Surface Processing of Additively Manufactured Ti-6Al-4V Pacemaker Shields

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Medtronic is exploring additive manufacturing (AM) powder bed fusion (PBF) processes for producing customizable titanium pacemaker shields. The shields require surface processing to create a visually smooth surface. Centrifugal Disc (CD) Finishing and Fine Shot Peening were explored to reduce surface roughness and enhance the visual quality of AM sample coupons. Roughness was measured via optical profilometry and AFM. Coupons produced using an E-beam energy source (EB-PBF) had a lower initial roughness than those using a laser source (L-PBF). CD processes resulted in an average 2.5 µm decrease in roughness for both L-PBF and EB-PBF coupons and an improved visual smoothness. Fine shot peening led to a decrease in roughness on average of 52% for EB-PBF and 26% for LA-PBF.

This work is sponsored by Medtronic PLC (Mounds View, MN), and The Barnes Group Advisors (Pittsburgh, PA)

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Project Background

- AM preferred over conventional deep drawn process for customizability, lower cost, and shorter production time but results in poor surface finish.

PBF method	Laser (L-PBF)	E-Beam (E-PBF)
Cooling Time	Faster *	Slower
Strength	Higher	Lower
Ductility	Lower	Higher
Ti Microstructure	α' Martensite *	α-β

* L-PBF expected to have higher hardness

AM shield vs. deep drawn

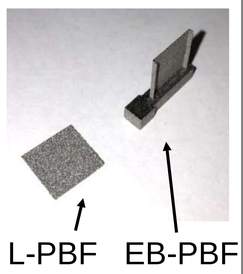
Rough AM shield (bottom) has poor weld seal quality

Objectives and Constraints

1	**Minimize surface roughness**	**Arithmetic average roughness Sa < 5 µm**
2	Maintain shape	No dents, bowing, etc.
3	Prevent discoloration	Ideally: mirror finish
4	Hardness constraint	< 300 Vickers
5	Total processing time	< 4 hours per batch

Procedures

- 100 AM Titanium 1x1 in. coupons each received from two suppliers:
  - Laser (L-PBF)
  - E-beam (EB-PBF)
- EB-PBF coupons had a "lip" and attached base from printing



Centrifugal Disc Finishing

- Parts placed with abrasive ceramic media, rotated in bowl for 1 hour
- 1% media concentration, 40 L/h flow rate
- Performed by Advanced Finishing Technologies (AF)

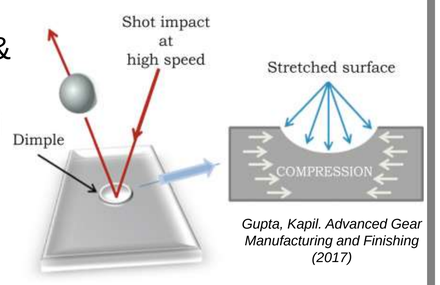
	Freq-uency	Ceramic polishing media
CD1	50 Hz	AFXX 4x4 triangular
CD2	35 Hz	AFHC 2x2 (smaller media, "gentler")
CD3	50 Hz	AFXX 4x4 triangular

AFXX 4x4 Ceramic Media

Advanced Finishing Technologies, Online Catalogue

Fine Shot Peening

- Spherical media (Al_2O_3, ceramic Z210 & Z150)
- Pressures: 20 – 70 psi
- Some coupons processed twice
- Progressive Surfaces Inc. conducted trials
- Roughness reported by Progressive using Mitutoyo SJ210 Handheld contact instrument



Gupta, Kapil. Advanced Gear Manufacturing and Finishing (2017)

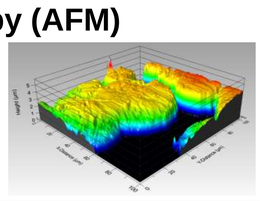
Hardness Measurements of Cross-Section

- Coupons were mounted in Bakelite and polished to expose cross-section
- Hardness was measured in Vickers (HV0.1) using a load of 100 gf with a dwell time of 15 seconds

Procedures (continued)

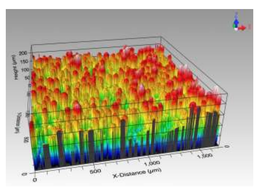
Atomic Force Microscopy (AFM)

- Roughness measured using contact mode, 3 measurements per sample.
- Primarily 10 µm scan size



Optical Profilometry (OP)

- Roughness measured using ZYGO 3D Optical Profiler.
- Primarily 1500 µm scan size
- Profile analysis performed in ProfilmOnline software.
- Two runs completed per sample for the scan size study.



Solutionizing Heat Treatment

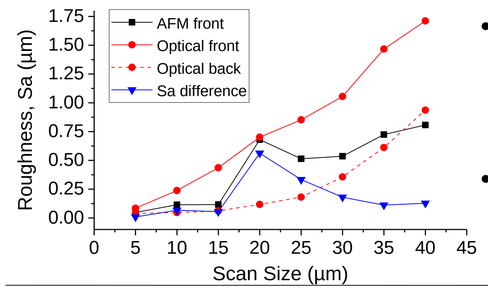
- 1050° C for 1 hour followed by slow cool
- Coupons wrapped in Ti foil and surrounded by Ti sponge to minimize oxidation
- Pre-process to soften material or post-process to alleviate residual stress

Results and Discussion

As-received average roughness (Sa) in µm:

Method	AFM	Optical	Progressive Surfaces Inc.
Scan size	**10 µm**	**1500 µm**	**> 1 mm**
L-PBF Sa	0.160 µm	30.75 µm	17.38 µm
EB-PBF Sa	0.183 µm	12.21 µm	7.61 µm

- Roughness varies with method/scan size



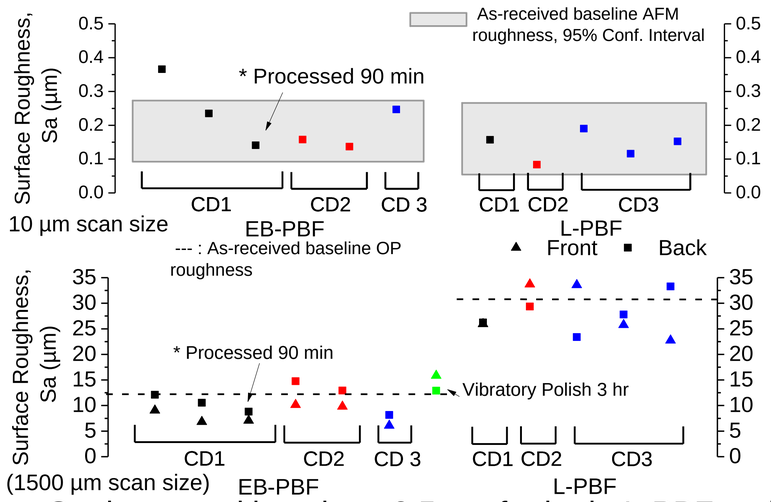
- Measured roughness (Sa) increases with scan size
- OP and AFM difference is relatively constant

Repeatability study performed on smoothest processed coupon using AFM

AFM, n=10
10 µm scan size,
CD3-EB-PBF coupon

Mean	0.0382 µm
Std. Dev.	0.0014 µm
95% C.I.	[0.0372, 0.0392] µm

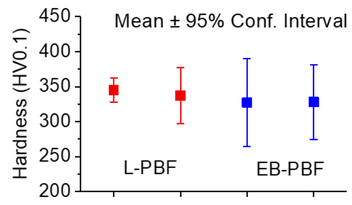
Centrifugal Disc (CD) Processed Roughness



- Sa decreased by about 2.5 µm for both L-PBF and EB-PBF coupons, EB-PDF had best visual finish
- OP data more consistent with expectation and visual assessment than AFM data

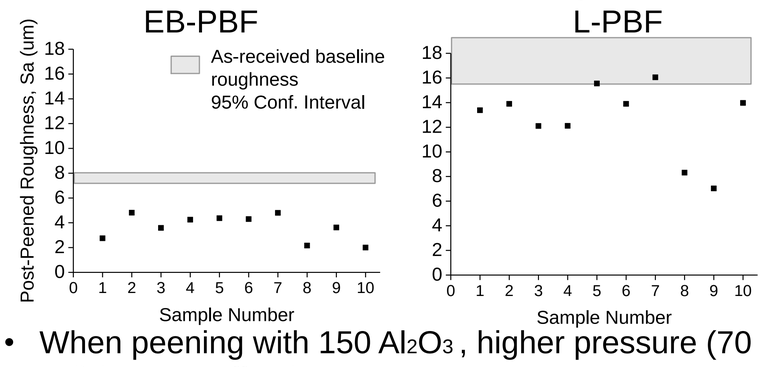
Results and Discussion (cont.)

Vickers Hardness of as-received coupons



- L-PBF and EB-PBF have same hardness resulting from different thermal processing conditions
- **Any difference in CD process effectiveness due to initial roughness, not hardness**

Fine Shot Peened Processed Roughness



- When peening with 150 Al_2O_3, higher pressure (70 psi) is more effective
- Ceramic Z150 is most effective at 55 psi
- Average Sa decrease: EB-PBF = 52%
  LA-PBF = 26%
- Visual surface smoothness improved only slightly

Conclusions

- Measured Sa increases with scan size, varies depending on roughness measurement method
- Hardness of as-received L-PBF and EB-PBF is the same (differences in surface process effectiveness due to initial roughness, not hardness)
- L-PBF coupons have higher as-received roughness
- 1-hour CD process decreased Sa by about 2.5 µm and resulted in visually smoother surface
- Shot peening reduces Sa to 52% for EB-PBF and 26% for LA-PBF but surface still appears rough

Recommendations

- Complete remaining roughness measurements
- Perform more repeatability studies for AFM and optical methods for variation information
- Measure hardness of processed coupons to determine if process significantly plastically deforms
- Perform residual stress measurements
- Heat-treat coupons above 1050°C to soften and then test effectiveness of surface processes
- Explore Trial 2 for centrifugal disc and shot peening using Design of Experiment procedure
  - CD: effect of process time and media size
  - SP: effect of media size and multiple successive processes with increasing shot pressure
- Due to lower initial roughness, EB-PBF coupons will take less time in CD process to achieve smooth surface. EB-PBF coupons also respond better to fine shot peening
- Optical profilometry is preferred measurement method
  - Scans larger area in shorter time
  - More consistent with expectations based on visual assessment (for CD coupons)
- CD processing is best for achieving visually smooth surface finish, especially for EB-PDF coupons