Metal Matrix Composite LOX Turbopump Housing Via Novel Tool-Less Net-Shape Pressure Infiltration Casting Technology

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MMCC

Metal Matrix Cast Composites, Inc.

WHY METAL MATRIX COMPOSITE FOR PROPULSION COMPONENTS

- **PERFORMANCE**
  - High Specific Strength & Specific Stiffness = Weight Savings
  - Compatibility With H_2 and O_2 -- Better Than PMC/CMC
  - Low Thermal Coefficient of Expansion
  - Higher Electrical & Thermal Conductivity than PMC
  - Ductility & Toughness From Metal Matrix
  - Particulate MMC's behavior More Like Metallic Alloys
- **AFFORDABILITY**
  - Complex Parts Can be Produced by Low Cost Casting
  - MMC Cost per Pound Comparatively Less Than PMC/CMC
  - Many Commercial & DoD Applications Now in Service

METAL MATRIX COMPOSITE TURBOPUMP HOUSING JOINT REDESIGN EFFORT

- **Metal Matrix Cast Composites, Inc.,**
  - **Phase II SBIR Award**
  - **Develop Materials And Manufacturing Process.**
  - **Cast 3 Full Scale "Redesigned" "Hybrid" Al MMC LOX Compatible Turbopump Housings**

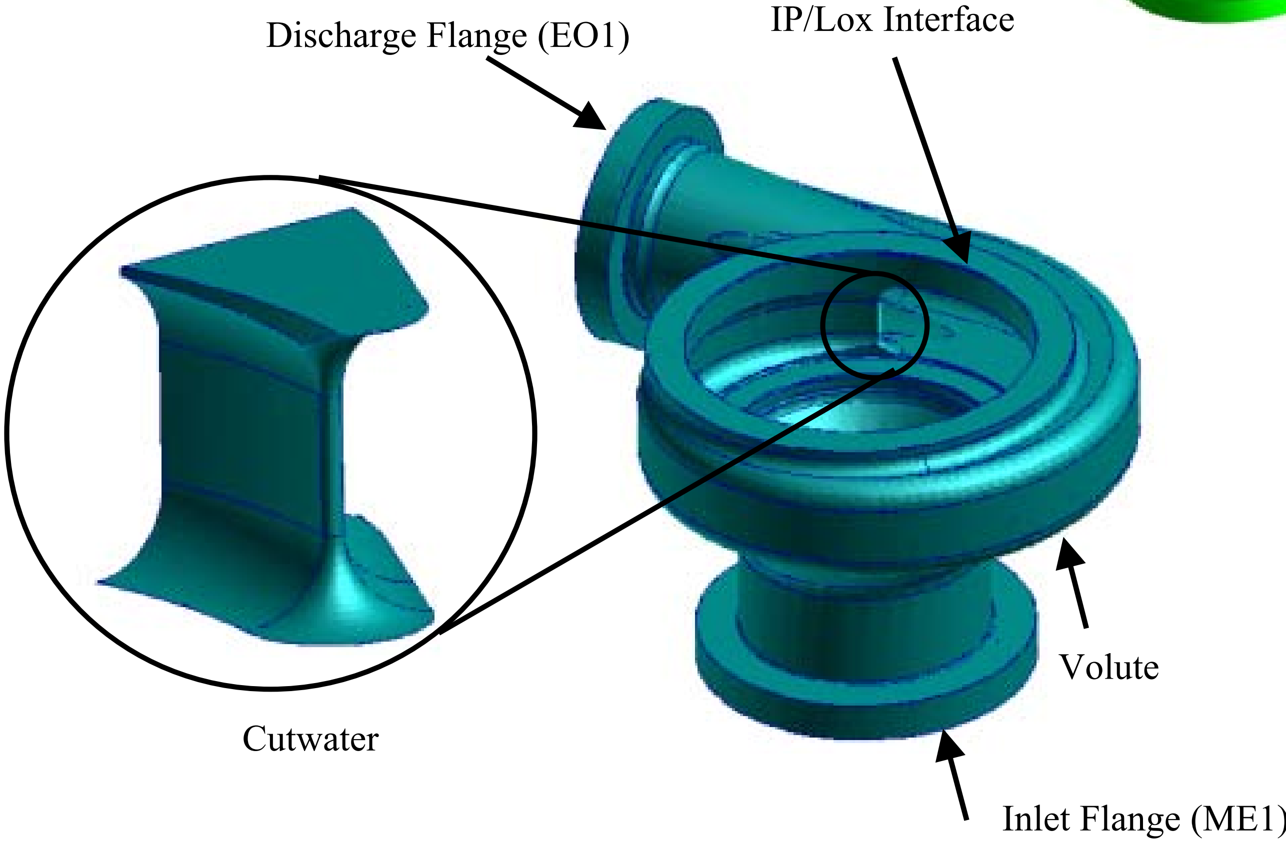
- **NASA MSFC Space Transportation Team**
  - **Internal NRA Award**
  - **Re-analyze and Re-design Al MMC Pump Housing**

- **NASA To Provide New Pump Housing Design To MMCC. Inc.**

Redesign Objectives – 40% weight Savings

BASELINE PUMP DESIGN AND ANALYSIS

BASELINE PUMP HOUSING DESIGN AND STRESS ANALYSIS



BASELINE PUMP HOUSING DESIGN AND STRESS ANALYSIS - Continued

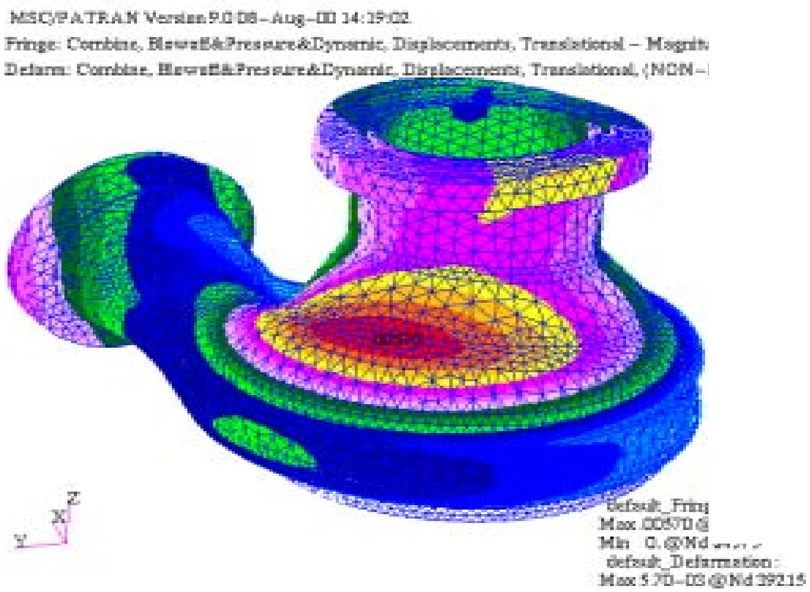
Material : Microcast Inconel 718

E = 29.6 Msi, v = 0.29, d = 0.297 pci UTS = 140 Ksi, YS = 110 Ksi

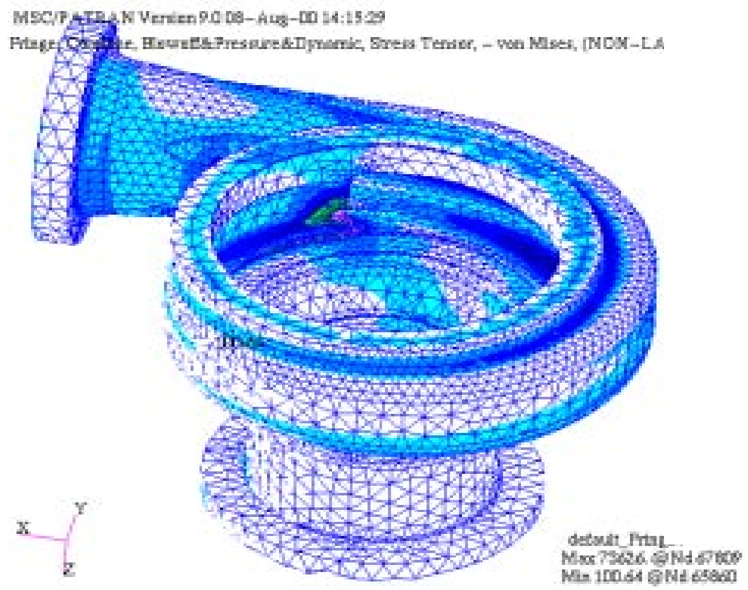
Safety Factor: 1.4 on UTS LEFM

PEAK STRESSES IN CUTWATER LOCATION

Baseline Deformation Plot



Baseline Stress Plot



TOOL-LESS ADVANCED PRESSURE INFILTRATION CASTING PROCESS

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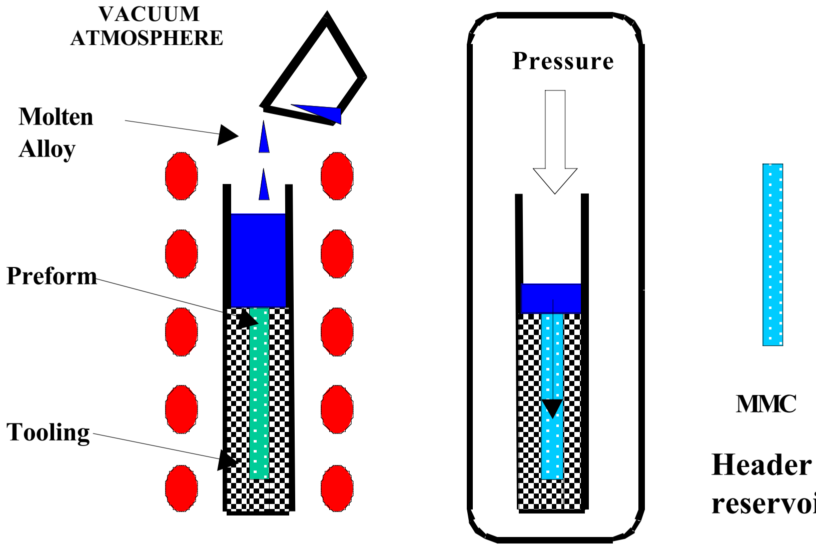


Header containing reservoir of molten alloy

Pre heated-pre evacuated mold vessel containing preforms

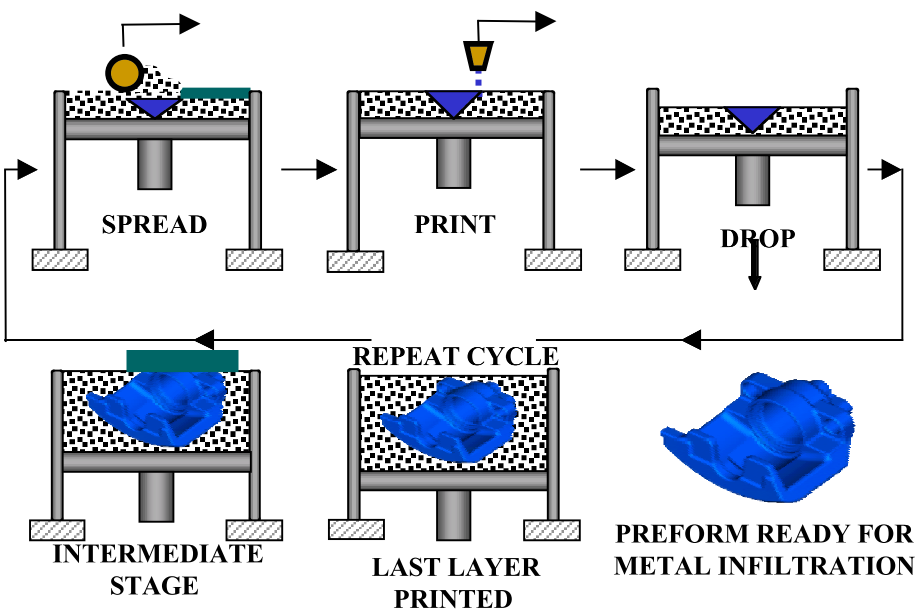
Autoclave for pressure infiltration

Two cubic foot casting being transferred to autoclave for pressure infiltration and directional solidification

TOOL-LESS ADVANCED PRESSURE INFILTRATION CASTING PROCESS: 3 Dimensional Printing (3DP) of Ceramic Preform

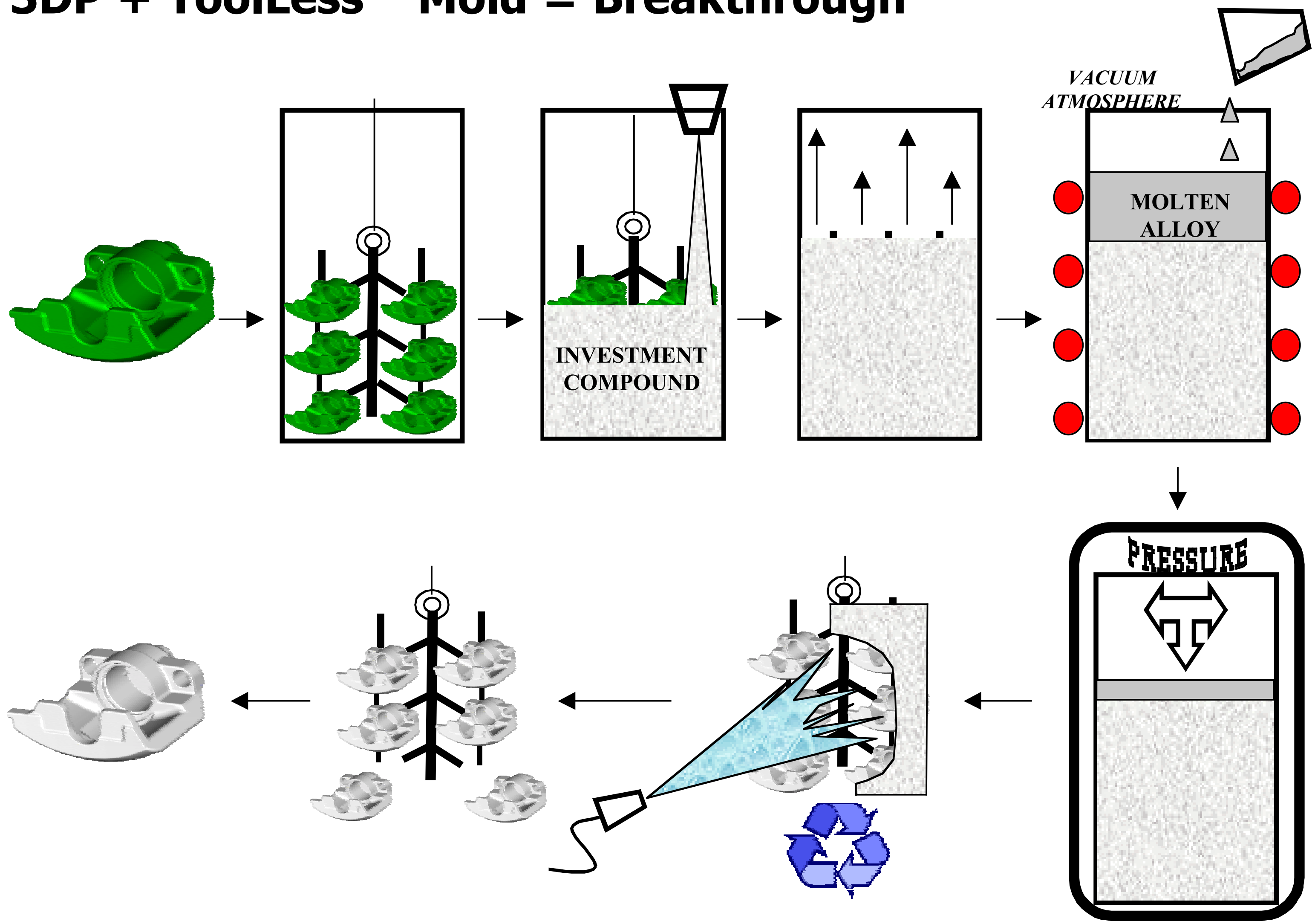
Novel 3D-Printing Technology

Advantages: From CAD file to preform with no tools; uniform defect-free preform



TOOL-LESS ADVANCED PRESSURE INFILTRATION CASTING PROCESS: Tool-Less Mold Process

3DP + ToolLess™ Mold = Breakthrough

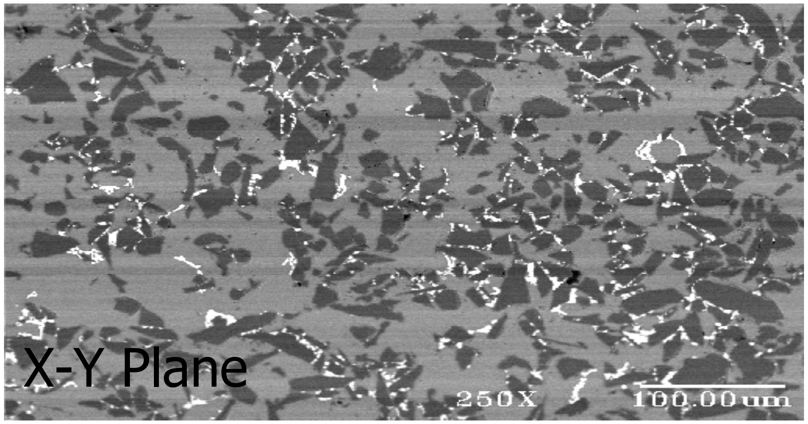


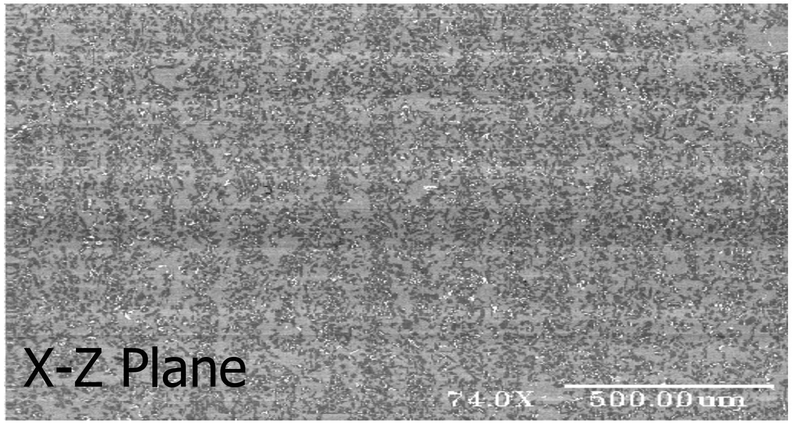
TOOL-LESS ADVANCED PRESSURE INFILTRATION CASTING PROCESS: Mechanical Properties and Microstructure Optimization

- **3DP Ceramic Reinforcement particle Size and Volume used**

Reinforcement Type	Particulate Size	Particulte Vf in final MMC Composite
Al2O3	(17 + 20% of 2.7) micron	35 - 38 %
Al2O3	17 micron	37 - 41 %
SiC	(17 + 20% of 2.7) micron	31 - 35 %

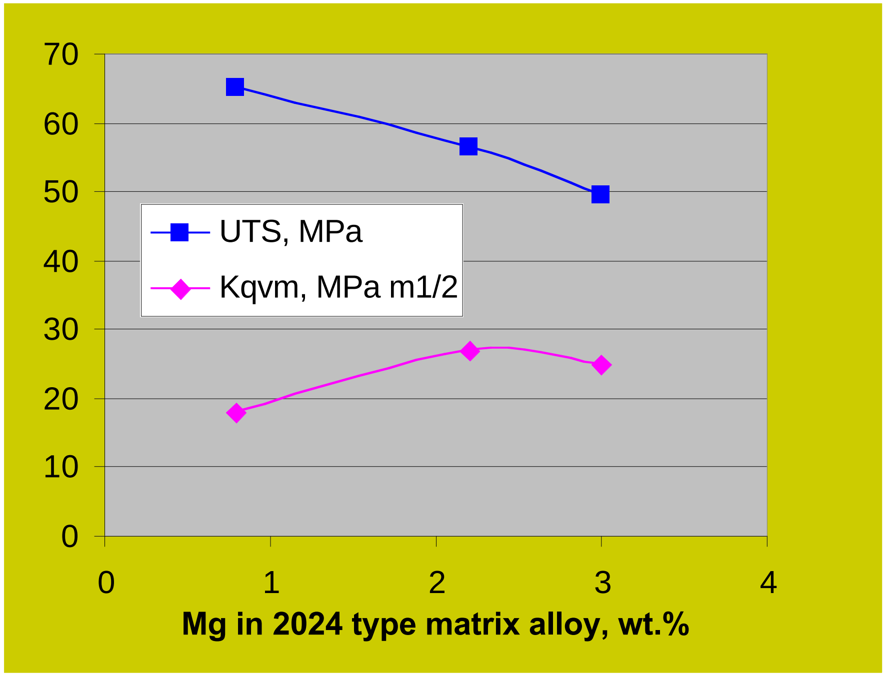
- **Typical microstructure of 3DP composite:**
  - isotropic in X-Y plane, anisotropic in X-Z plane

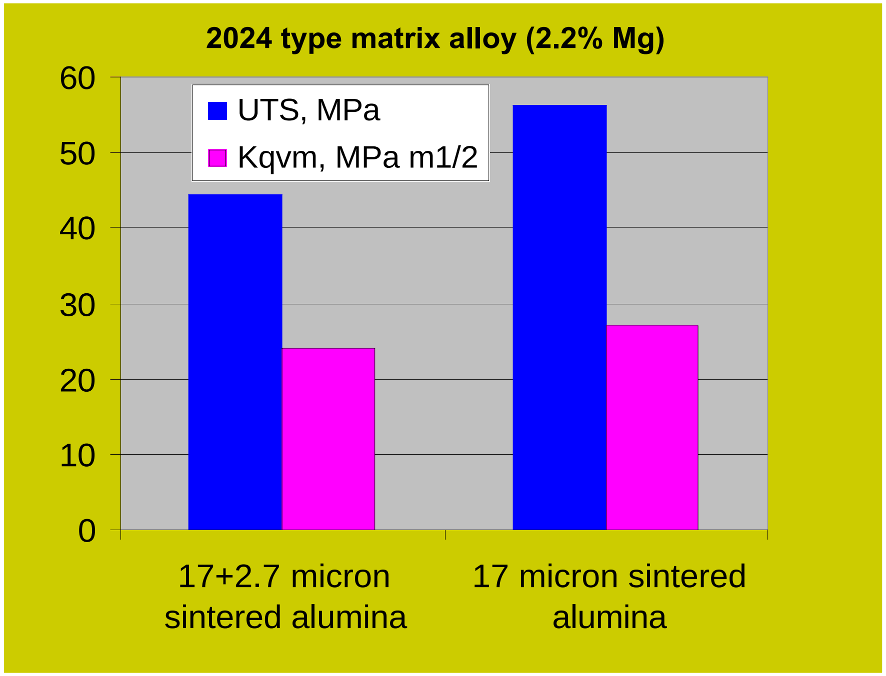




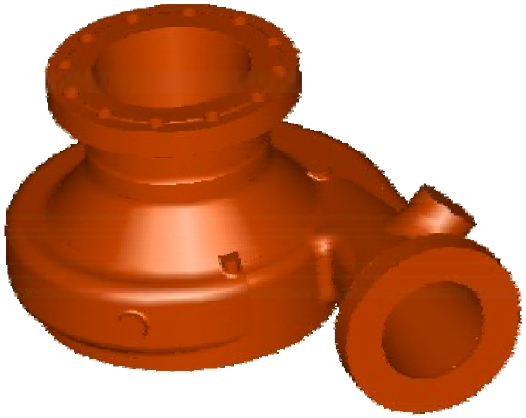
TOOL-LESS ADVANCED PRESSURE INFILTRATION CASTING PROCESS: Typical Mechanical Properties

- 3DP sintered alumina Al alloy composites: Strength, toughness vs alloy composition and particle size





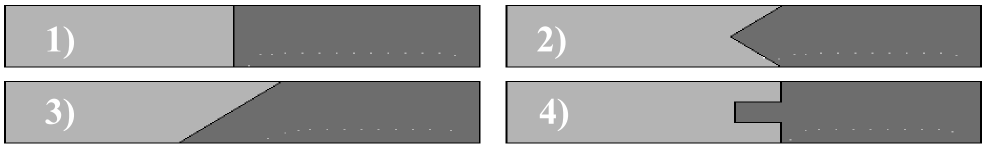
SUBSCALE PUMP HOUSING: Pressure Infiltration Casting Demonstration



PREFORM SPLICING AND JOINING FOR LARGE COMPONENTS SUCH AS PUMP HOUSING

PREFORM SPLICING AND JOINING STUDY

3D PRINTING IS LIMITED IN SIZE REQUIRING SPLICING AND JOINING OF LARGE PART PREFORMS



Joint type	Sintered	UTS		Std. Dev.	Sintering
	Connection	ksi	mPa	mPa	Lot #
# 1) Butt	yes	53.4	368	27.1	2
"	no	59.0	406.8	27.1	2
# 2) V-Joint	yes	62.1	428.1	9.5	1
"	no	56.6	390.5	15.1	1
"	no	51.1	352	28.8	2
# 3) 45 Degree	yes	67.9	468.4	26.2	1
"	yes	57.0	392.8	31.7	2
"	no	62.6	431.6	28.3	1
"	no	62.1	428.1	13.7	2
#4) Tongue & Grove	yes	55.6	383.0	36.4	1
	no	64.5	444.8	39.6	1
	no	59.4	409.4	37.9	2

1) 3DP Print Preforms
   Join Preforms
   Sinter Together
   Infiltrate
   Heat Treat
   Tensile Test Coupon

2) 3DP Print Preforms
   Sinter Separate
   Join Preforms
   Infiltrate
   Heat Treat
   Tensile Test Coupon

3DP- Al_2O_3 Particulate Preform Joining Study- Conclusions:

1. Tensile properties relatively insensitive to joint design
2. Components can be printed as parts and joined after sintering
3. These results lead to processing flexibility

FULLSCALE PUMP HOUSING REDESIGN

FULLSCALE PUMP HOUSING REDESIGN

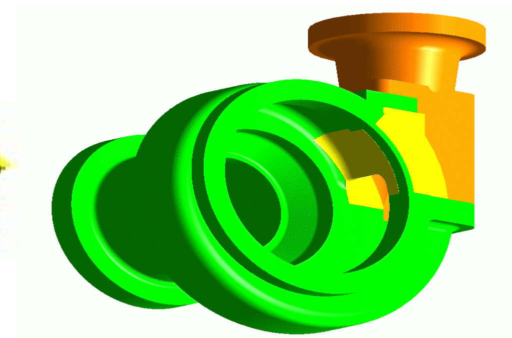
Objective: Redesign the pump housing to reduce the maximum stress yet keeping the 40% weight savings.

Full Scale Manufacturing	Positive Margin in Design

FULLSCALE PUMP HOUSING REDESIGN-
Manufacturing Design Options Considered

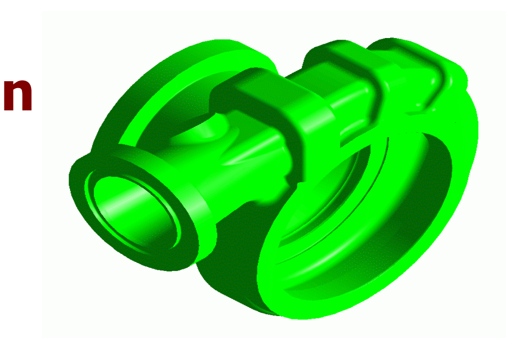
Hybrid: Wrap fibers around volute in cutwater area

- **Alloy not suitable for hybrid reinforcement**
- **manufacturing complexity**



Inconel718 insert in cutwater area

- **Manufacturing complexity**
- **Cost and Schedule**



Al particulate MMC with gussets in volute

- **Selected for Manufacturing Demonstration**

Hybrid: Sic Fiber stiffened gussets in volute

- **Cracking in Fiber/particulate interface in subscale specimen. Need to match CTE.**

FULLSCALE PUMP HOUSING REDESIGN - FEM Analysis

FEM Analysis Particulate Al MMC Properties Used: **Linear Isotropic Material**

E = 22 Msi, UTS = 58Ksi, YS = 50Ksi, ν = 0.3, δ = 0.111 pci,

Factor of Safety = 2.0 on UTS Allowable Max Stress = 29 Ksi

Margin of Safety = ((actual safety factor/required safety factor) –1)

Al Particulate MMC Design Options Analyzed	Weight Lbs	Margin of Safety ***
Baseline - Inconel 718	25.95	0.0
Baseline - MMC	9.70	-0.606
Baseline + Thicker Volute	10.71	-0.518
Baseline + Thicker Volute+ Larger Cutwater Radius	10.70	-0.471
Baseline + 3 Radial Gussets Added to Volute	10.56	-0.455
Baseline + Deeper Radial Gussets, Larger Cutwater Radius	10.84	-0.372
Baseline + 4-ply SiC Fiber Reinforced Gussets	10.84	-0.371

*** MOS using a Factor of Safety = 2.0 and not 1.4

FULLSCALE PUMP HOUSING PREFORM - Spliced, Joined and Sintered Preform

Housing after sintering but prior to application of Soft-Shell[tm] Tool-Less Mold compound-

(Note stainless steel threaded inserts in bolt circle)

FULLSCALE PUMP HOUSING - Casting

Inserts for threaded mechanical joint

Holes for Bolted Joints

FULLSCALE PUMP HOUSING – Lessons Learned

- Alloy composition needs further development for a hybrid design.
- Cracking at SiC fiber/particulate interface.
- 3 Dimensional printing of large preform sections resulted in sagging and loss of dimensional control of the preform.
- Obtaining surface finish with tool-less mold process needs more development. Surface finish is determined by perform technology, not by tool-less mold technology

SUGGESTED FUTURE DEVELOPMENTS

- ❑ **For 100% particulate housing, the alloy can be optimized to produce higher strength MMC.**

- ❑ **Sagging can be avoided by printing thinner sections of 3DP preforms. Subsequently, preform joining technique can be used to obtain a complete part.**

- ❑ **Preform volume fraction limited to ~35-40%. Slurry/slip casting, an alternative to 3DP preforms can raise the volume fraction to 55%.**

- ❑ **Surface finish of MMC component is totally dependent upon surface of preform. Improve the surface of the preform prior to casting.**

- ❑ **CTE differences between SiC fibers and particulate composite that leads to cracking at fiber interface could be avoided or reduced by using Nextel fibers.**