

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 $\alpha+\beta$ 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).

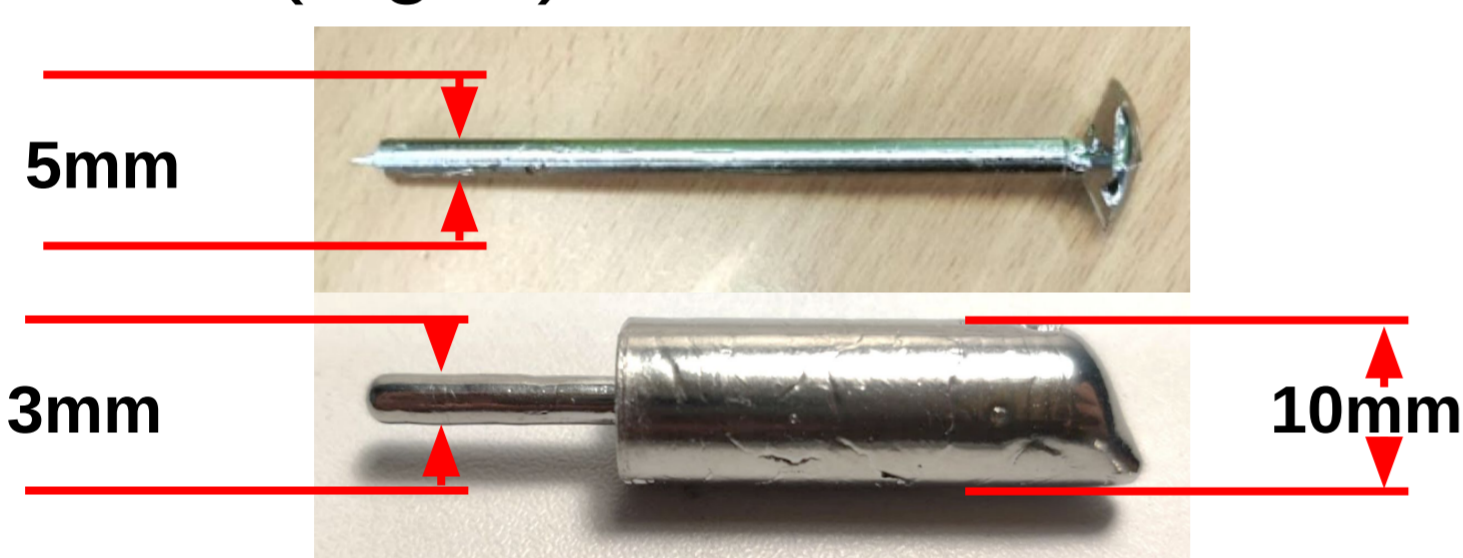


Fig. 1: Vacuum cast TNT samples

Heat Treatment:

A 3mm, 5mm, and 10mm sample of TNT were heat treated in a ceramic crucible in a preheated 700°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

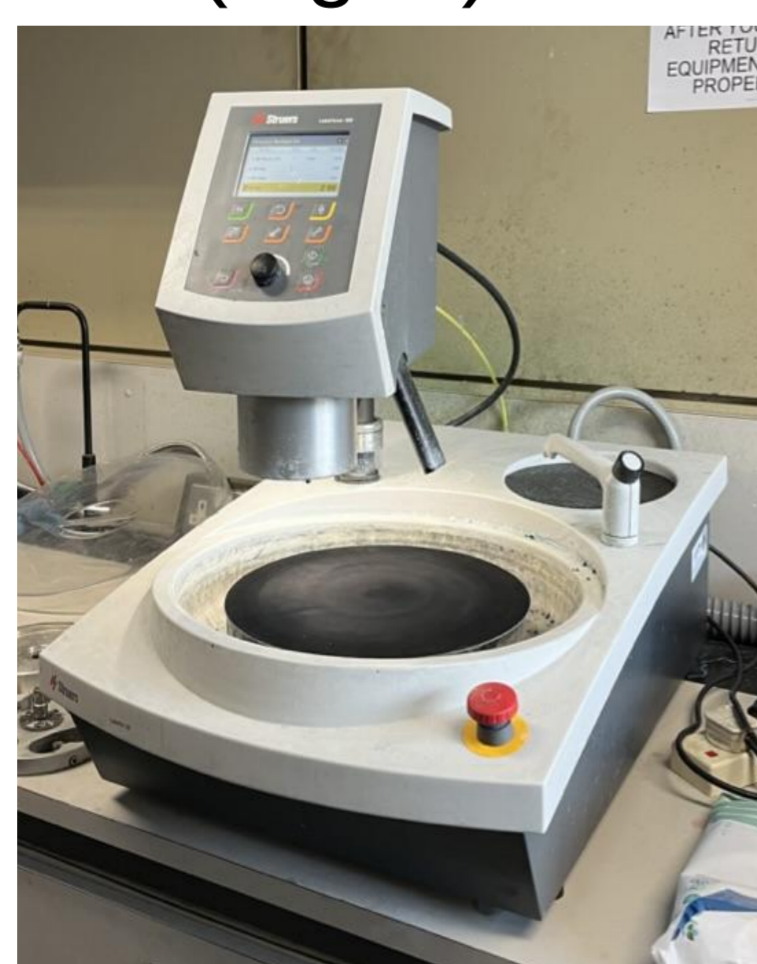


Fig. 3: Polishing machine

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)

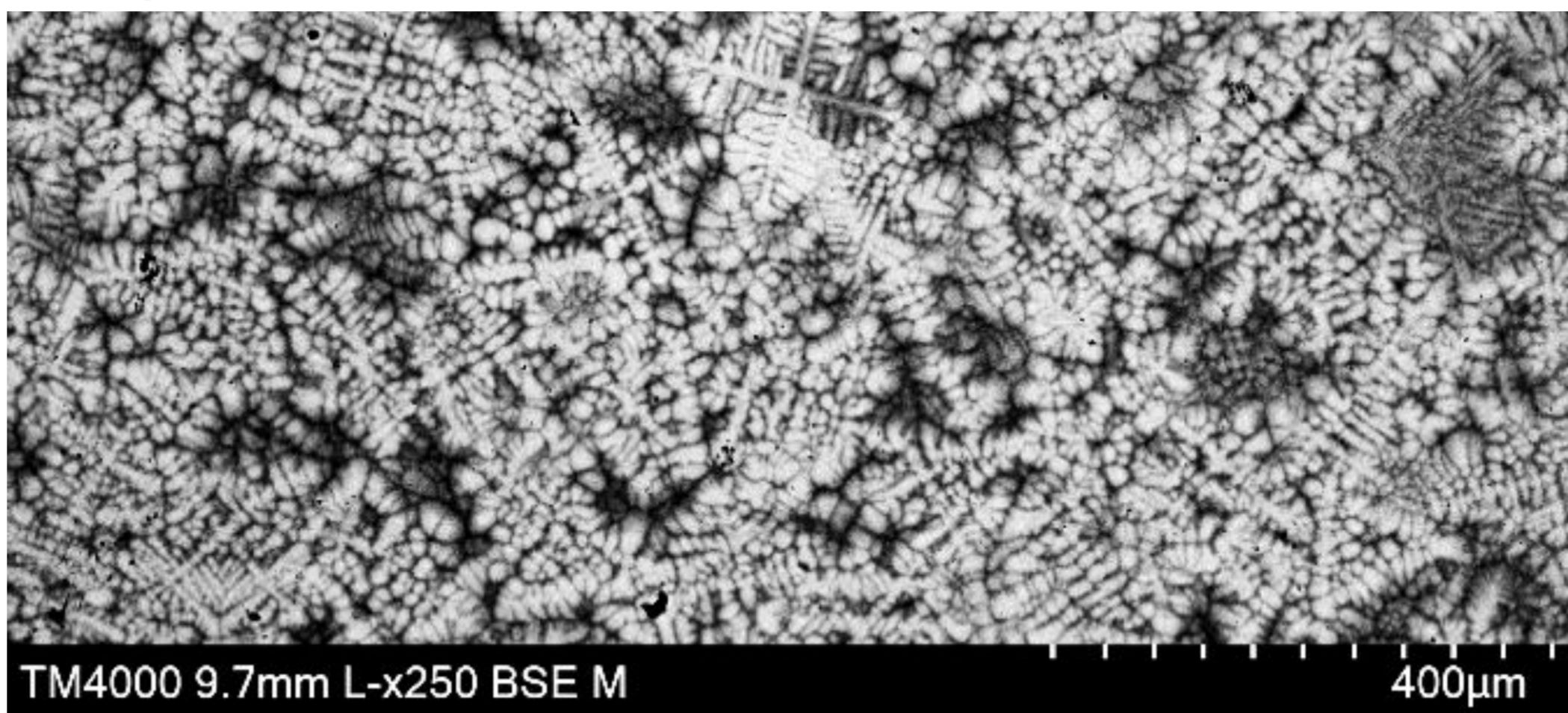


Fig. 4: SEM image of non-heat treated 3mm sample at 250x magnification

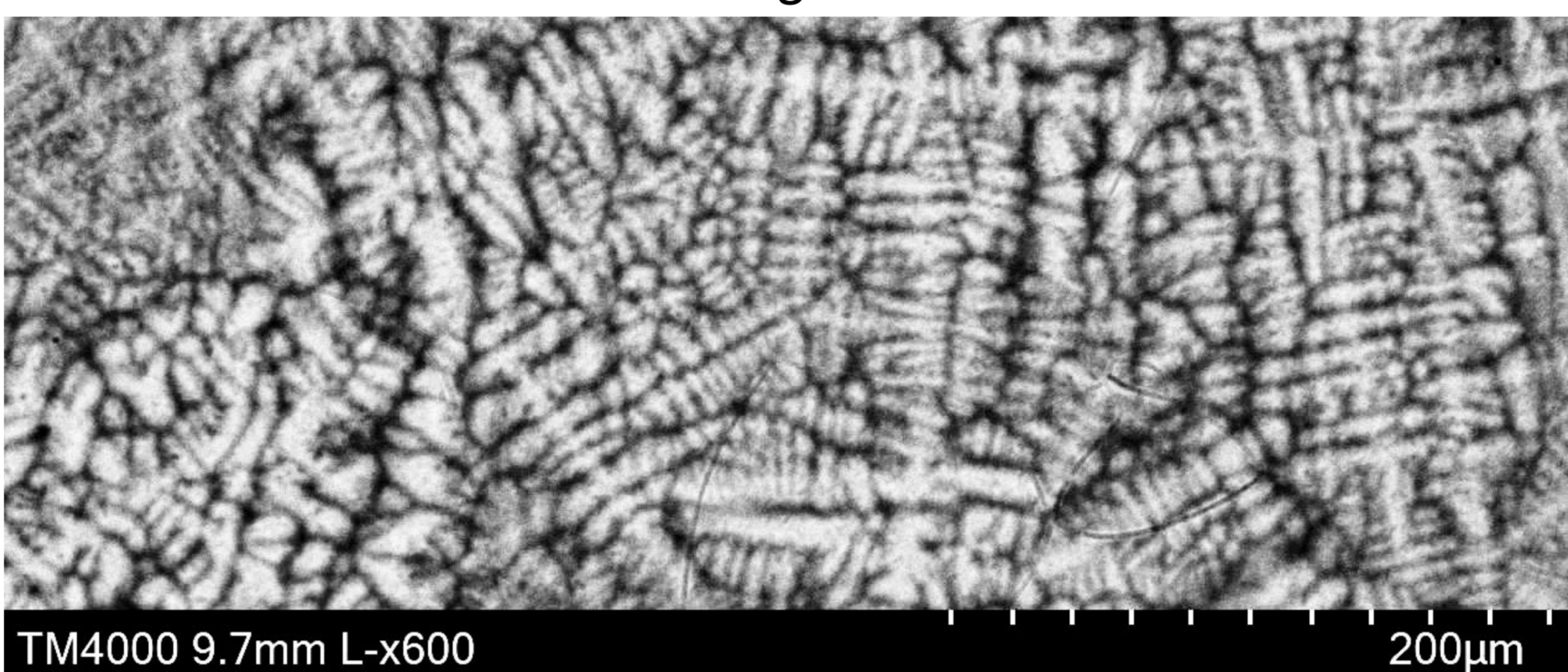


Fig. 5: SEM image of heat treated 3mm sample at 600x magnification

EDX analysis of the dendrites and interdendritic regions revealed that in the untreated samples, the partition coefficient ($\text{wt}\%_{\text{dendritic}} / \text{wt}\%_{\text{interdendritic}}$) 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).

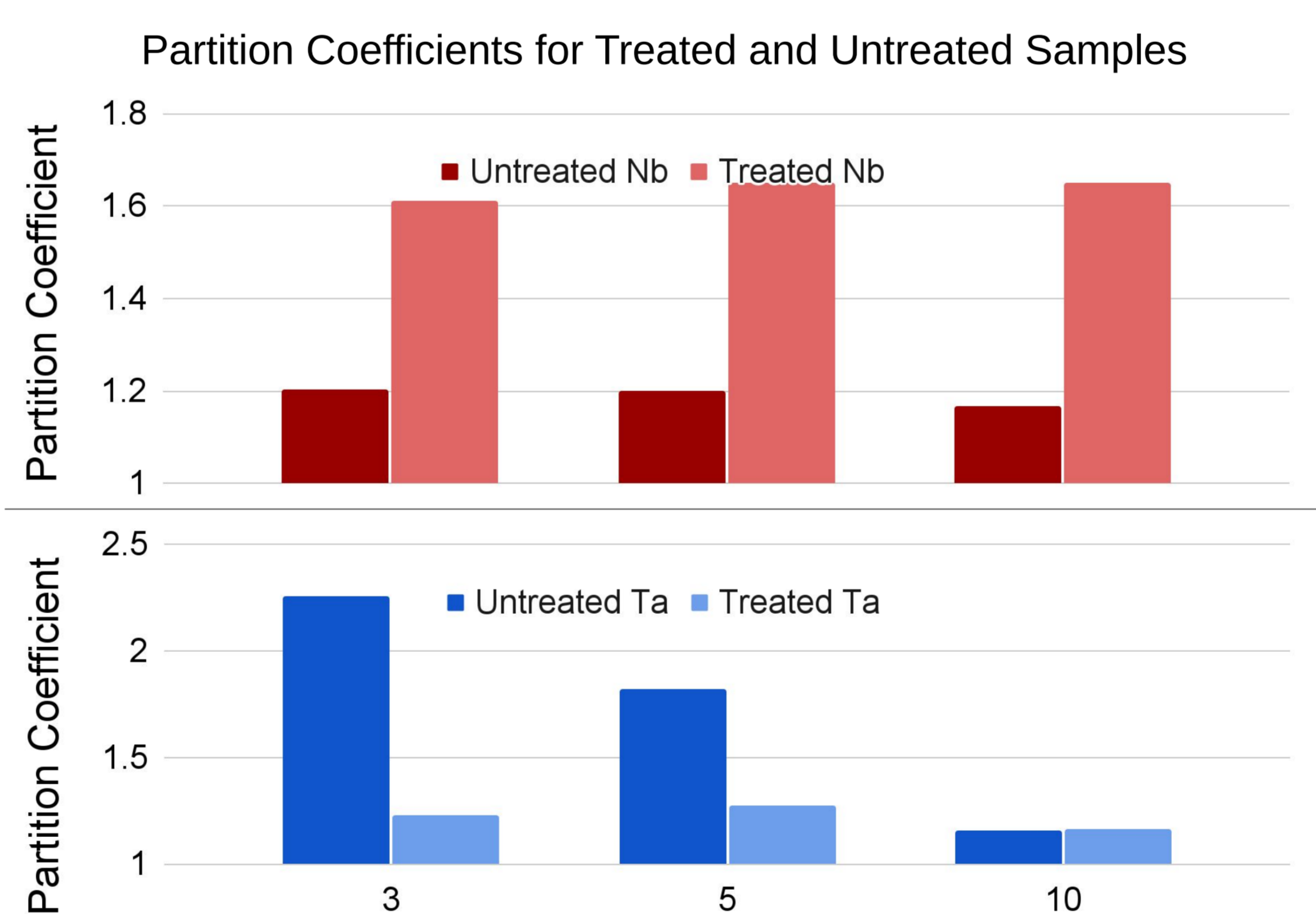


Fig. 6: Graph of the partition coefficients for treated and untreated samples of Ta and Nb

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).

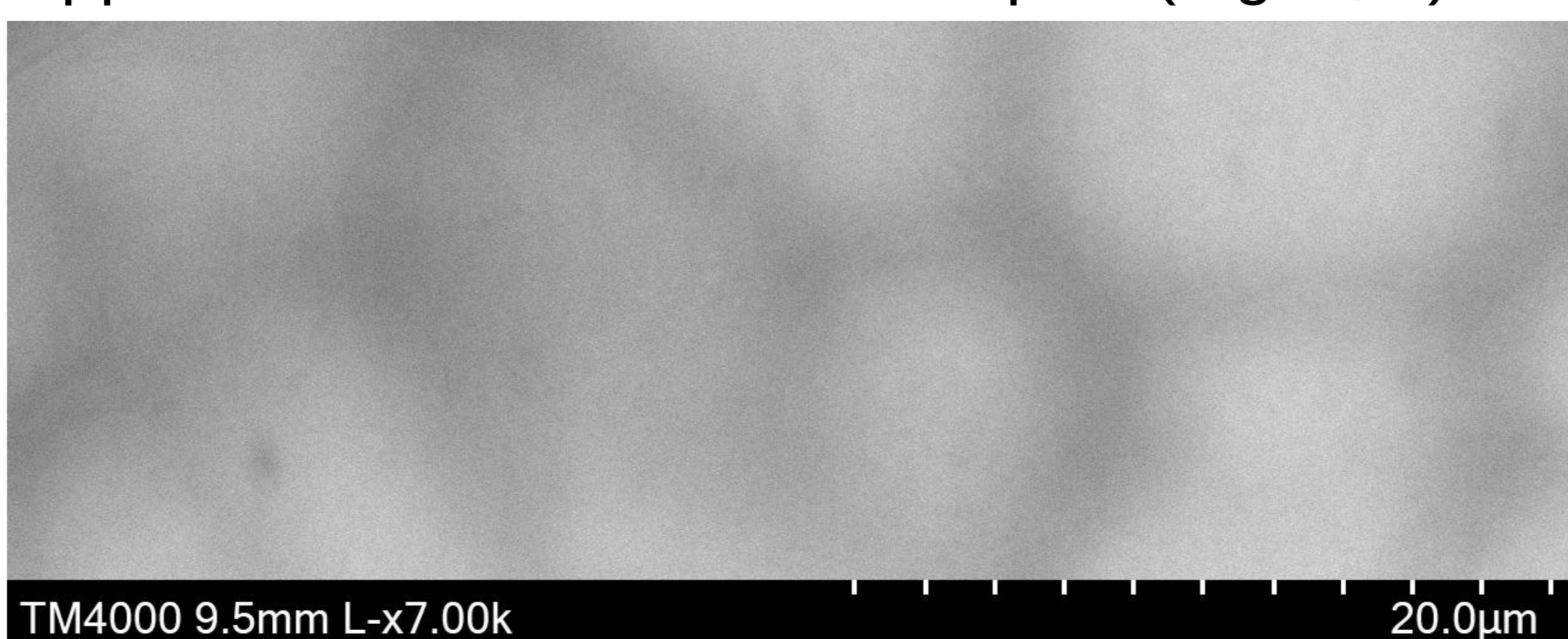


Fig. 7: SEM image of untreated 3mm sample at 7000x magnification

Results cont.

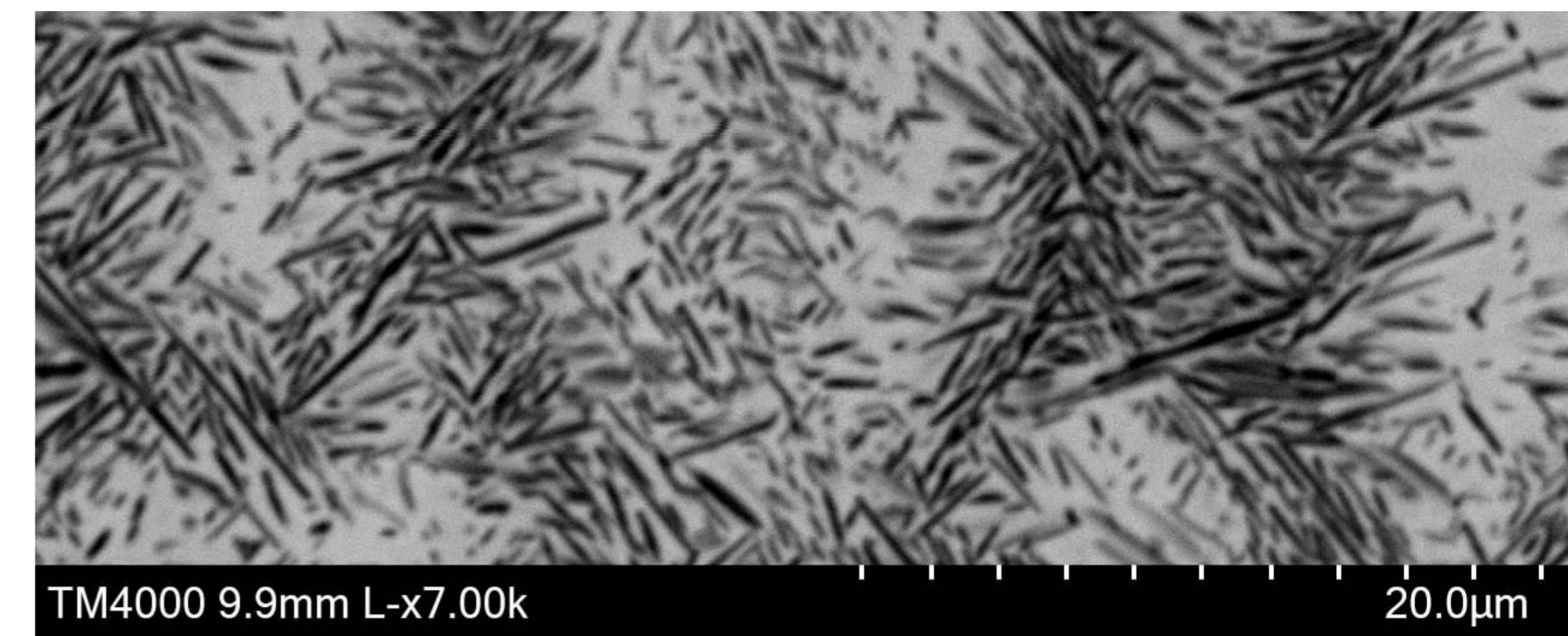


Fig. 8: SEM image of heat treated 3mm sample at 7000x magnification

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).

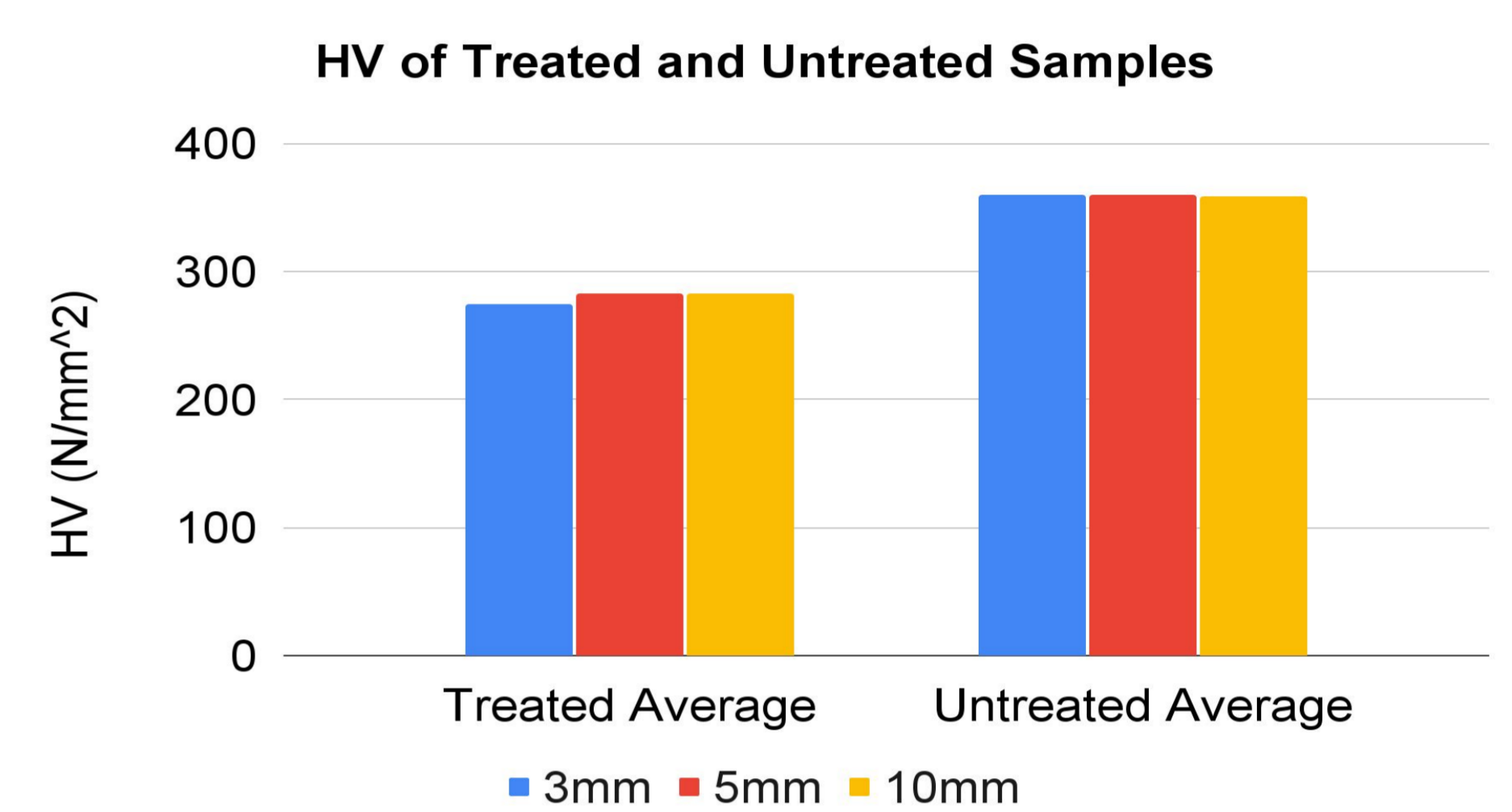


Fig. 9: Graph of the hardness measurements for treated and untreated samples

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.