PURDUE UNIVERSITY
School of Materials Engineering

Surface Finishing of Titanium Pacemaker Shields Fabricated Through Selective Laser Melting

Student names: Megan Balog, Kwame Boateng, Torey Caldwell, and Karan Sachdev
Faculty Advisor: Dr. David Bahr | Industrial Sponsor: Dr. Peter Tortorici

The purpose of this project was to determine the ideal post-processing steps for Medtronic's additively manufactured Ti-6V-4Al pacemaker shields. Heat treating and fine shot peening were implemented to combat the high hardness and surface roughness values associated with printing. The ideal post-processing procedure includes hot isostatic pressing, followed by fine shot peening then annealing. This order resulted in the lowest final hardness and surface roughness.

This work is sponsored by Medtronic in Mounds View, Minnesota.

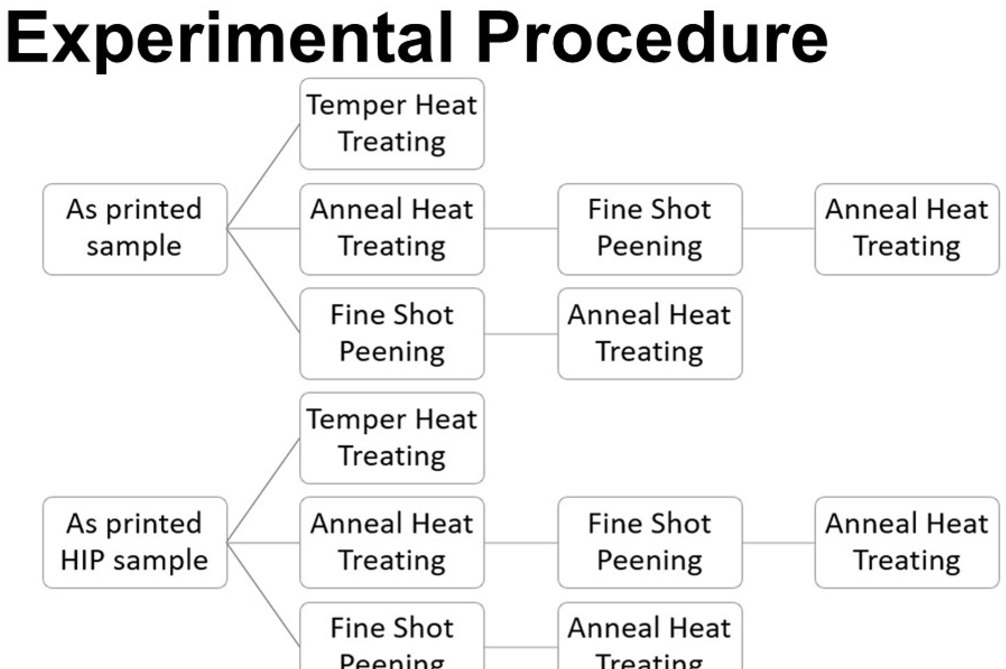
Medtronic

Project Background

- Selective laser melting (SLM) is a form of additive manufacturing used by Medtronic to produce pacemaker shields.
- The shields manufactured using SLM have a higher hardness and surface roughness in the as-printed state than is acceptable for use in medical applications
- This hardness us due to the formation of a martensitic microstructure
- A softer α-β microstructure exists for Ti-6V-4Al
- Utilizing fine shot peening and vacuum heat-treating methods, post-processing parameters were determined to obtain the desired qualities

Figure 1: Image of Ti-6V-4Al shields used by Medtronic. On the left is a shield created through SLM, and on the right is the traditional deep drawn shield.

Experimental Procedure



Heat Treating

Tempering (T-HT)

- Argon flow into furnace
- Ramp up to 900°C at 5°C/minute, hold 30 minutes, cool down 5°C/minute

Annealing (V-HT)

- Vacuum furnace
- Ramp up to 1080°C at 10°C/minute, hold 90 minutes, cool down 5°C/minute

Hardness Testing

- Utilized Vickers hardness scale
- Conducted following ASTM standard E92-17
- Minimum of 5 measurements for each sample
- Included load of 100g and dwell time of 15 seconds

Profilometry

- Surface roughness measurements were collected through optical and stylus profilometry
- ZYGO 3D Optical surface profiler provided images of the sample surface taken in 2-3 areas at 10x magnification and scan sizes of 0.85mm and 1.68mm
- Images were analyzed with ProfilmOnline software
- Stylus profilometry used the mitutoyo surftest 211 with a 5µm diamond stylus at scan lengths of 0.8mm and 0.25mm with 2-5 measurements/sample

Fine Shot Peening (FSP)

- Conducted by Progressive Surfaces Inc.
- Session 1: 150 µm White Al2O3 at 70 psi.
- Session 2: Ceramic Z150 µm at 20 psi.

Results

Hardness Data

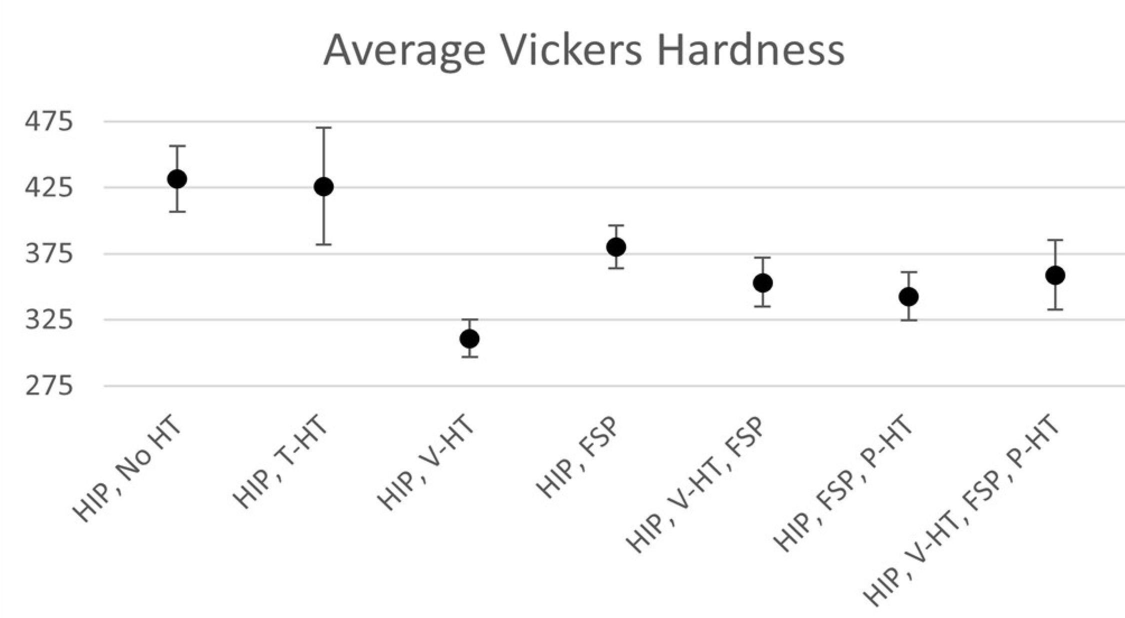


Figure 2: Hardness data collected after various post-processing steps.

Microstructures

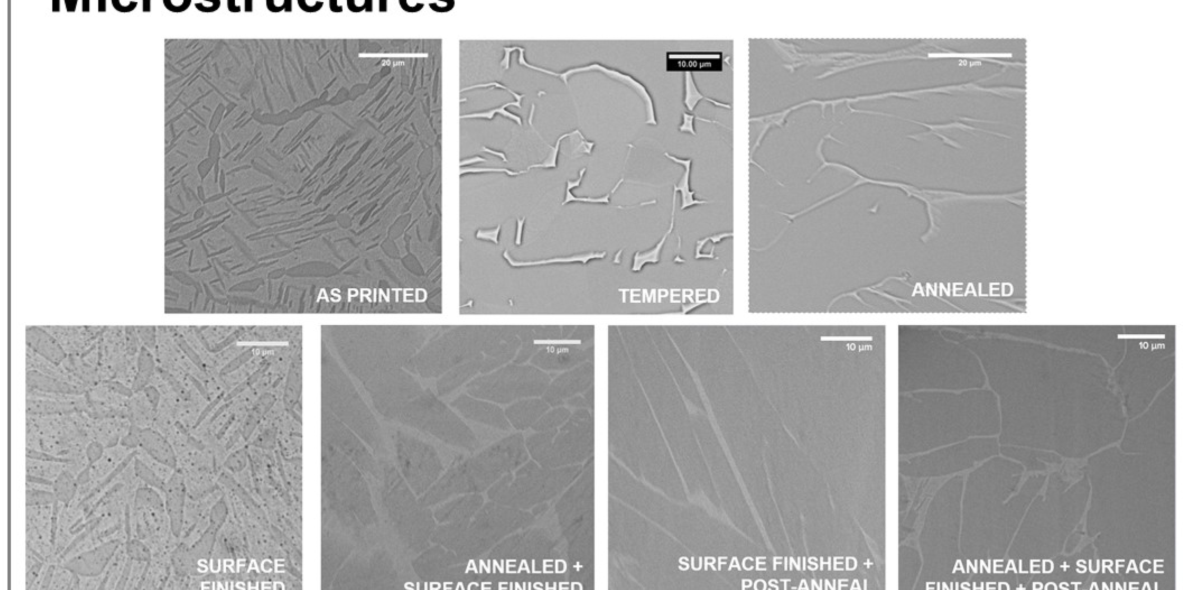


Figure 3: Comparison of microstructures obtained after each post-processing step.

Roughness

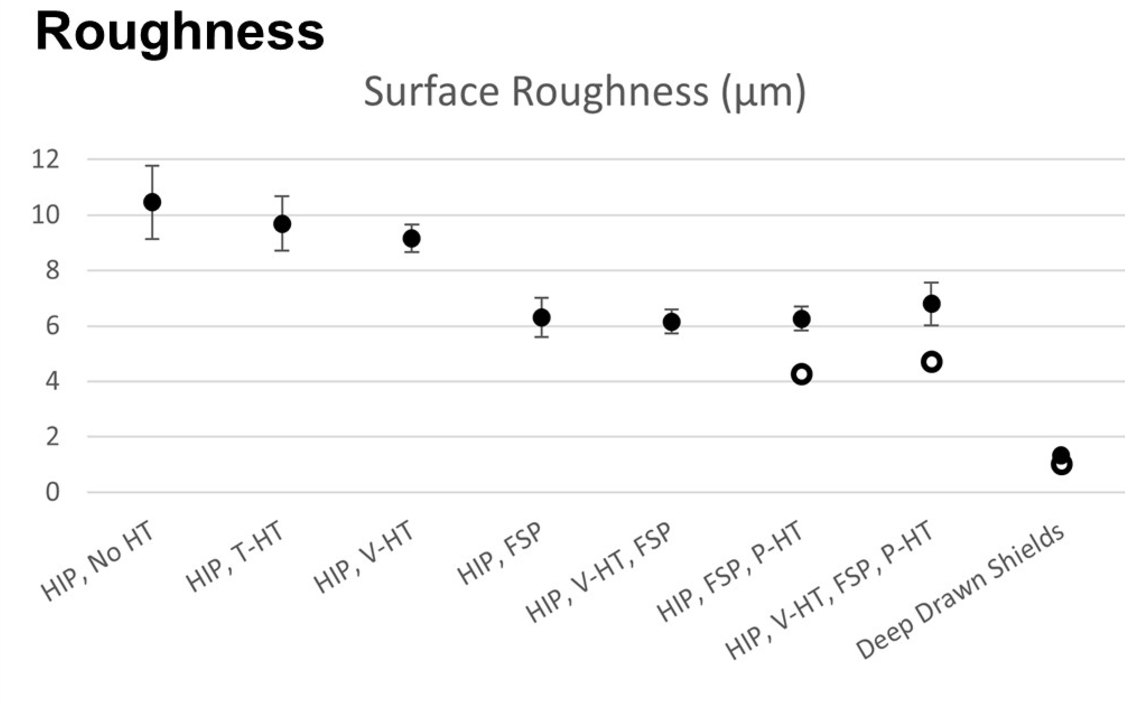


Figure 4: Surface roughness measurements after each post-processing step.

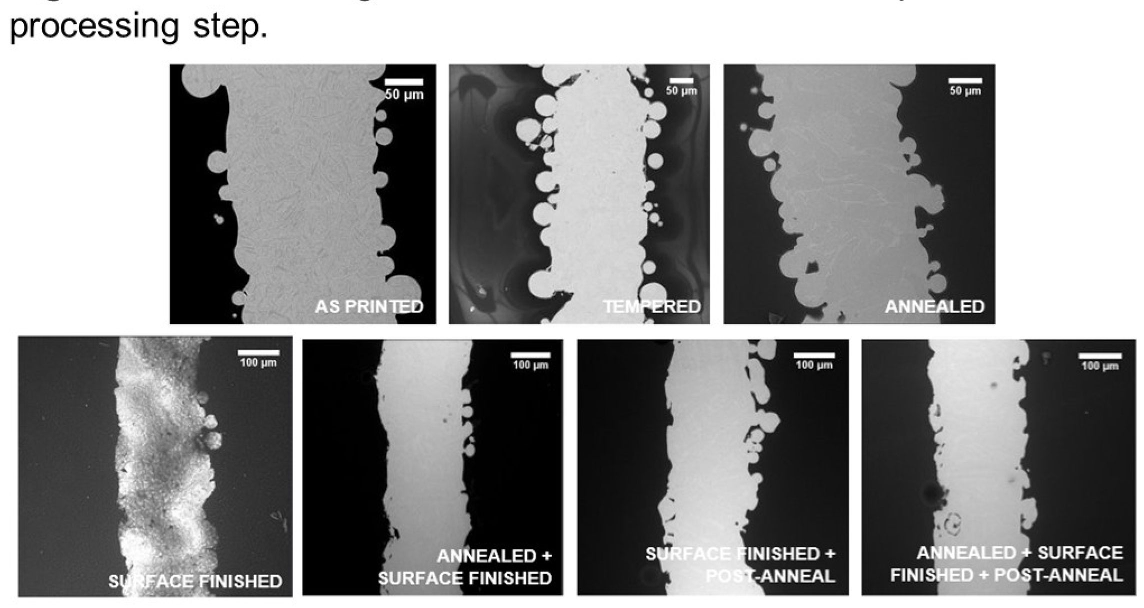


Figure 5: Comparison of surface roughnesses obtained after each post-processing step. The images on the bottom row were shot peened on the left-hand side of the sample and remained in the as-printed condition on the right.

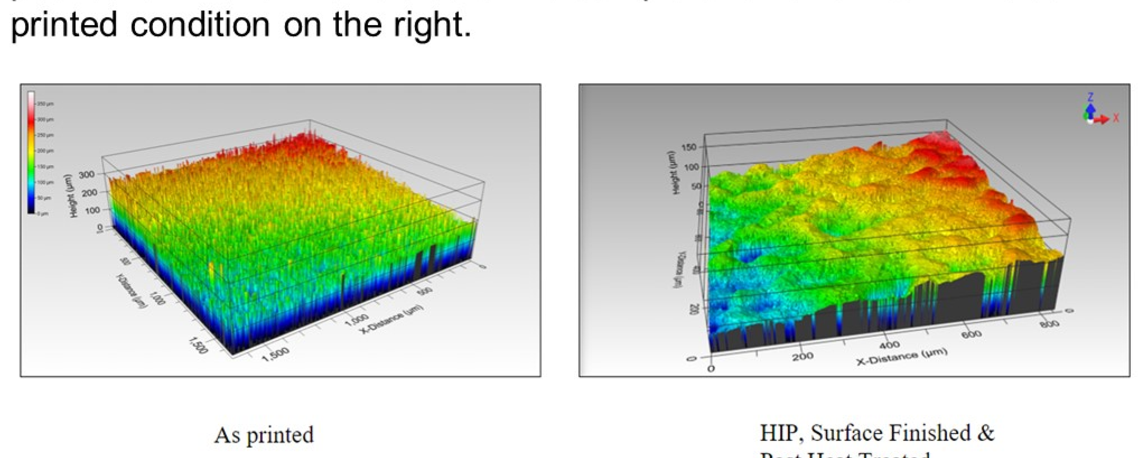


Figure 6: Comparison of surface roughnesses of an as printed sample versus a sample that has undergone HIP-ing,surface finishing, and post heat treatment. Obtained through optical profilometry.

Discussion

Hot Isostatic Pressing (HIP)

Data for only the HIP-ed cases are included because HIP-ing the samples resulted in fewer closed pores, which is desirable for this application.

Heat Treating

Although tempering did have a visible impact on microstructure, it was unsuccessful in lowering the average sample hardness. In order to lower hardness, the microstructure needs to fully transition from martensitic to α-β. The lowest hardness values were associated with annealing the samples in a vacuum furnace. Completing two annealing processes resulted in similar hardness values to either of the singular annealing cases. Therefore, the extra processing step of a second round of annealing is unnecessary. Heat treating also had minimal-to-no effect on the surface roughness.

Fine Shot Peening

Fine shot peening had minimal impact on microstructure, as the "as printed" and "surface finished" micrographs are visually similar. Though fine shot peening did not impact the microstructure, it did impact the surface roughness of the samples. In Figure 5, which displays micrographs of the cross sections of the different processing parameters, the top row displays samples which had not gone through any surface finishing but just annealing had partially melted beads caused by SLM present on both sides of the cross section. Observing the bottom row which displays samples that underwent fine shot peening, the left side of the micrograph which was the peened side is visually smoother and does not have the partially melted beads present. Figure 6 highlights this as well where rough individual peaks can be observed on the as printed sample, but a smoother less elevated surface is seen for the HIPed sample that underwent peening.

Order of Processes

When considering hardness, there was not a significant difference between surface finishing before or after annealing, with average values of 353.6HV when annealing before and 342.8HV when annealing after fine shot peening. However, having a higher hardness during fine shot peening was beneficial in removing the partially melted beads from the edge of the samples. As a result, it is recommended to heat treat after surface finishing is completed.

Recommendations

Figure 7: Recommended sequence of post-processing steps to obtain the desired final hardness and surface roughness.