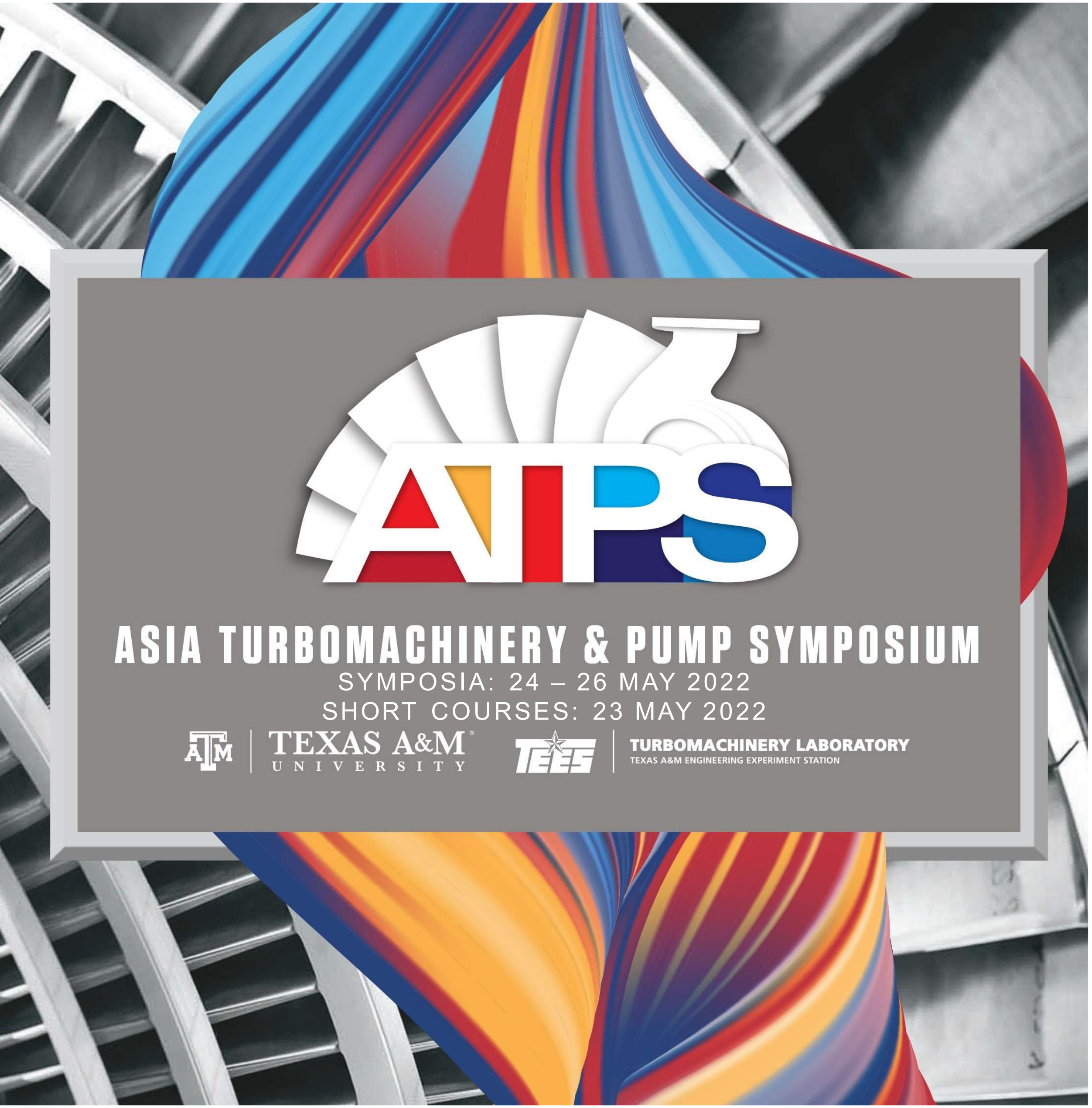

LASER ADDITIVE MANUFACTURING IN GENERAL PURPOSE EQUIPMENT REPAIR

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Tarun Chand is an Account Manager with 3D Metalforge. He has been in Additive Manufacturing space since graduating with a Specialist Post Diploma in Additive Manufacturing, helping customers drive the adoption of AM to their product lines and supply chain. In addition to the forward customer centric role he also assists in Industry 4.0 activities and digital solutions for the AM specific workflow. He has worked for world class manufactures based in India, China and Singapore.

Abstract

Deploying new technology that can benefit equipment component repair lead time, while sustaining its integrity, is becoming more crucial in this age of nimbleness. Many repairs have traditionally occupied conventional methods (coating, machining, casting), which have been proven to work well. However, the lead time and quality do not always meet users' expectation. Additive Manufacturing (AM) in the form of Laser Printing and Cladding are viewed as alternatives to repair methods, which can close the gap in lead time and quality.

AM is a process involving repeated melting/deposition of a substrate layers by a laser beam. The prominent types of AM have been Powder Bed Fusion and Directed Energy Disposition, where its usage selection depends on the extent of damage that the component experienced. Laser Cladding can be used for smaller scale repair, while Laser Printing can be selected for components that experienced a significant extent of damage that it is more economically justified to fabricate a new component. Some of the recent experiences of utilizing AM technology, which covered aspects in evaluations, quality checks, limitation, and other notable learnings, will be shared in this case study.

ASIA TURBOMACHINERY & PUMP SYMPOSIUM

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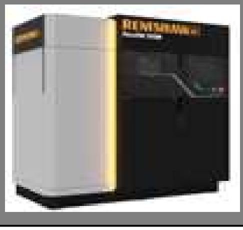
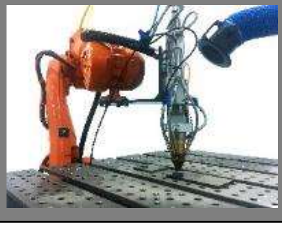
Case Study Overview

- Component repair is often on critical path in an equipment overhaul. Faster turn-over is preferred over keeping ware-house stocks of spares.
- Procurement lead time can take months causing extended schedule.
- Laser technology is viewed as front-runner alternative that can address the gap in lead time without compromising quality.
- Additive Manufacturing (AM) is a 3-dimensional part fabrication using powder filled into a molten pool created by laser; rapidly solidified to form successive layers with strong metallurgical bonds as a result of energy input produced by laser high energy density.
- Enabled complex design fabrication with certain type of materials, which are typically difficult to be fabricated using casting and forging method.

Additive Manufacturing (AM) Types

- AM is broadly classified into 7 types of technologies.
- Powder Bed Fusion (PBF) and Direct Energy Deposition (DED)are those with the most developed standards and proven usage.

	PBF 	DED Powder 	DED Wire 
Raw Material Size	10 - 45 µm powder	45 - 106 µm powder	1 – 1.2 mm dia. wire
Part Complexity	High	Low; Movement axis limited	Low; movement axis limited
Build considerations	Removable support structures; Enclosed chamber	Inbuilt support structures; In semi enclosed chamber	Mounted on support structure; In semi enclosed chamber
Size Limit	Up to 500x500x500 mm³	~1000x1000x1000 mm³	Typ. several mm
Power Source	Laser / Electron Beam	Laser / Electron Beam	Arc Source / Laser / Electron Beam

Laser Printing (PBF, DED Powder)

Laser Cladding (DED Wire)

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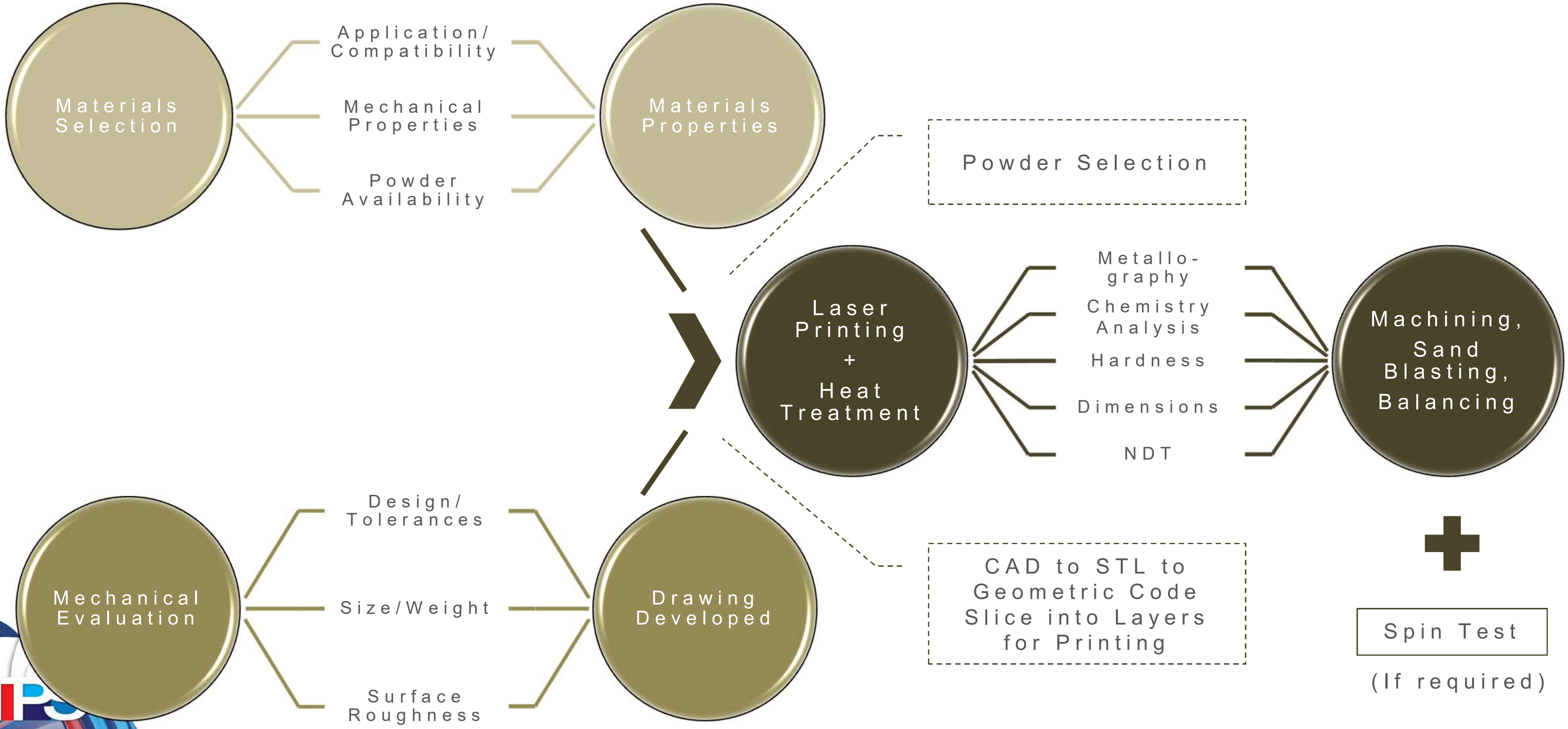
Additive Manufacturing Types

Category	Materials selection available	Materials under evaluation
Metal	• Stainless steel 316L • 17-4PH • Inconel 625 • Inconel 718 • Maraging steel • CoCrMo • Hastelloy C22 • Ti64Al • AlSi10Mg • AlSI7Mg	• Hastelloy C276 • Duplex 2205 • Hastelloy X • 15-5 • SS4140/4340 equivalent • SS420 • SS304 • Copper
Polymer	• PA 12 nylon • PVDF • PC • Nylon (with optional Carbon Fibre) • PEEK (with optional Carbon Fibre)	• PVC • ABS • ASA

Evaluation and Process Selection



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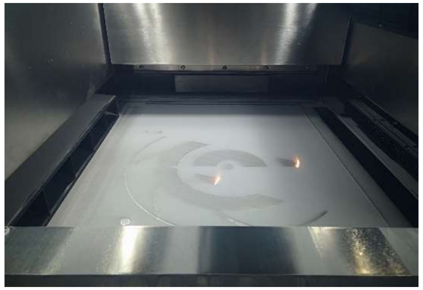
Inspection and Test Protocol

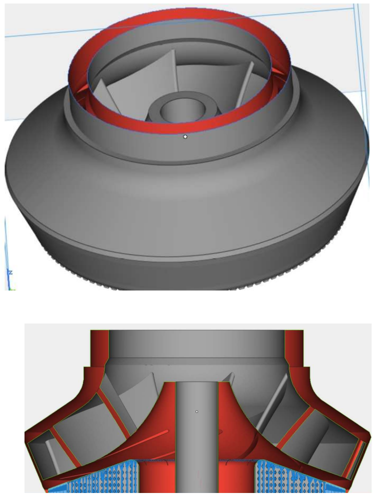
Evaluation Criteria	Purpose	Acceptance Criteria
Process Compatibility	○ Select powder with suitable lead time. ○ Define heat treatment processing. ○ Determine if aging precipitation is required. ○ Match mechanical properties compatibility. Possible upgrades options.	• Powder composition & final mechanical properties meet application. • Particle shape & size range meet manuf. process needs.
Mechanical Properties		
Powder Availability		
Component Design	○ Component size within printer size limit. ○ Define specific characteristics that require smoother surface roughness. Possible additional post processing. ○ Understand any weight differences that can affect equipment bearing loads.	• Component drawing (CAD; Final dimension/tolerances). • Typ. Roughness for pump impeller is 5–12 μm.
Size and Weight		
Surface Roughness		
Metallographic Coupon (ASTEM E3)	○ Check parts materials micro-structure, porosity defects.	• No significant deviations against datasheet and application requirement.
Chemistry Analysis (ASTM E1086-2014)	○ Verify parts materials element composition against datasheet.	
Mechanical Properties (Hardness/ASTM E92, Yield Strength/ASTM E8, Charpy Impact)	○ Verify parts materials properties	
Final Dimensional	○ Verify part dimension after final machining.	• Within dimensional specs.
Dye Penetrant Test	○ Check for cracks post machining.	• No cracks.
Spin Test (API617)	○ Check mechanical integrity.	• Does not disintegrate.

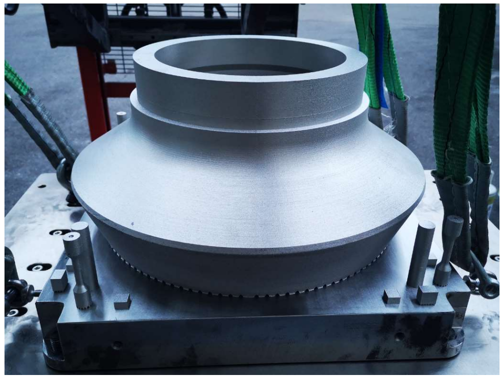
Examples of Laser AM Component

Application	Case Justification	Original	Upgraded
Pump Impeller	• Warehouse spare of Bowl Assy. Lesser downtime for pump O/H. • Improved metallurgy selection for better corrosion resistance. • Higher mechanical strength for better erosion protection. • IN625 can be fabricated using conventional method (casting) but difficult to fabricate complex shaped component.	NiAlBronze 70% Cu, 8-10% Al, 4-5% Ni, 4-5% Fe	Inconel 625 3% Cu, 20-24% Cr, 58% Ni, 8-10% Mo



Printing in-progress.





Post printing, before wire-cutting from support structure

Post machining

Examples of Laser AM Component

Metallographic Test

- Revealed IN625 microstructure is free of defects.
- Mechanical Testing showed higher UTS, Yield and Elongation compared to ASTM requirements.
- Elongation values indicated good weldability property.

Tensile Test

Properties	Coupon 1	Coupon 2	Reference ASTM F3056
Ultimate Tensile Strength	880 MPa	876 MPa	Min. 827 MPa
Yield Strength	583 MPa	576 MPa	Min. 414 MPa
Elongation at Break	60%	59%	50%

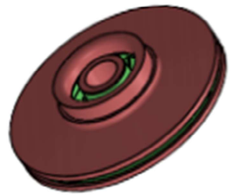
* For Comparison: Ni-Al-Bronze UTS 655 MPa, YS 290 MPa, Elongation 10%

Hardness Test

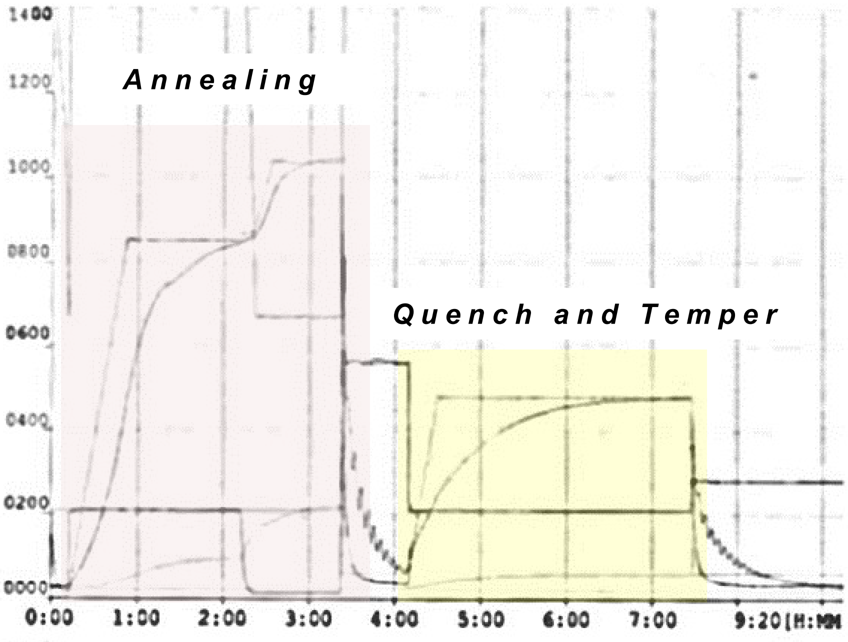
Test Location	Vickers Hardness Number			Reference
	Point 1	Point 2	Point 3	
At Surface	261	268	265	≤ 225

* For Comparison: Ni-Al-Bronze casting – 171 HV

Examples of Laser AM Component

Application	Case Justification	Materials
Between Bearing 2-stages pump	• Requires fastest lead time due to pump criticality; prompted local fabrication instead of order from Investment Casting vendor. • Impeller mechanical drawing available. • Requires additional heat treatment processing to retain 17-4 PH SS hardness.	17-4 PH SS Martensitic SS with Cu and Nb/Cb 

Post Processing:
(Furnace Oven)



Hardness Test Result:

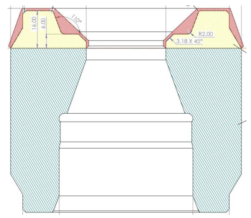
Test Location	Vickers Hardness Number			Reference
	Point 1	Point 2	Point 3	
At Cross Sectional Area	416	407	409	362

* For Comparison: 316SS – 140HV, CS 120HV, Iron 80HV

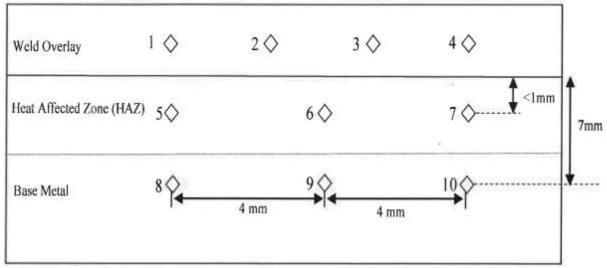
Operation Result:

Pump performed well (hydraulic and mechanical) with the fabricated impeller.

Examples of Laser AM Component

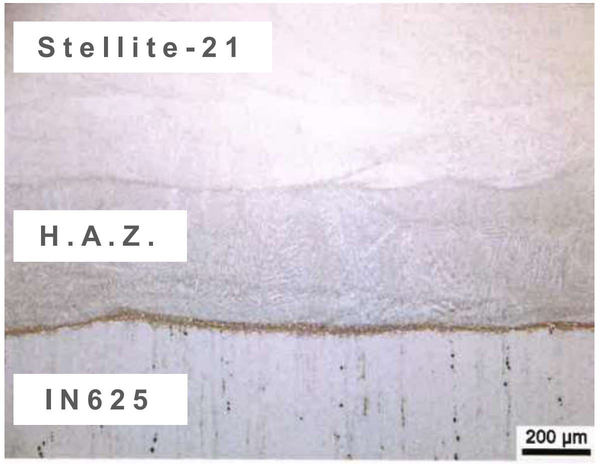
Application	Case Justification	Materials
Positive Displacement Pump	• Valve body revealed a longitudinal sub-surface crack in the overlay materials. • Short window to return the equipment back to service. • Laser cladding repair method was selected; Stellite-21 was stripped off and rebuilt back to size.	IN625 overlaid with Stellite-21 

Hardness Test Locations:



Specimen Identification	Test Location	No.	Vickers Hardness Number (HV)	No.		No.	
Stellite Overlay on Inconel 625 (Side 1)	Weld Overlay	1	352	2	354	3	360
		4	344	-	-	-	-
	Heat Affected Zone	5	248	6	234	7	237
	Base Metal	8	239	9	232	10	224

Specimen Identification	Test Location	No.	Vickers Hardness Number (HV)	No.		No.	
Stellite Overlay on Inconel 625 (Side 2)	Weld Overlay	1	356	2	365	3	372
		4	371	-	-	-	-
	Heat Affected Zone	5	255	6	251	7	247
	Base Metal	8	233	9	225	10	222



Micrograph of test specimen
Magnification: 100X

Micrograph of test specimen
Magnification: 400X

Operation Result:

Pump performed well (hydraulic and mechanical) with the cladded valve body.

Examples of Laser AM Component

Application	Case Justification	Materials
Positive Displacement Pump	• Pump cylindrical plunger rod worn out after years in service. • Plunger base material was SS420 coated with Hard Chrome coating (40-50 HRC) using HVOF technique. • Diametrical thickness needed to be rebuilt by at least 890 microns, which exceeded a typ. acceptable HVOF coating thickness of 300 microns. • Laser cladding repair method was selected to apply Stellite 21 weld overlay with similar hardness of Hard Chrome coating.	SS420 with Stellite 21 

Hardness Test:

Test Location	Vickers Hardness Number			Reference
	Point 1	Point 2	Point 3	
Weld Overlay	426	425	416	285 - 382 (27-40 HRC)

Operation Result:

Pump performed well (hydraulic and mechanical) with the cladded plungers.

Before Cladding

After Cladding

NDT Test

What's Next?

Potentials	1-to-1 component replacement in high speed, complex machineries
	Metallurgical improvement
Technical Evaluations	Recognize original component application, risks, design details, materials
	Recognize laser printing limitation, selection criteria, post printing processing and tests
Challenges and Further Studies	Selective surface finishing/post processing technique (ie. abrasive flow machining)
	Effect of laser printing processing to material grain structure and its long term effect on chemical/mechanical properties in applications