PURDUE UNIVERSITY
Materials Engineering

# Characterization of Additively Manufactured Ti-6Al-4V for Use in Pacemaker Shields

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Medtronic evaluated two suppliers to determine if their additive manufacturing process was a suitable replacement for the current method of deep drawing custom pacemaker shields. A heat treatment softened the as-printed fine, brittle microstructure. After heat treatment, 3D Systems shields had a point defect density comparable to the deep drawn samples. After heat treatment, TransMachine shields had a microhardness most like the deep drawn samples. 3D Systems pores had a lower aspect ratio and average pore size (27.9um), with a more predictable pore formation and geometry compared to TransMachine (49.1um).

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## Project Background

Titanium (Ti-6Al-4V) shields provide a barrier between the body and internal pacemaker electronics

Current Production: Deep Drawing


*Custom shapes are required for prototyping and select patients*

Medtronic plc, "Our Pacemakers"

Current Custom/Prototype: Machine from Solid Block

**Future Custom/Prototype: Additive Manufacturing**

- Cost ↓ 25%
- Lead time 4-6 weeks → 24 hours

## Objectives

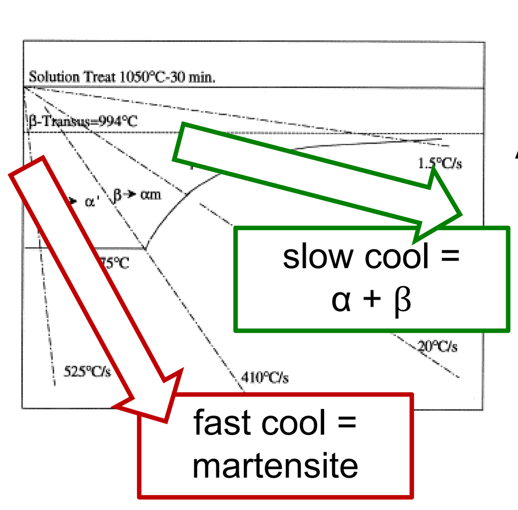
1) **Characterize** shields from suppliers to determine similarities to deep drawn
2) Develop **heat treatment** for microstructure similar to deep drawn
3) Advise on concerns of **porosity**, **brittleness**, and **residual stress**

## Procedures

Shields from two suppliers, 3D Systems (3DS) and TransMachine (TM), were examined.

| 3DS | TM |
|---|---|
| standard 0.016" | standard 0.020" |
| HIP'ed 0.020" | standard 0.012" |
| stress relief 0.020" | |

### Heat Treatment




Rapid cooling characteristic to additive manufacturing leads to **fine, brittle microstructure**

Annealing and **cooling slowly** results in **grain growth**

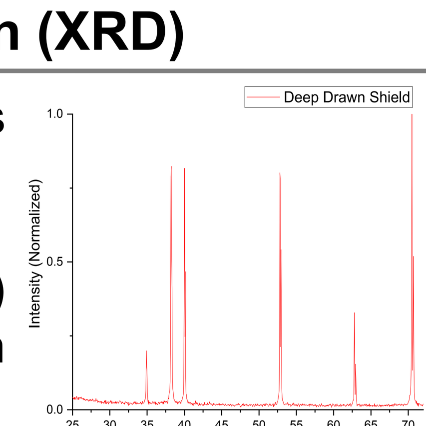
Sample Heat Treatment:
**Hold 3 hours at 1100°C**
**Cool at 5°C/min**

T. Ahmed, H.J. Rack. Materials Science and Engineering A. (243) 1998

### X-Ray Diffraction (XRD)

Diffraction scans on all samples elucidated microstructure

**Full Width at Half Max (FWHM)** analysis gives information on **point defects**




### Microscopy

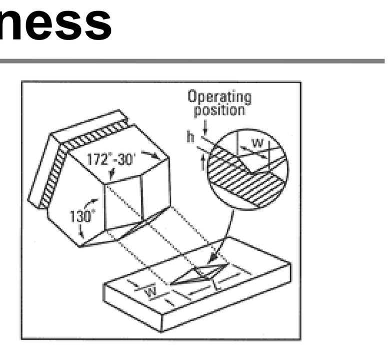
**SEM** - Lineal analysis on BSE micrographs of shield cross sections

**Optical** – Pore size analysis on shield cross sections

### Knoop Microhardness

Long aspect ratio of Knoop tip appropriate for thin shields

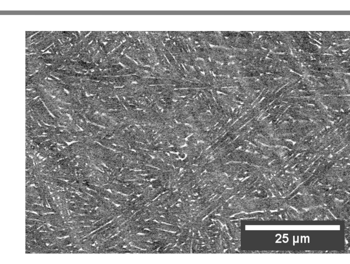
Hardness scales with strength and will indicate brittleness



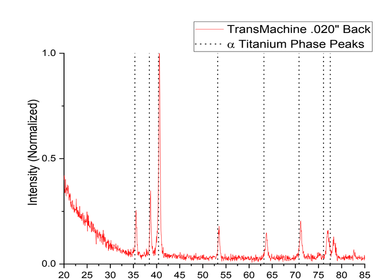

Instron, "Instron Knoop Test"

## Results & Discussion

### Characterization

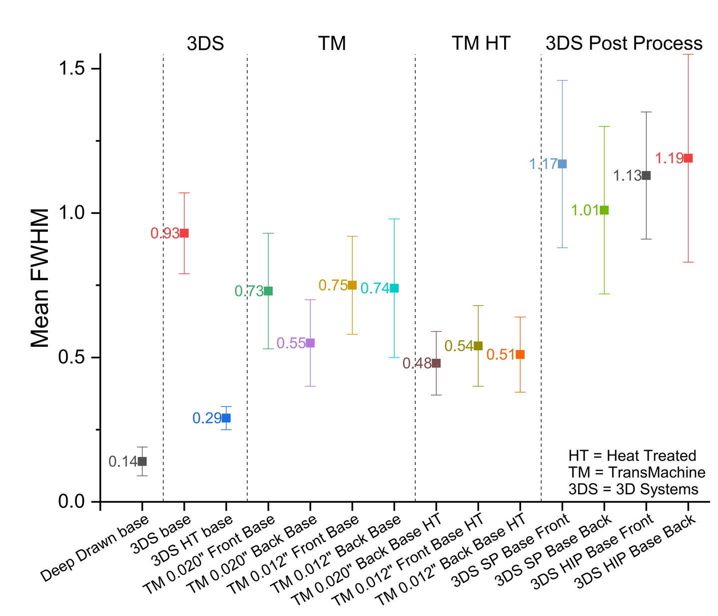


Shields as deposited had a fine lamellar **α + β microstructure**.



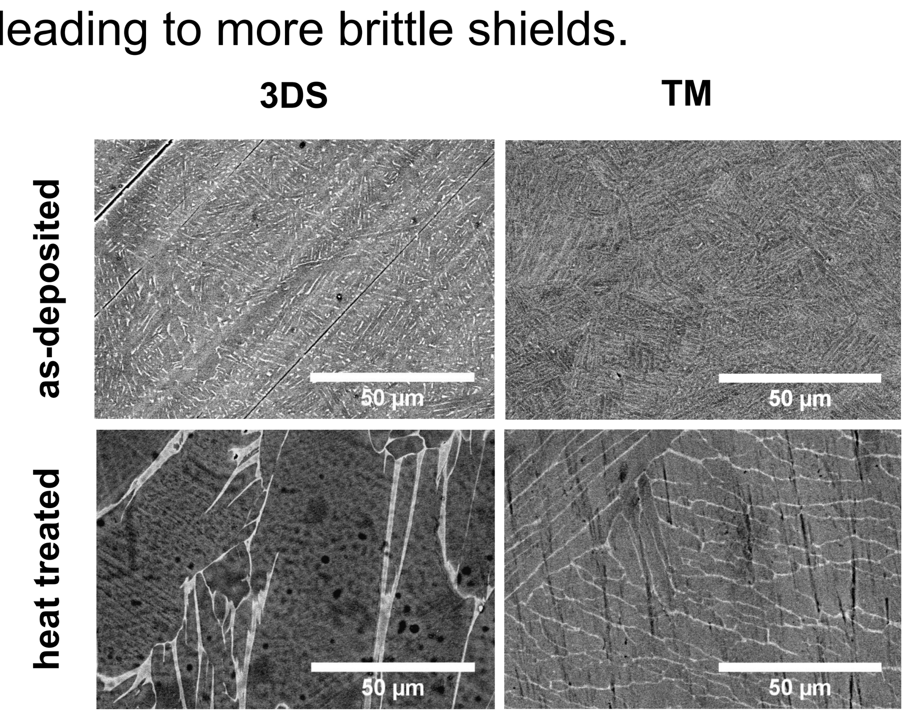

XRD peaks confirmed the above microstructure. No other phases were present.

### Heat Treatment Softening

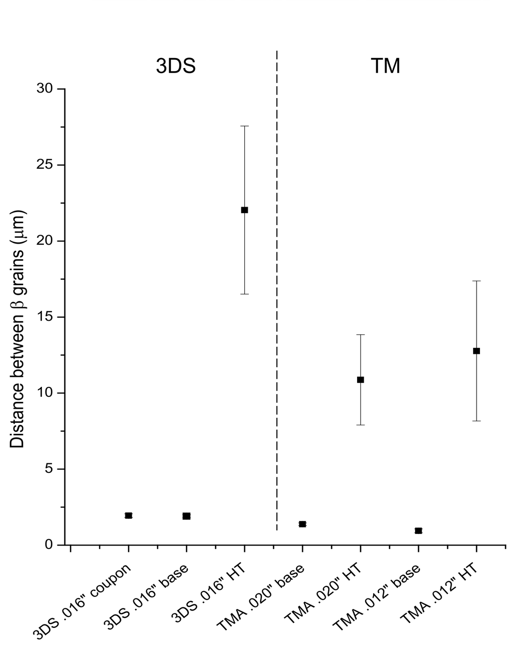



Higher FWHM
=
Higher density of point defects
=
Lower ductility

**Heat treatment reduced the FWHM value** for both suppliers. As-deposited, 3DS shields had a higher FWHM than TM. After heat treatment, 3DS shields had a lower FWHM than TM and were closest to the deep drawn shields. Shield thickness and location of scan had no effect. 3DS shields with additional processing steps have higher FWHM values, likely leading to more brittle shields.

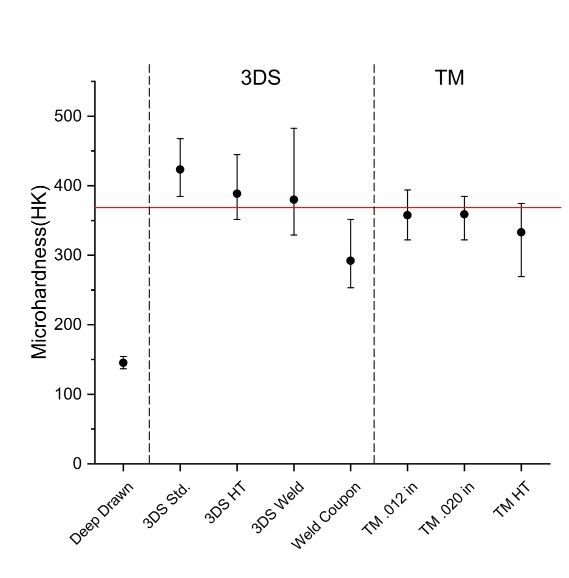



dark phase: **α**
light phase: **β**




TM shields consistently had a finer microstructure than 3DS shields. Heat treatment **increased grain size** significantly in all parts, decreasing the grain boundary strengthening effect. This change was greater for 3DS.

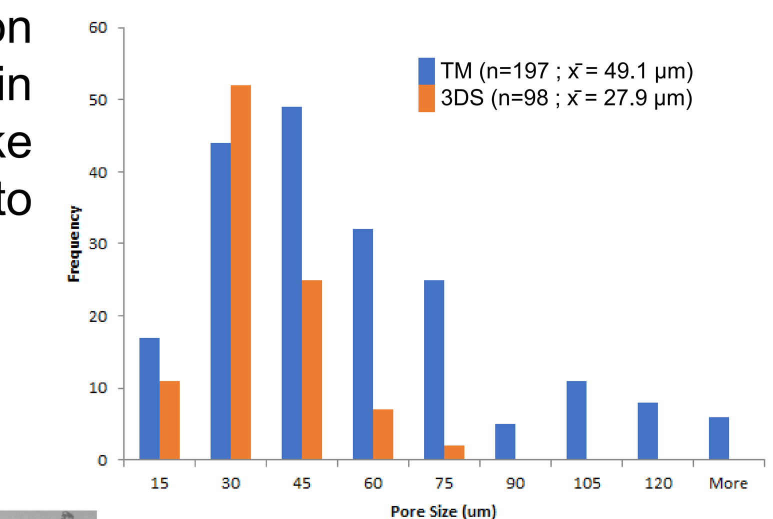
After heat treatment, **only TM shields are statistically softer than the required 365 HK specification;** the 3DS shields were not. Location and shield thickness did not effect microhardness.

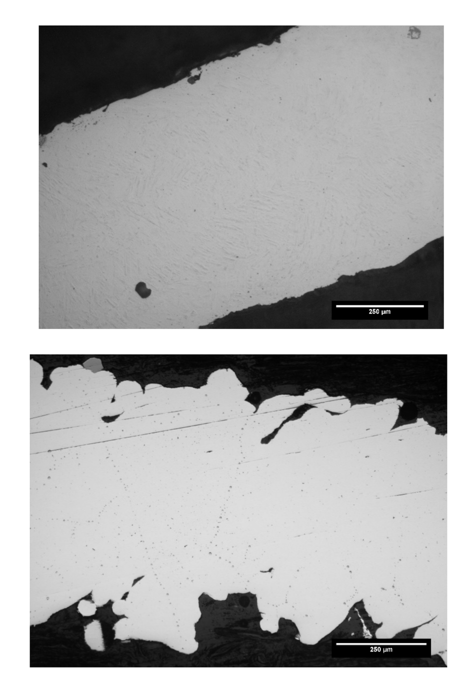



## Results & Discussion (cont.)

### Porosity Analysis

Wide distribution of pore sizes in TM shields make porosity harder to predict.



Sharp pore morphology is more likely to lead to crack propagation and part failure. 3DS pores had a lower aspect ratio, reducing likelihood of fracture initiation. Pores did not form preferentially in certain areas of the shields of either supplier.

### Residual Stress

Residual stress measurements on two regions of a 3DS shield resulted in measurements of -599 MPa and -668 MPa. Both values are more than half the yield strength of Ti-6Al-4V.

## Conclusions

- XRD and SEM confirmed additively manufactured shields had a lamellar α + β microstructure.
- While heat treatment revealed point defects for both suppliers, the heat treated 3DS shields were most similar to deep drawn shields.
- Heat treatment increased grain size which decreases the Hall-Petch effect on hardness, leading to more ductile shields.
- The Knoop microhardness data agreed with the SEM and XRD data.
- Heat treated TM shields were the only samples below the maximum microhardness of 365 HK
- 3DS pores are less likely to initiate crack propagation due to their equiaxed morphology
- TransMachine pores are large and unpredictable, making bridging a concern
- As-deposited shields have high residual stress
- **As delivered from suppliers, shields do not have desired properties for use in pacemakers**
- **The designed heat treatment resulted in more favorable shields that were not all within specification**

## Recommendations

3D Systems
- Heat treatment to soften and reduce residual stress

TransMachine
- Modification of printing parameters to reduce porosity

**While the designed heat treatment was effective, a shorter process should be researched**