# Heat Treatment of Metastable β Ti-Nb-Ta Alloy for Biomedical Applications

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## Introduction

Titanium is a popular material for joint replacements due to its biocompatibility, high fatigue strength, and relatively low Young's modulus compared to other materials. However, commonly used alloys like Ti-6Al-4V (wt%) have low ductility and high Young's modulus compared to bone. This mismatch in Young's modulus can lead to a phenomenon known as stress shielding in the bone, leading to the failure of the implant [1].

As a solution, metastable β-phase Ti alloys are being explored due to their BCC structure which results in a lower Young's modulus closer to that of bone. β-Ti alloys also show improved corrosion resistance and biocompatibility compared to α+β alloys [2].

This project aims to investigate whether heat treatment is effective at changing the the microstructure and mechanical properties of Ti 20Nb-10Ta (wt%), referred to as TNT.

## Methodology

### Casting:

Using vacuum casting in an arc furnace, samples of Ti-20Nb-10Ta (wt%) (TNT) were cast at three different diameters: 3mm, 5mm, and 10mm (Fig. 1).

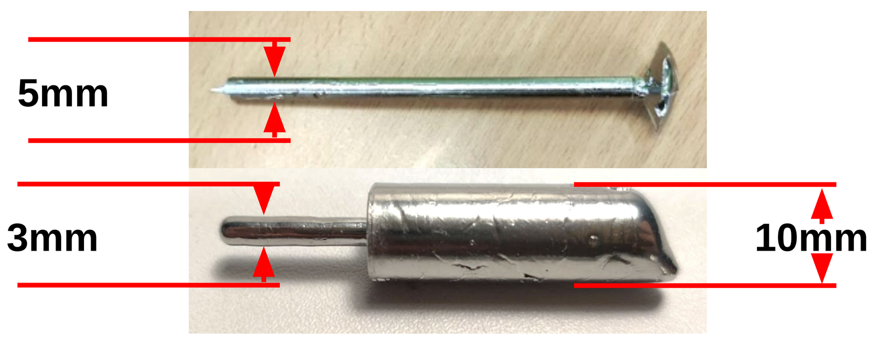


*Fig. 1: Vacuum cast TNT samples*

### Heat Treatment:

A 3mm, 5mm, and 10mm sample of TNT were heat treated in a ceramic crucible in a preheated 700$^{O}$C furnace under a regular atmosphere. Samples were removed after 7 hours and water quenched.

### Mounting and Polishing:

The heat treated and non-treated samples were cut into shorter sections and cast into conductive resin pucks (Fig. 2). These pucks were then polished with colloidal silica 0.01 μm using a polishing machine (Fig. 3).

*Fig. 2: Mounted and polished heat treated samples*

*Fig. 3: Polishing machine*

### Hardness Testing:

Hardness testing was performed on the samples using the Vickers method. A force of 500g was applied to the samples for 15 seconds in 5 locations per cross section.

### SEM/EDX Characterisation:

The polished samples were imaged using a scanning electron microscope (SEM). Imaging revealed a dendritic structure, and energy dispersive x-ray spectroscopy (EDX) was performed on the dendritic and inter-dendritic regions to determine the elemental composition of the regions.

## Results

### SEM Imaging

Between 250x and 600x magnification, a clear dendritic structure is visible in all the samples, demonstrated below with the 3mm samples (Fig. 4, 5)

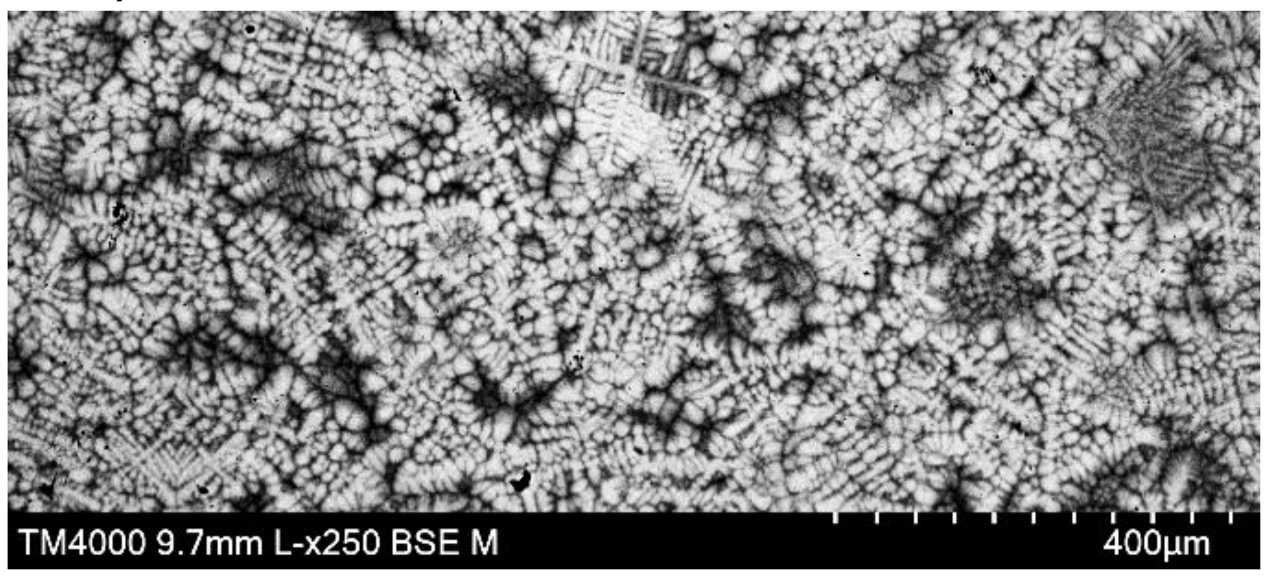


*Fig. 4: SEM image of non-heat treated 3mm sample at 250x magnification*

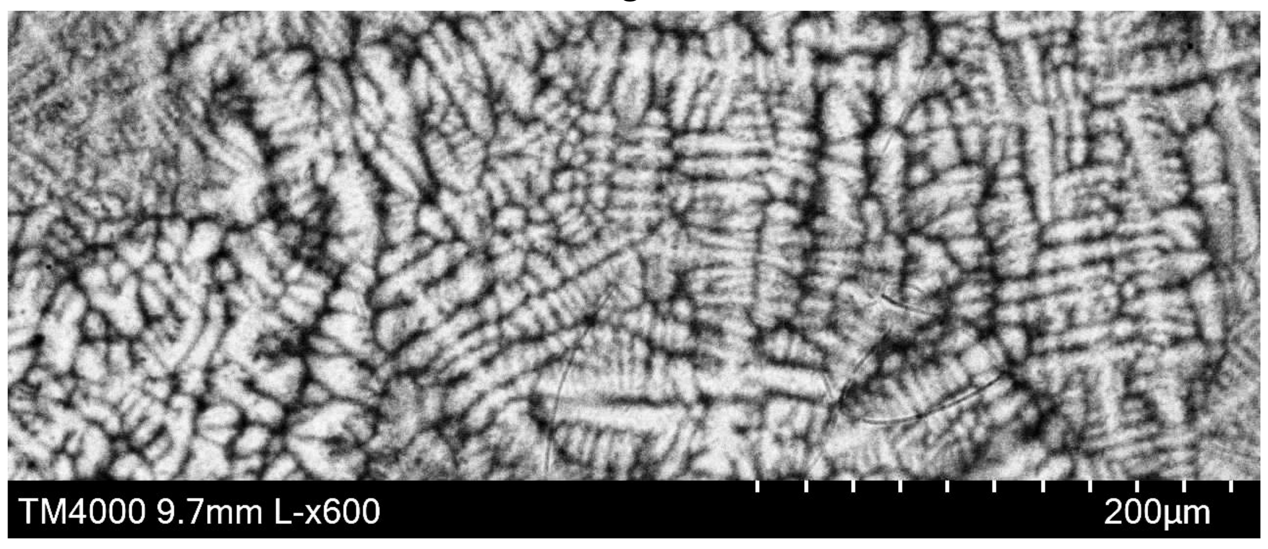


*Fig. 5: SEM image of heat treated 3mm sample at 600x magnification*

EDX analysis of the dendrites and interdendritic regions revealed that in the untreated samples, the partition coefficient ($wt\%_{dendritic}$ / $wt\%_{interdendritic}$) of Ta changed with sample diameter, while Nb partition coefficients remained relatively constant. In the treated samples though, both Ta and Nb partition coefficients remained relatively constant across diameters (Fig. 6).

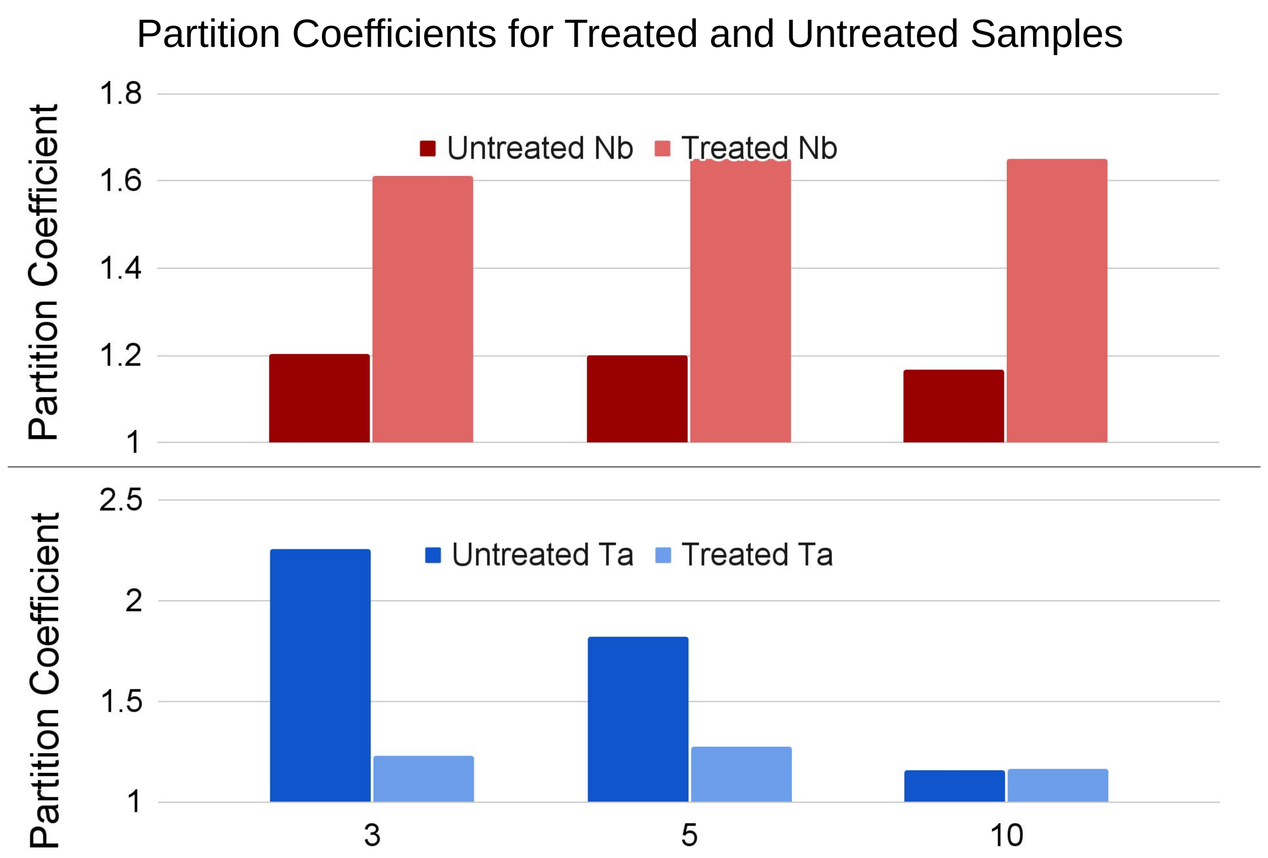


*Fig. 6: Graph of the partition coefficients for treated and untreated samples of Ta and Nb*

In **Figure 6**, note the decreasing relationship between partition and diameter in the untreated samples (especially with Ta), and the relatively constant relationship in the treated samples. This indicates a relationship between cooling rate and element partition.

SEM analysis of the samples at 7000x magnification revealed that another phase appears in the heat treated samples (Fig. 7, 8).

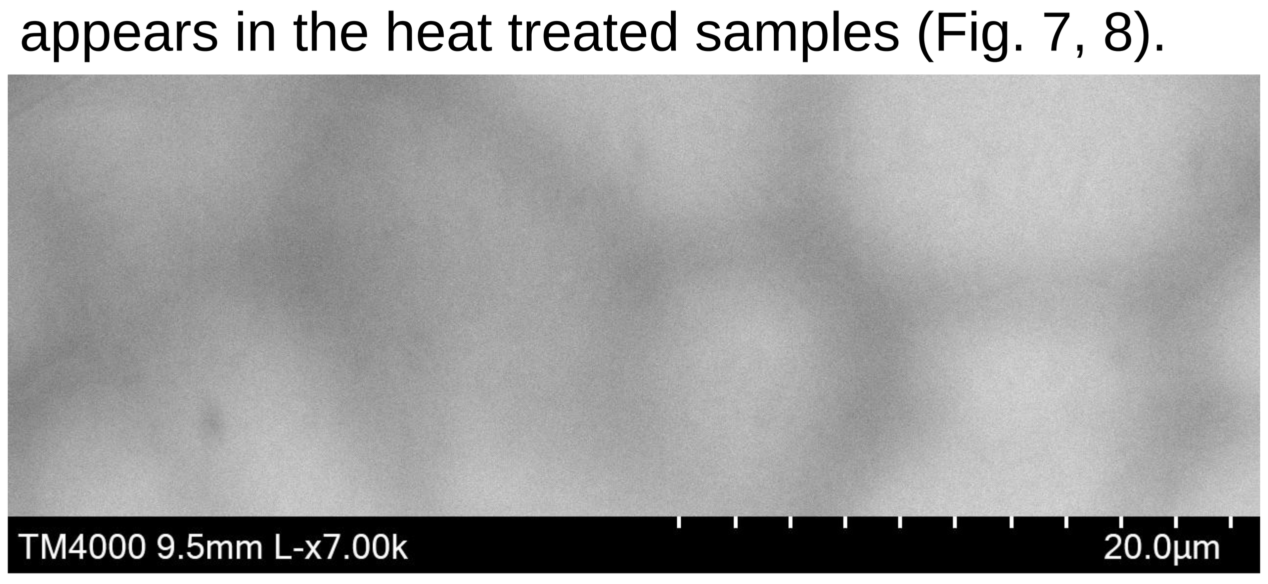


*Fig. 7: SEM image of untreated 3mm sample at 7000x magnification*

## Results cont.

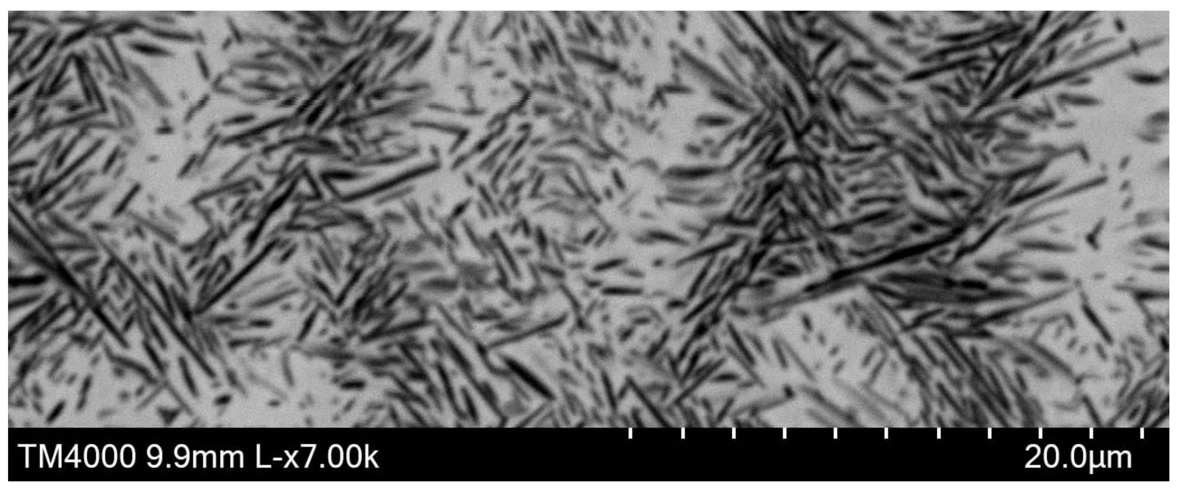


*Fig. 8: SEM image of heat treated 3mm sample at 7000x magnification*

This new phase in the heat treated sample (Fig. 7) is acicular, appearing dark needle-like streaks.

### Hardness Testing

Vickers hardness testing results indicated that the hardness of the material decreased in the heat treated samples (Fig. 9).

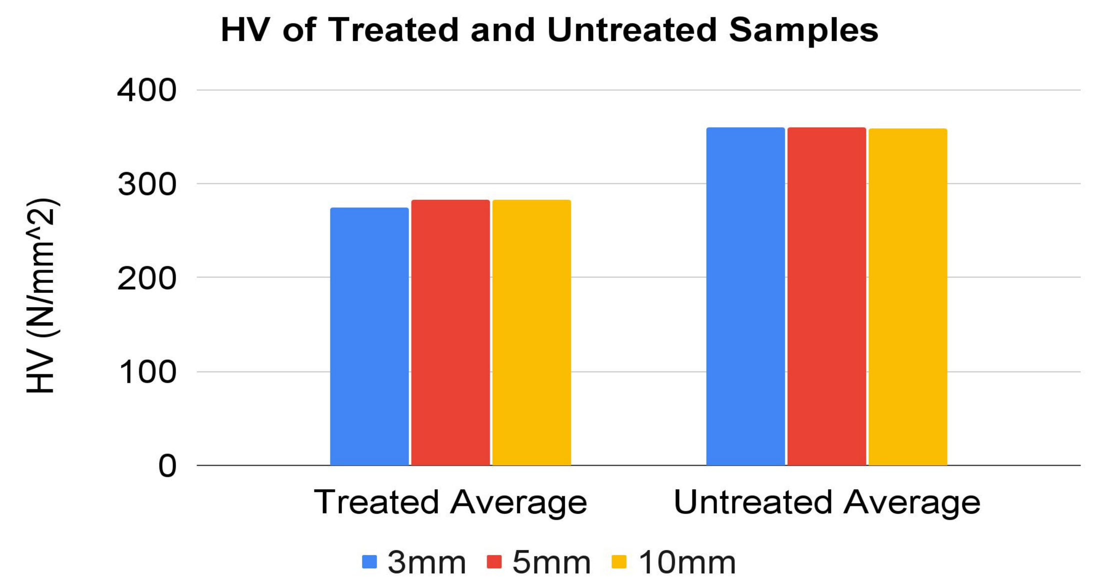


*Fig. 9: Graph of the hardness measurements for treated and untreated samples*

## Discussion

SEM analysis revealed that heat treatment promotes the growth of a new acicular microstructure, which could be the β-phase, although more testing is needed.

The microstructural changes brought by heat treatment also led to a decrease in the hardness of the alloy. This could be a result of the heat treatment leading to a relaxation of the residual stresses from casting. It is also possible that this mechanical change is a result of the new phase, as some phases, including β, possess a lower hardness. More analysis is needed to determine the root cause of this reduction.

Heat treatment also removed the cooling-rate dependence of the elemental segregation. There was consistent partition across all treated samples

## Conclusion

The heat treatment of TNT alloy samples is effective at changing their microstructure and mechanical properties. The emergence of a new phase in the heat treated sample, as well as a decrease in hardness may indicate the presence of increased quantities of β-phase Ti, however further testing is needed to confirm this.

## References

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[1] - R. HUISKES, H. WEINANS, and B. V. RIETBERGEN, "The Relationship Between Stress Shielding and Bone Resorption Around Total Hip Stems and the Effects of Flexible Materials," Clinical Orthopaedics and Related Research®, vol. 274, 1992, [Online]. Available: https://journals.lww.com/clinorthop/Fulltext/1992/01000/The_Relationship_Between_Stress_Shielding_and_Bone.14.aspx

[2] - M. Kaur and K. Singh, "Review on titanium and titanium based alloys as biomaterials for orthopaedic applications," Materials Science and Engineering: C, vol. 102, pp. 844–862, Sep. 2019, doi: 10.1016/j.msec.2019.04.064.