|---|---|---|
| 1xxx (Pure Al) | Electrical conductors, chemical equipment | +12-15% | Excellent hydrogen removal |
| 3xxx (Al-Mn) | Heat exchangers, cooking utensils | +15-18% | Improved corrosion resistance |
| 5xxx (Al-Mg) | Marine applications, pressure vessels | +18-22% | Enhanced weldability and strength |
| 6xxx (Al-Mg-Si) | Automotive, architectural extrusions | +17-20% | Case study alloy (6061, 6082) |
| 7xxx (Al-Zn-Mg) | Aerospace, high-strength applications | +20-25% | Critical for fatigue-sensitive parts |

## 7.2 Other Metal Systems

The ceramic-coated foam metal technology has been adapted for:

- **Magnesium Alloys:** AZ91, AM60 with improved corrosion resistance
- **Copper Alloys:** Bronze and brass casting for decorative applications
- **Zinc Alloys:** Die casting applications with reduced porosity
- **Superalloys:** Nickel-based alloys for aerospace components

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## 7.3 Alternative Foundry Processes

### Compatible Casting Methods

- **Sand Casting:** Improved surface finish and reduced inclusions
- **Permanent Mold Casting:** Extended mold life through cleaner metal
- **Die Casting:** Reduced porosity in high-pressure applications
- **Investment Casting:** Enhanced dimensional accuracy and surface quality
- **Low-Pressure Casting:** Improved filling characteristics

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# 8. Quality Certification & Compliance

## 8.1 Industry Standards Met

- **ASTM B108:** Standard Specification for Aluminum-Alloy Permanent Mold Castings
- **ASTM E505:** Standard Reference Radiographs for Inspection of Aluminum and Magnesium Castings
- **SAE AMS 2175:** Castings, Classification and Inspection of
- **IATF 16949:** Automotive Quality Management System
- **NADCAP:** National Aerospace and Defense Contractors Accreditation Program

## 8.2 Customer Quality Performance

### OEM Customer Feedback

- **Zero Defect Performance:** 18+ months without a quality rejection
- **Supplier Rating Improvement:** Moved from Tier 2 to Tier 1 supplier status
- **Quality Awards:** Received "Supplier Excellence" awards from 2 major OEMs
- **Audit Performance:** Perfect scores on 3 consecutive quality audits
- **Warranty Reduction:** 92% reduction in warranty claims related to casting quality

## 8.3 Environmental & Safety Benefits

- **Reduced Energy Consumption:** 12% less energy per ton of good castings
- **Lower Emissions:** Reduced dross formation means less landfill waste
- **Improved Workplace Safety:** Reduced molten metal splatter and turbulence
- **Material Efficiency:** 8% less raw material consumption for same output
- **Recyclability:** Filters are 100% recyclable at end of service life

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# 9. Conclusion & Recommendations

The implementation of PrometheanFoam's ceramic-coated foam metal filtration technology has transformed aluminum foundry operations through:

### Strategic Impact Summary

- **Quality Transformation:** Defect rates reduced from 22% to 4%
- **Economic Revolution:** $2.8M annual savings with 1.7-month payback
- **Technical Superiority:** Hydrogen levels reduced to 0.05 ml/100g Al
- **Market Positioning:** Achieved zero defect status with major OEMs
- **Sustainable Advantage:** Reduced material and energy consumption

## 9.1 Recommendations for Implementation

1. **Start with a Pilot:** Implement on one production line to validate results
2. **Engage Cross-Functional Teams:** Include production, quality, and maintenance teams
3. **Establish Baseline Metrics:** Document current performance before implementation
4. **Plan for Training:** Allocate resources for operator and maintenance training
5. **Monitor & Adjust:** Establish KPIs and regular review meetings

## 9.2 Future Development

Based on this success, we are developing next-generation systems with:

- **Smart Monitoring:** IoT sensors for predictive maintenance
- **Advanced Coatings:** Nanocomposite coatings for extended service life
- **Modular Design:** Quick-change filter systems for reduced downtime
- **Integrated Degassing:** Combined filtration and degassing units

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