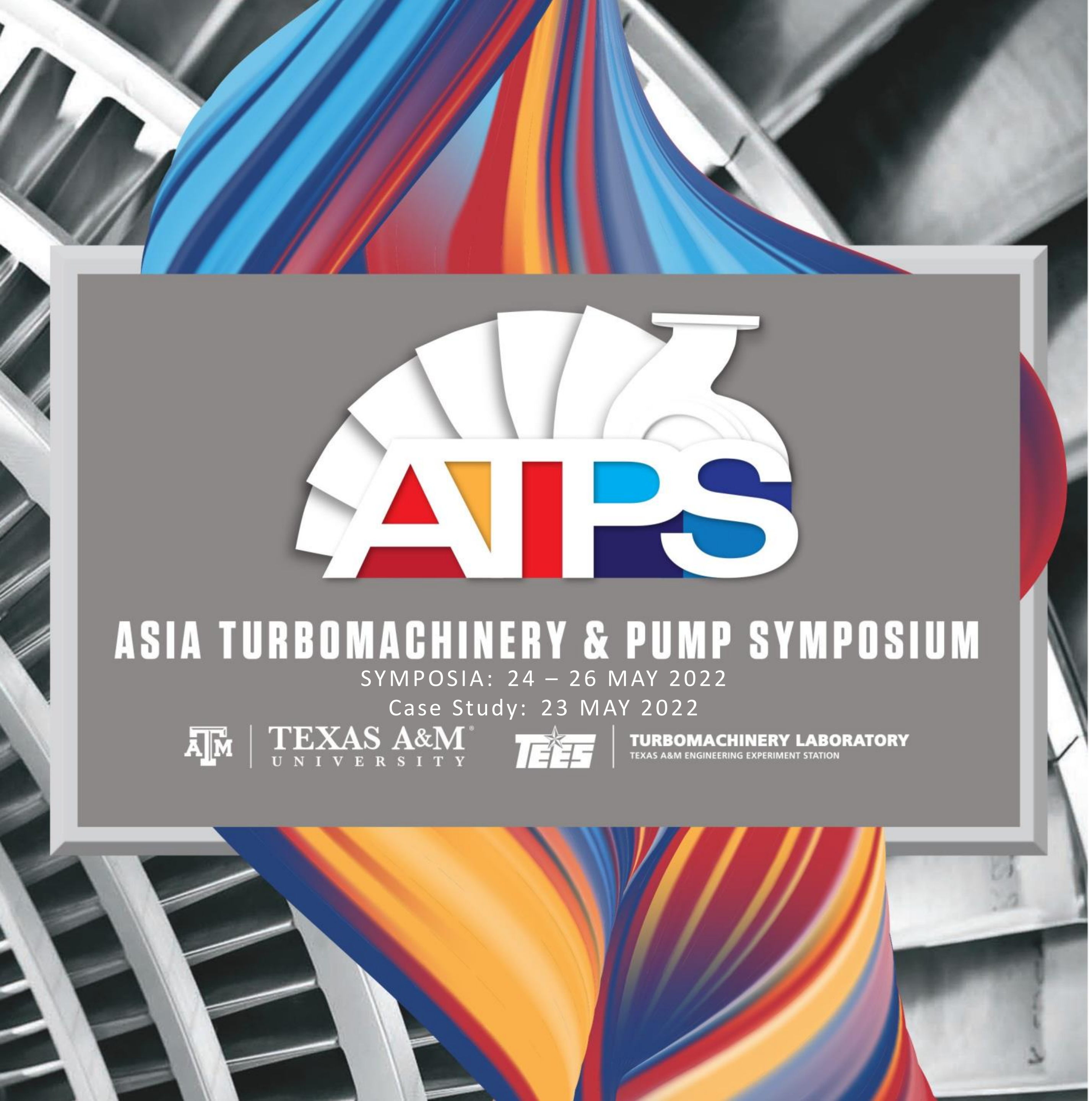

Case Study on Additive Manufacturing Metallic and Non-Metallic Pump Impellers for Corrosive Application.

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FLOWSERVE

Authors Bios

Grace Chew
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Grace Chew is part of Flowserve R&D team at Additive Manufacturing Center of Excellence based in Singapore. She leads projects to qualify new 3D-printable non-metallic materials and is also involved in investigating and applying new AM technologies to optimize the design and performance of Flowserve parts. She has vast experience in the Design and Manufacturing of Automation equipment. She holds a Bachelor's degree in Mechanical & Manufacturing Engineering from the University of South Australia and a Diploma in Mechatronic Engineering from Ngee Ann Polytechnic Singapore. She is a member of the Additive Manufacturing ASTM sub-committee and API 20T standards committee.

Kaushik Asokan
Supervisor R&D
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Kaushik Asokan joined Flowserve in 2011 and currently leading the Additive Manufacturing R&D team based in Singapore. In his role, he is supporting strategic initiatives on Additive Manufacturing technology development and commercialization activities for Flowserve. He has both Mechanical seal and pumps aftermarket engineering, technical services experience in Flowserve. Prior to joining Flowserve, he had worked in a similar industry with companies such as Emerson and AESSEAL in Design and Development. He holds a master's degree in Rotating Machinery from the University of Zaragoza, Spain, and a bachelor's degree in Mechanical Engineering from Anna University, Chennai India.

Abstract

At one of our Customer/ End-user chemical plants in Singapore, they had a problem with frequent replacement of the Hastelloy C impellers **[Existing cast]** used in their centrifugal pumps in corrosive service with Sodium Hypochlorite application. The existing impellers were always noticed with severe pitting corrosion damage and often required a quick turnaround to replace the parts back to service.

With Additive Manufacturing (AM) / 3D printed **[Metallic]** Ti6Al4V Impeller solution, it helped to improve the part life together with a quick turnaround time. 3D printed Ti-6AL4V was found to have better corrosion properties and has superior mechanical properties over existing part. The summary of test results of the 3D-printed part with standard corrosion test in the pumping media and test plan verification of mechanical properties are detailed in this presentation.

3D printing special Metallic materials are not always economical. The alternate solution to Additive manufacturing (AM) **[Non-Metallic]** materials such as PEKK CF (23%) were also explored to replace special metallic materials like Titanium and Hastelloy for low-duty corrosive applications. Lessons learned from material test and corrosion test are also discussed in this presentation.

Hastelloy C Impeller ***[Existing cast]***
with server pitting corrosion

3D printed ***[Metallic]***
Ti6Al4V Impeller

3D printed ***[Non-Metallic]***
PEKK CF (23%) Impeller

Problem:

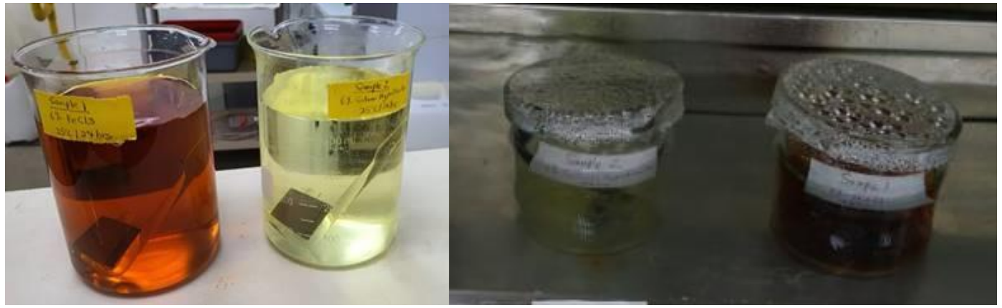
At one of our Customer/ End-user chemical plants in Singapore, they had a problem with frequent replacement of the Hastelloy C impellers casted used in their centrifugal pumps in service with Sodium Hypochlorite application. The existing impeller were always noticed with severe pitting corrosion damage and often required a quick turnaround to replace the parts back to service.



Pitting Corrosion attack on Metal impeller attacked by Sodium Hypochlorite

Solution 1: AM Metal Impeller

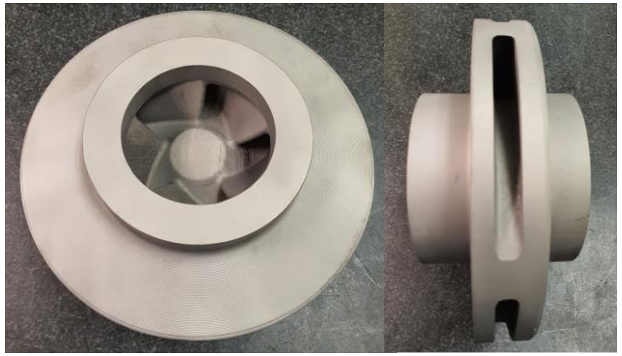
The 3D printed titanium material samples lab tested and corrosion rate estimated with 0.15 to 6% sodium Hypochlorite @ 25Dec C to 50 Dec C was 0.01 mm/y within acceptable range.



Result for 50ºC for 48 hours

Sample Description	Initial Weight (g)	Final Weight (g)	Weight Loss (g)	Surface Area (mm^2)	Corrosion Rate ($g/m^2/24hr$)	Corrosion Rate (mm/year)
Sample 1 6% $FeCl_3$	14.0153	14.0151	0.0002	1850	0.11	0.0043
Sample 2 0.15% Sodium Hypochlorite	14.1269	14.1268	0.0001	1850	0.05	0.0022

As Printed



After Final Machining

Titanium (Ti6Al4v) 3D printed impeller in service since Dec 2019

Solution 1: AM Metal Impeller

Mechanical Properties Test

Tested Material Properties

Material Description: ASTM F3001-14

Chemical Analysis % (IS-228-1987)

	Min	Max	Actual
Al	5.50	6.75	**6.18**
V	3.5	4.5	**4.10**
C	-	0.1	**0.04**
Fe	-	0.30	**0.14**
Ti	-	Bal	**Bal**

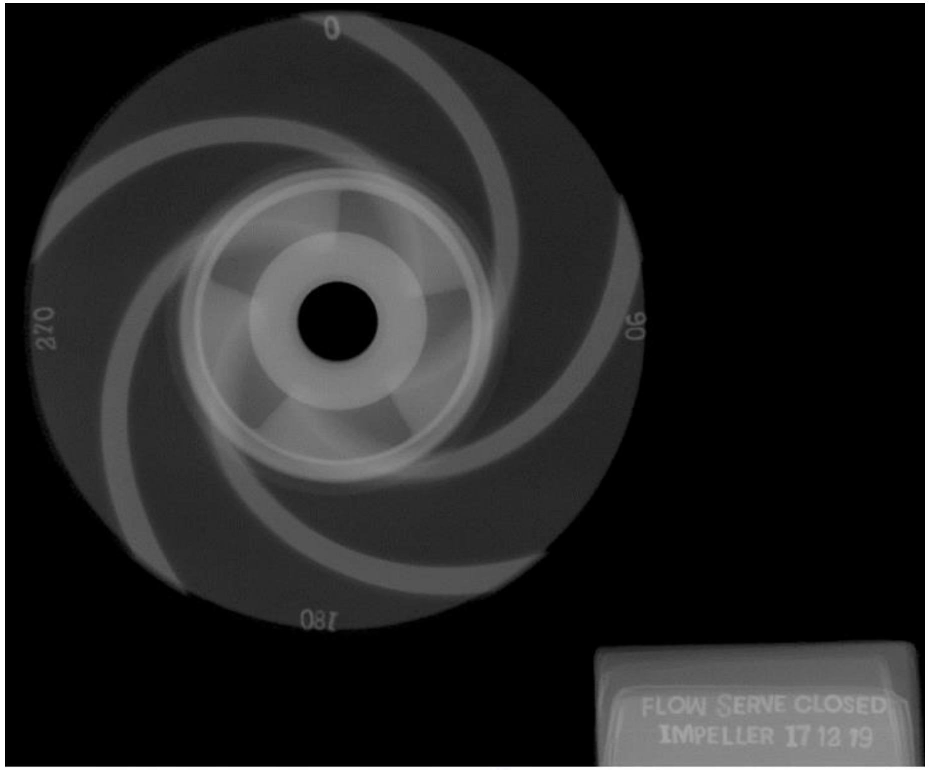
Mechanical Properties (ASTM E8M-13a)

	Spec	Actual
UTS -	860 MPa	1071.4 MPa
Yield -	795 MPa	1016.4 MPa
Elongation -	10%	10.8%

Solution 1: AM Metal Impeller

NDE: PT examination results shows no significant surface defects.

NDE: RT examination results shows no significant volumetric defects.



Solution 2: AM Non-Metal Impeller

Chemical resistance comparison of common SLS printable materials:

Polyaryletherketone (PAEK) is a family of semi-crystalline thermoplastics with high-temperature stability and high mechanical strength.

Materials that fall within this family include:

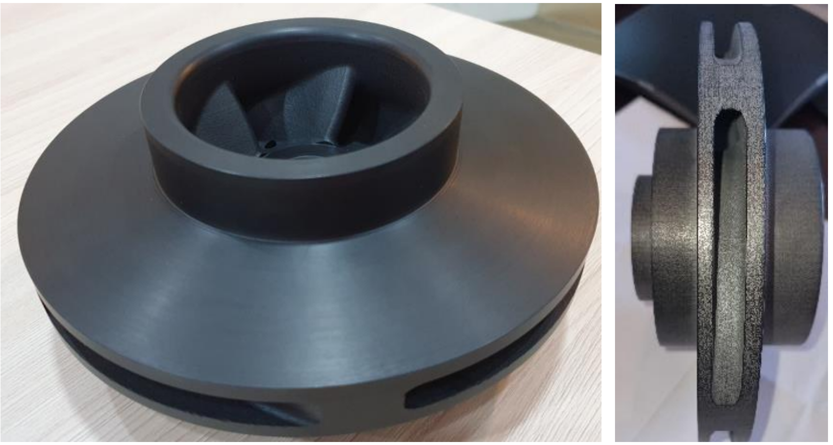
- Polyetherketone (PEK)
- Polyetheretherketone (PEEK)
- Polyetherketoneketone (PEKK)

	Hydrochloric Acid	Sodium Hypochlorite 15% (Chlorine Bleach)
PEKK	A	A
PEEK	A	A
PPS	A	B
Nylon	D	D
PP (Polypropylene)	A	A

Corrosion Resistance

A= No Attack, Negligible effect on mechanical properties
B= Slight attack by absorption. Some swelling and small reduction in mechanical
C= Moderate attack of appreciable absorption. Material will have limited life
D= Material will decompose or dissolve in a short

As Printed



PEKK (HT 23) 3D printed impeller

ASIA TURBOMACHINERY & PUMP SYMPOSIUM

Solution 2: AM Non-Metal Impeller

Benefits of PEKK CF 3D printed impeller over metallic material:

PEKK CF 3D printed impeller for corrosive service.

- **Improved Corrosion Resistant/ Improve part life:**

  One of the most important advantage of PEKK CF 3D printed impeller over metal is its resistance to corrosion and erosion.

- **Impeller integral wear ring/ Reduced volumetric leakage:**

  3D printed impeller can be designed with integral wear ring. PEKK CF integrated ring will not gall or seize like metal ring which can be operated with tighter clearance and permitting less leakage through the ring which increase pump efficiency.

- **Reduced weight/ shaft deflection:**

  PEKK CF material permit a much lighter weight impeller which allows reduction in start-up load and less shaft deflection. Sever pitting corrosion in metallic cause imbalance in rotor with non-metallic corrosion resistance material the corrosion and imbalance are eliminated.

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Solution 2: AM Non-Metal Impeller

Corrosion test:

ASTM D543-20
Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents

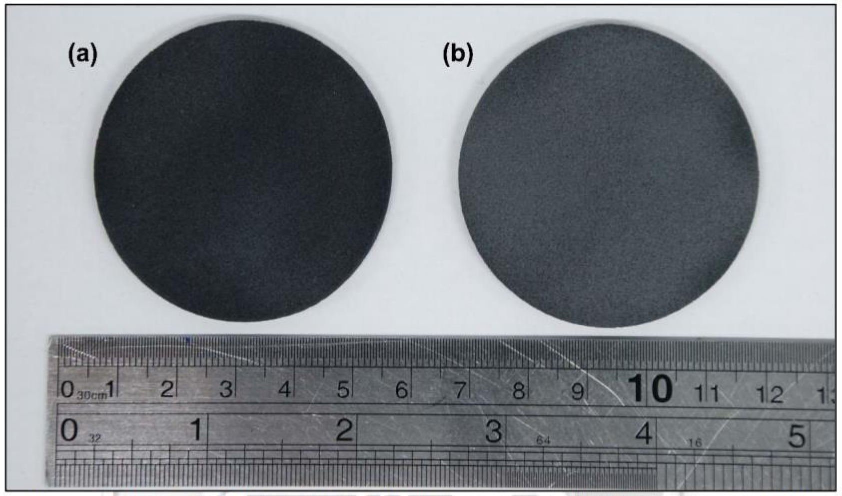

Figure 3. Photo of "PEKK CF HT-23, SLS": (a) control and (b) after immersion in HCl
Whitening of sample observed

Immersion Reagents:

- 37% hydrochloric acid (HCl) solution
- 5% Sodium hypochlorite (NaOCl) solution

Observation:

1. No physical swelling and extra weight gain on sample
2. No increase of diameter
3. No visible loss of gloss, no tackiness, no softening and no cracking on tested PEKK CF samples.

Solution 2: AM Non-Metal Impeller

Mechanical testing is done on as printed samples and verify result against feedstock provider datasheet,

As printed part with test specimens

Mechanical Specification	Unit	Datasheet	Tested
		PEKK CF (HT-23)	Tested PEKK CF (HT-23)
Tensile Strength	MPa	80 (X) 77 (Y) 61 (Z)	66.97 (X) 57.9 (Y) 55.1 (Z)
Elongation at break	%	1.16 (X) 1.06 (Y)	1.43 (X) 1.16 (Y) 1.4 (Z)
Charpy impact strength, Notched	J/m^2	20 / 18	13.8 (X) 15.2 (Y) 15.1 (Z)
Shore Hardness	-	-	86.65 (X) 84.75 (Z)
Density	g/m^3	1390	1371

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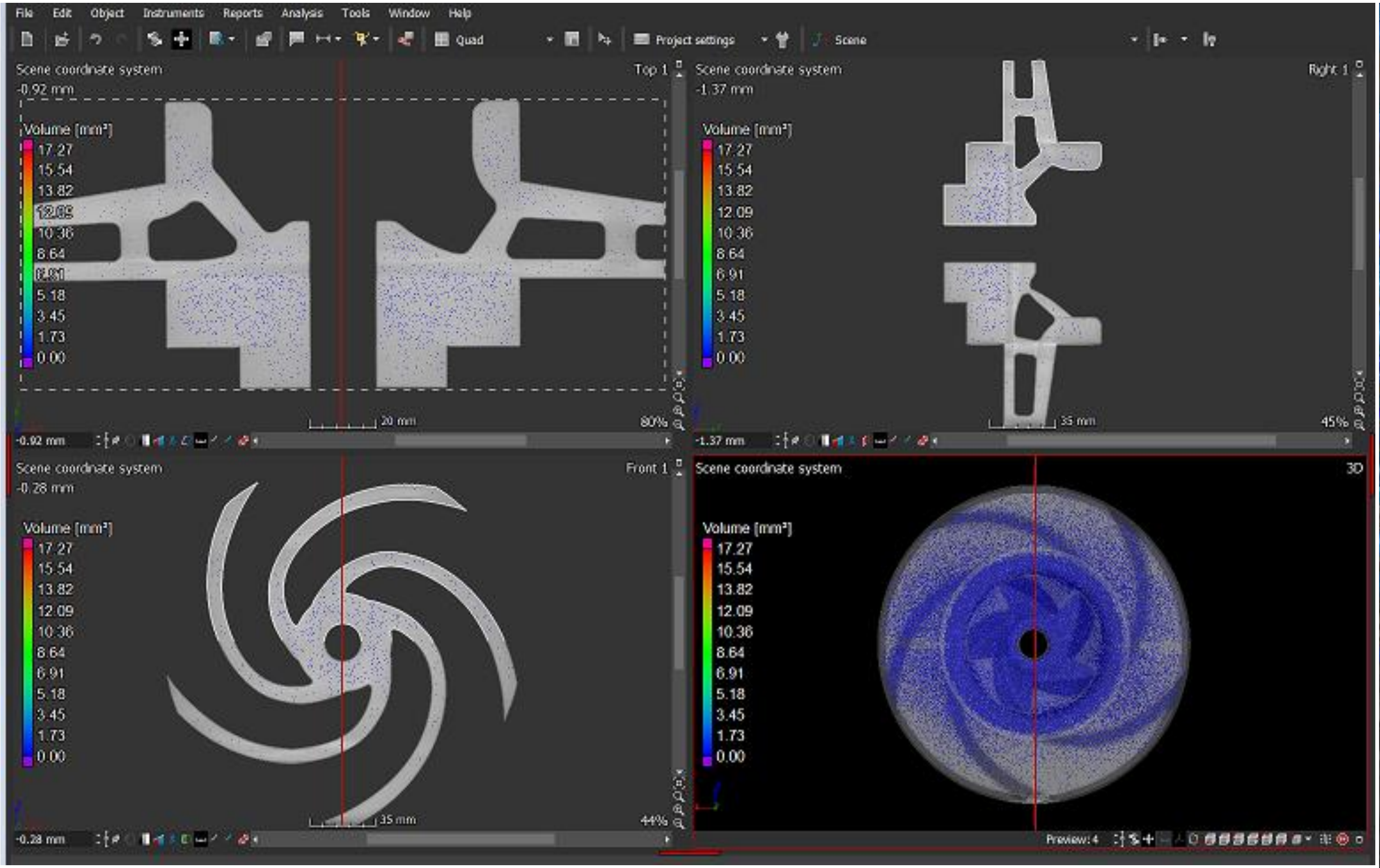
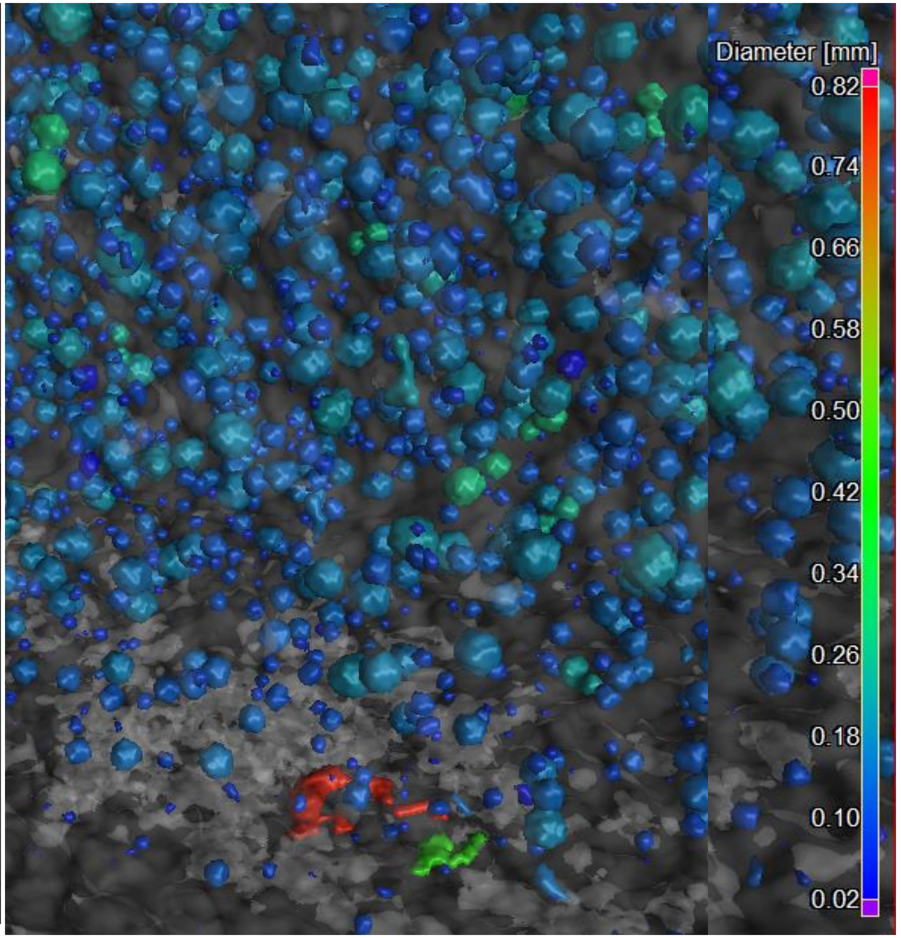
Solution 2: AM Non-Metal Impeller

NDE: CT Scan on PEKK CF SLS printed Close Impeller





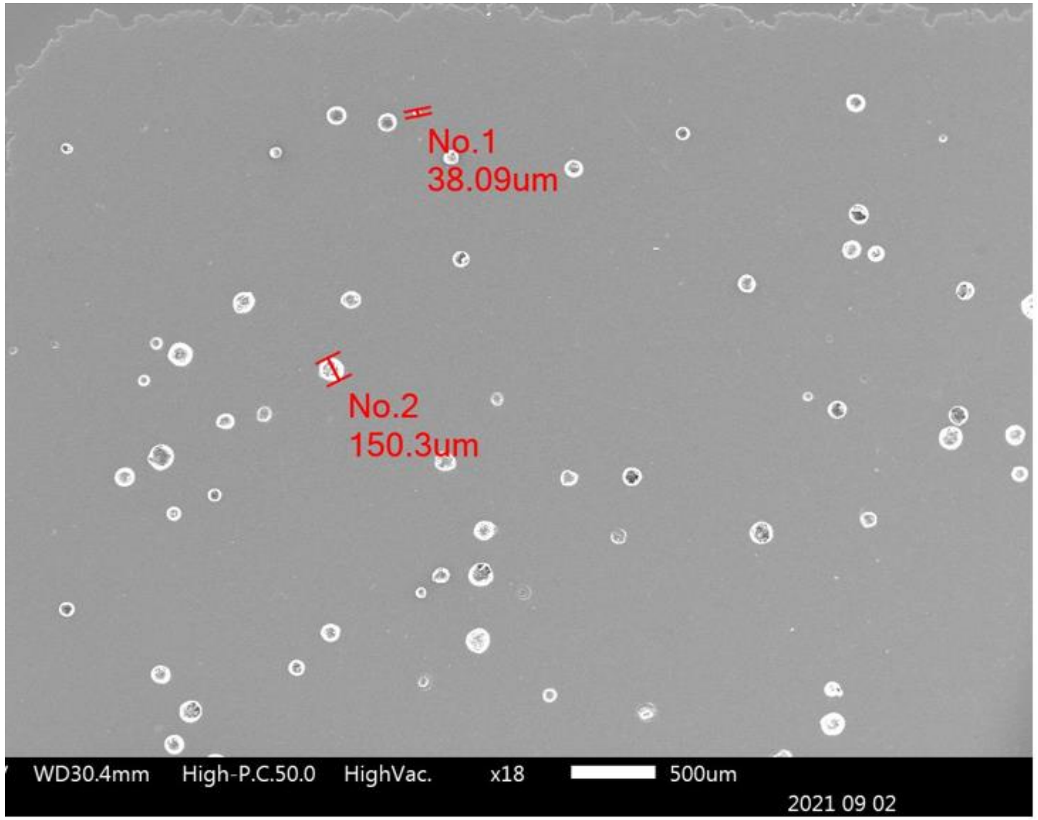
Observation: Porosity percentage of the impeller is 2.19%.

Porosity size range from 0.02 to 0.82mm from 3Dprinted samples

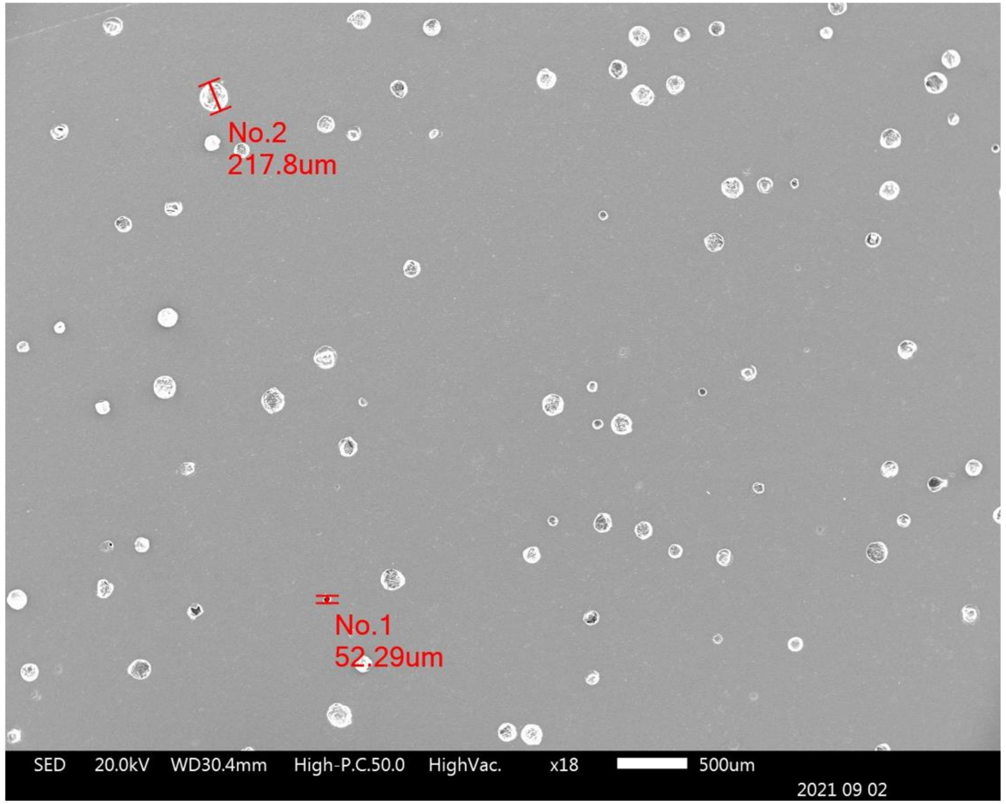
Solution 2: AM Non-Metal Impeller

Scanning electron microscope (SEM) Testing on PEKK CF: Pores distribution on printed sample

Pore size range : 38.09µm (**Minimum**)



Pore size range : 217.8µm (**Maximum**)



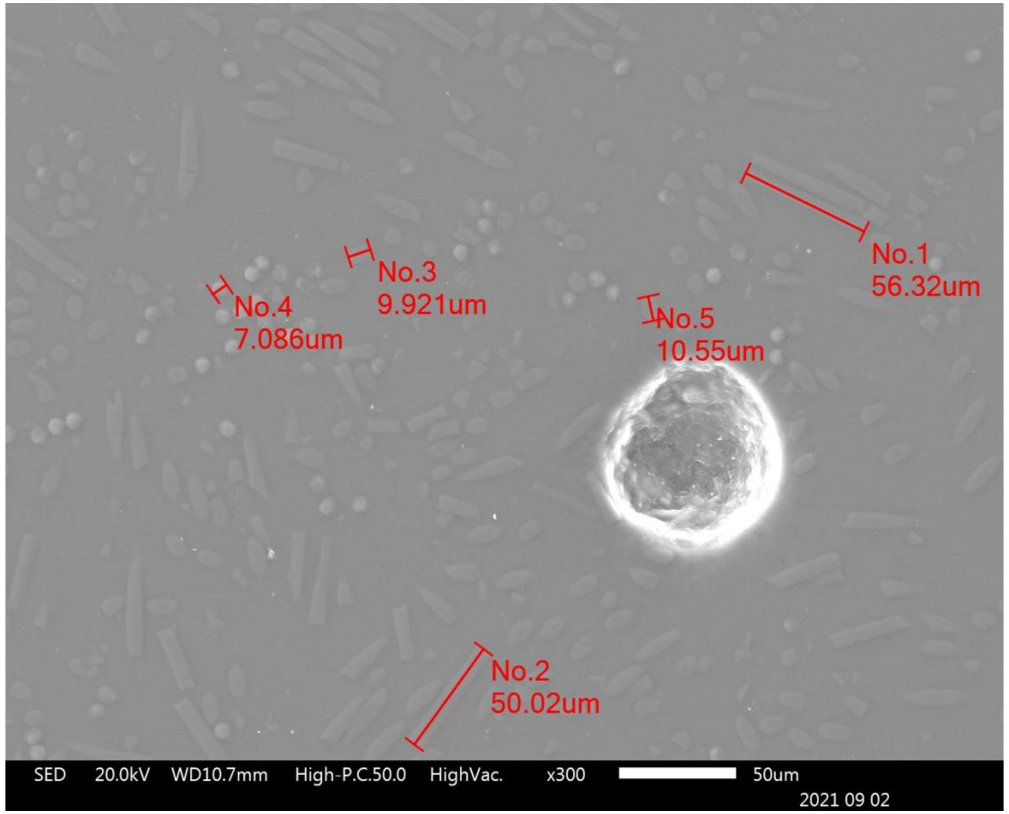
Solution 2: AM Non-Metal Impeller

Energy Dispersive X-Ray Analysis (EDX) analysis: Carbon Fiber Distribution

Carbon fiber uniformly distributed

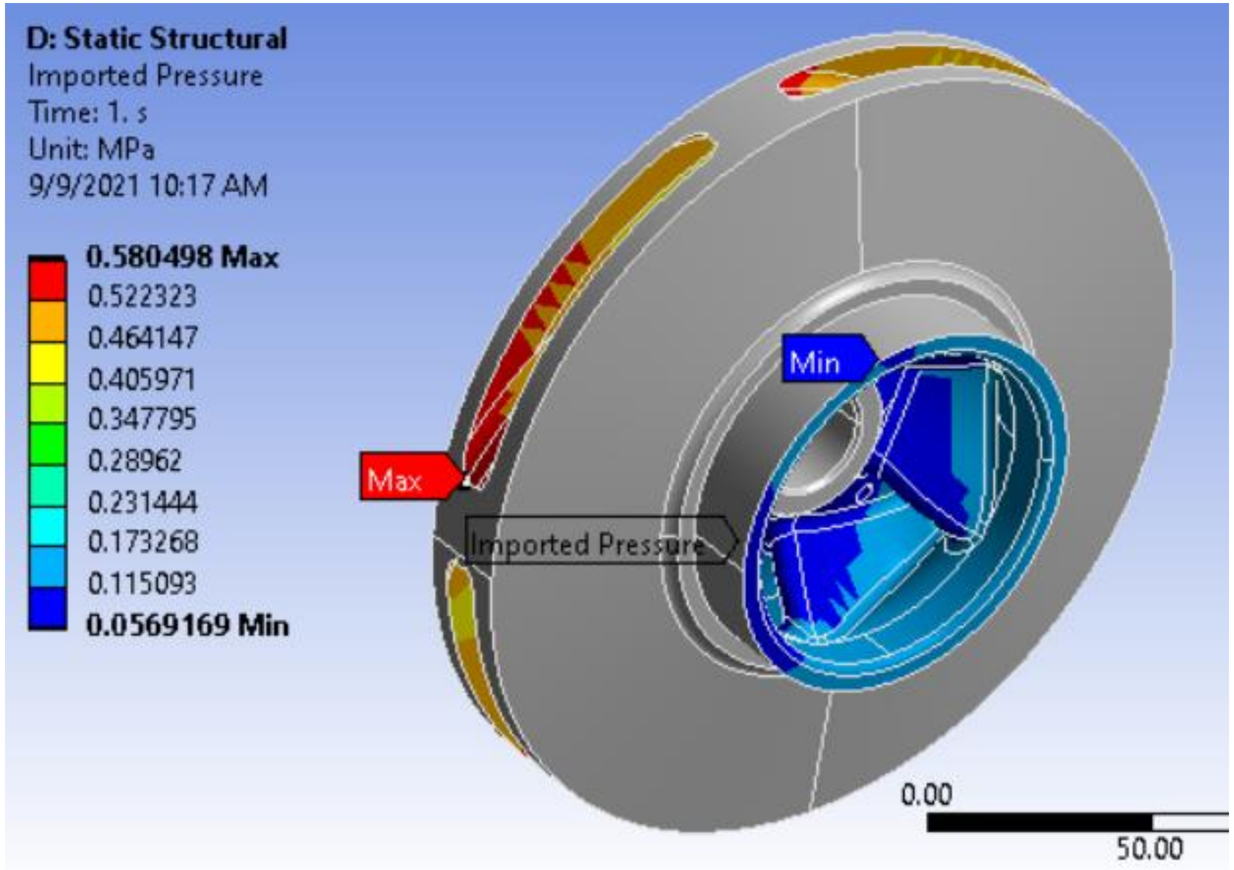
Carbon fiber is much smaller than pores (217.8µm)

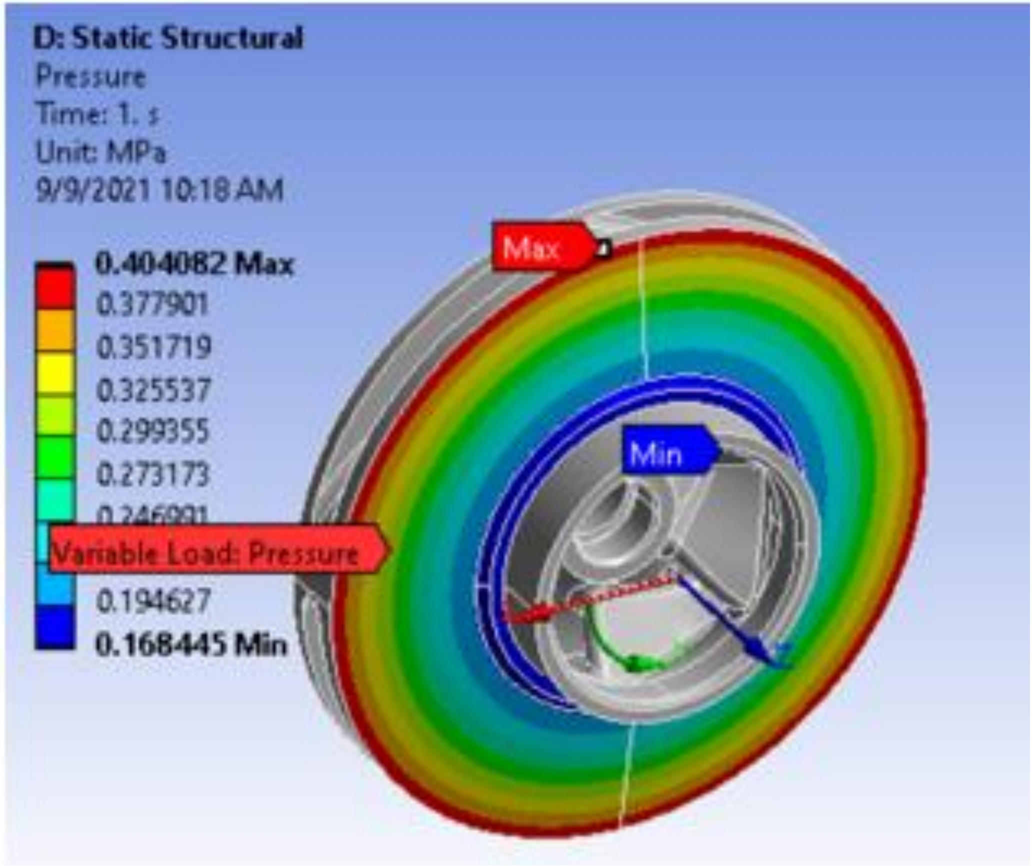
Carbon fiber size range: 7.086µm (Diameter) to 56.32µm (Length)



Solution 2: AM Non-Metal Impeller

FEA Analysis on Non-Metallic impeller

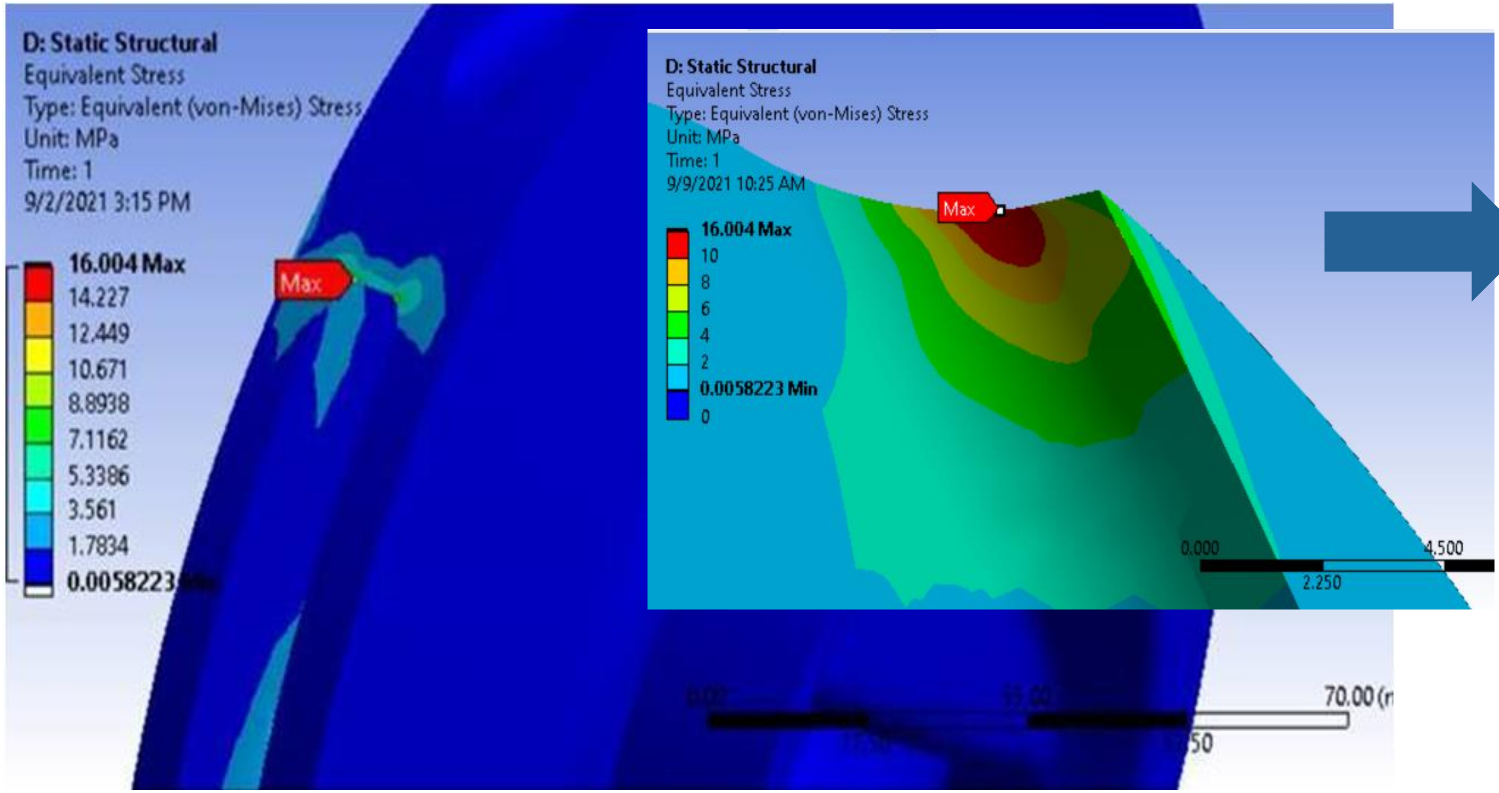




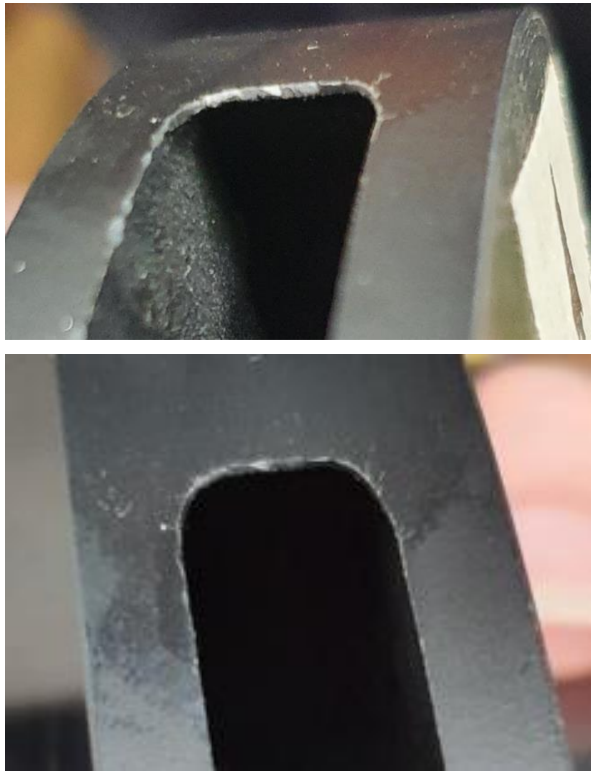
- Radially variable pressure on outside hub and shroud.
- The hub and shroud OD to account for pressure pulsations and provide conservate inputs.

Solution 2: AM Non-Metal Impeller

FEA Analysis on Non-Metallic impeller



Debur sharp edges



- Peak stress found at the sharp trailing edge of the impeller blade.
- Max Von Mises Stress on Trailing blade edge:16 MPa vs. 55 MPa yield strength.
- Operation at min flow value will significantly increase these stresses.

Lessons Learned:

- The non-metallic impeller was calculated to have adequate mechanical strength for operation at its rated duty. Operation at minimum flow rate may cause issues with respect to structural integrity.
- Tensile and impact strength result for non-metallic printed coupons huge directional dependency compared to metallic 3D printed parts. Porosity level in non-metallic SLS parts higher than metal.
- Degradation on mechanical properties after non-metallic material exposure to chemicals are not been evaluated. Needed further study.
- The processing parameters of SLS processes significantly affect the structural, physical, and mechanical properties of the fabricated parts.

Solution Summary:

Table below show the relative lead-time comparison of 3D printing of impeller in Titanium and PEKK CF (HT-23) with existing cast. Polymer printed impeller significantly reduce in lead-time as it does not have to go through heat treatment and support removal post processes.

	Problem case	**Solution 1**	**Solution 2**
	Existing Hastelloy C Impeller Pitting damage Requires Frequent Replacement	**Metal AM** Titanium impeller	**Non-Metal AM** PEKK (HT-23) impeller
Impeller			
Technology	Casting	AM-DMLS	AM - SLS
Leadtime	18 weeks	6 weeks	4 weeks

AM – Additive Manufacturing; DMLS – Direct Metal Laser sintering; SLS – Selective Laser sintering