Effect of processing techniques on electrical and thermal properties of 14YWT

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Motivation:

Nanostructures Ferritic Alloys (NFAs) are promising candidates for Generation IV nuclear reactors due to their remarkable radiation tolerance, high thermal stability, creep resistance, and high temperature strength. However, the high strength also makes the alloy difficult to form. Recent results indicate that electrically assisted (EA) forming is a suitable technique to produce core internals out of NFAs. For optimum EA processing conditions, physical properties including the electrical and thermal properties are needed.

Introduction:

The attractive properties of NFAs, like 14YWT, are principally due to the presence of Y-Ti-O containing nano-oxides (NOs) and fine grain size which can immobilize dislocations resulting in greater structural stability and high strength. The result is a fine microstructure that has high dislocation density which result in enhanced resistance to radiation damage and helium management in NFAs [2]. Different processing techniques and the temperatures at which they are conducted, result in distinct grain morphologies [3]. Two principal processing techniques were used to obtain the 14YWT sample: Hot Isostatic Pressing (HIP) and Hot extrusion (ER). The purpose of this study is to investigate how different processing techniques result in varying grain size and physical properties including electrical resistivity and thermal conductivity. The physical properties will then be used to optimize EA forming process for the desired microstructure.

Experimental:

Material: 14YWT with a nominal composition of Fe-14Cr -3W-0.4Ti-0.2Y (wt%) have a stable microstructure up to 1300 ⁰C and high temperature creep strength up to 800 ⁰C [4].

Microstructure: FEI Quanta SEM/FIB was used to (Ga^+ ion) etch and image the grain morphologies.

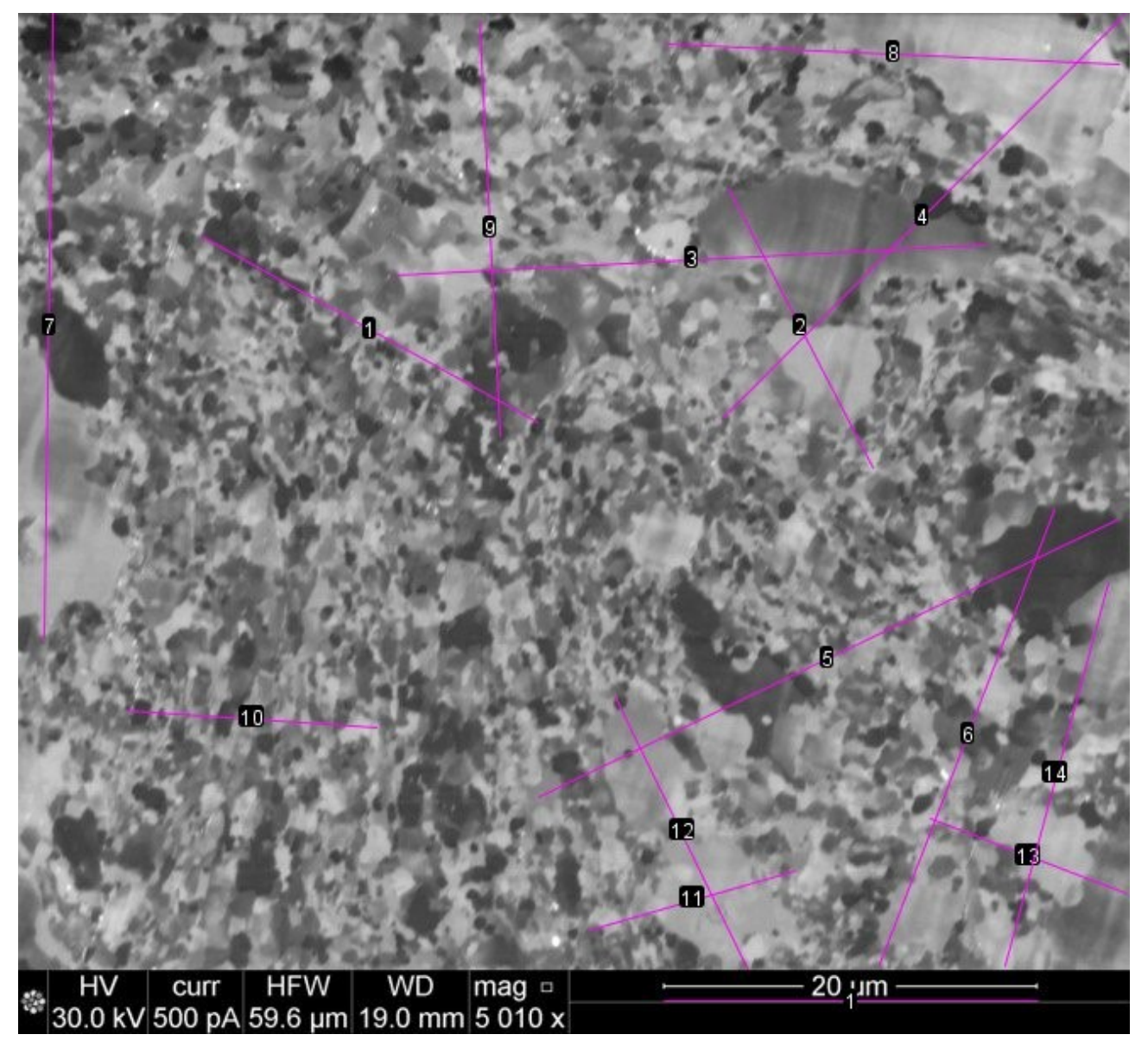
Grain size measurement: Exact polygons were used to obtain the size of the big grains, whereas intercept method was used for the small grain on FIB micrographs .

Electrical resistivity measurements: A low-frequency ac resistance bridge was used to obtain temperature dependent electrical resistivity measurements for temperatures ranging from around 400 K down to ~4K.

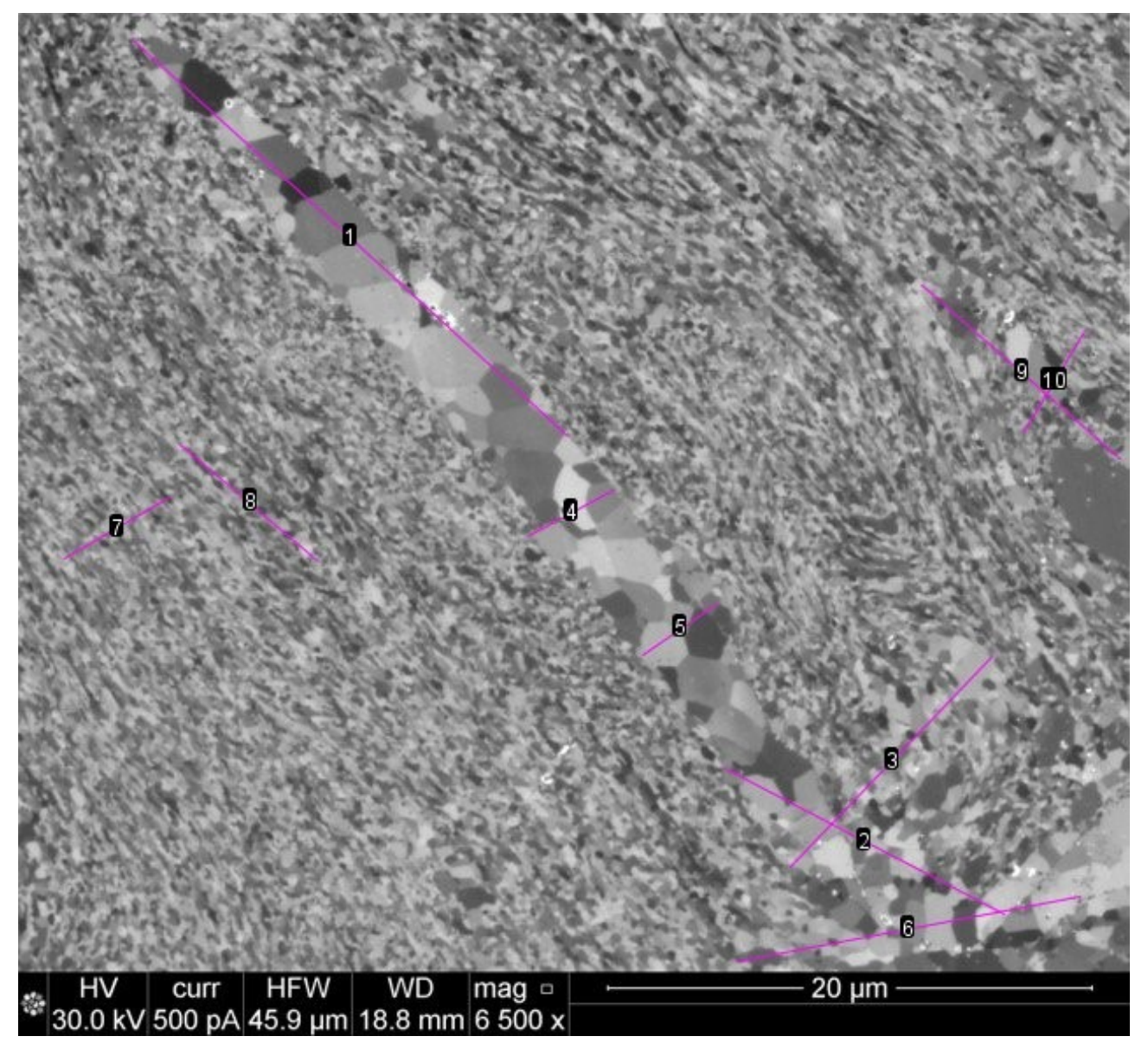
Thermal Conductivity measurements : The thermal expansion coefficient (α) was determined using dilatometry. Differential Scanning Calorimeter (DSC) was used to measure C_p of the specimen using the ratio method. The LFA method was utilized to determine the thermal diffusivity, D. The thermal Conductivity is, thus determined using the α, C_p, and D data.

Results and Discussion

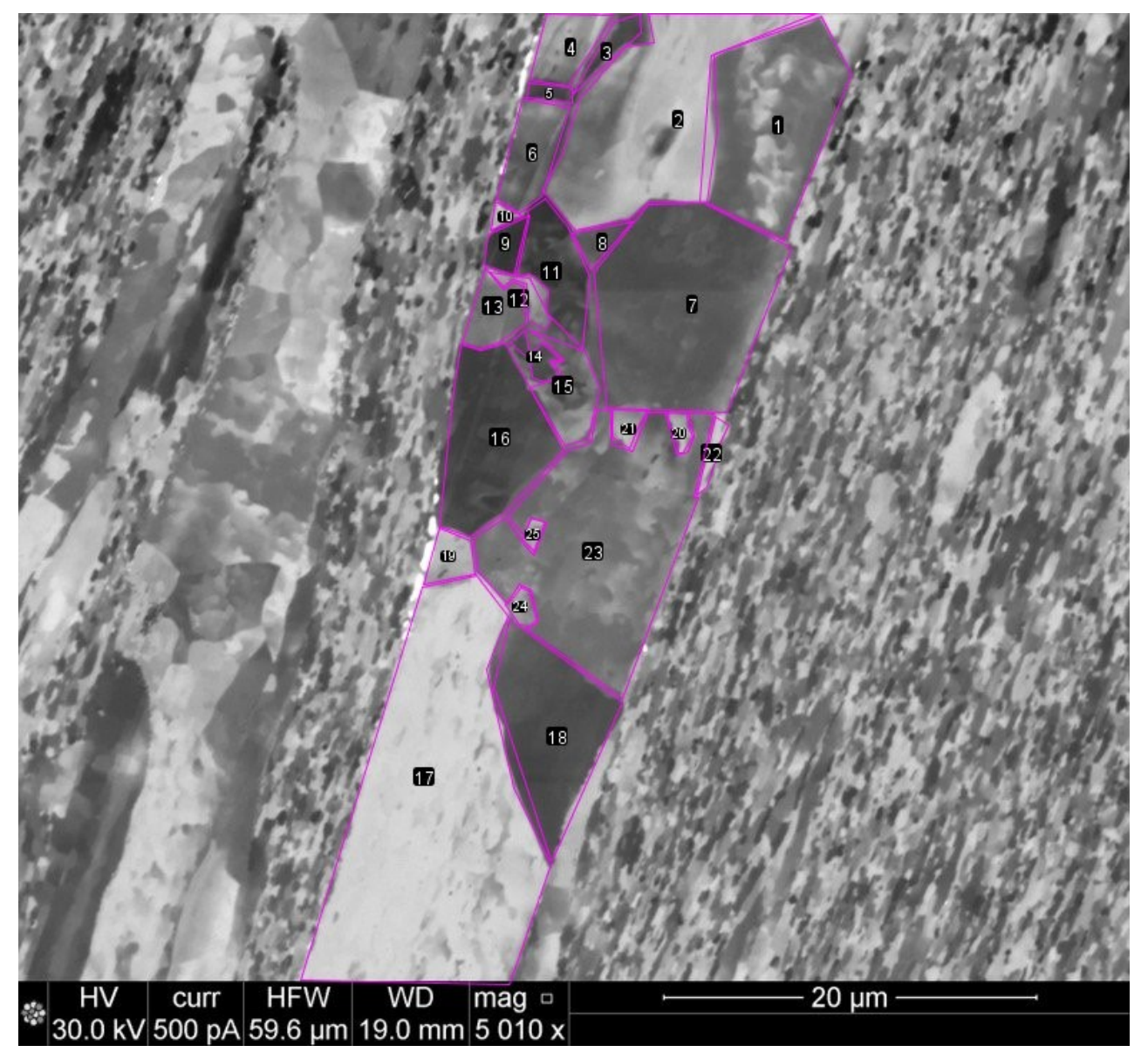
14YWT HIPed at 1150 ⁰C

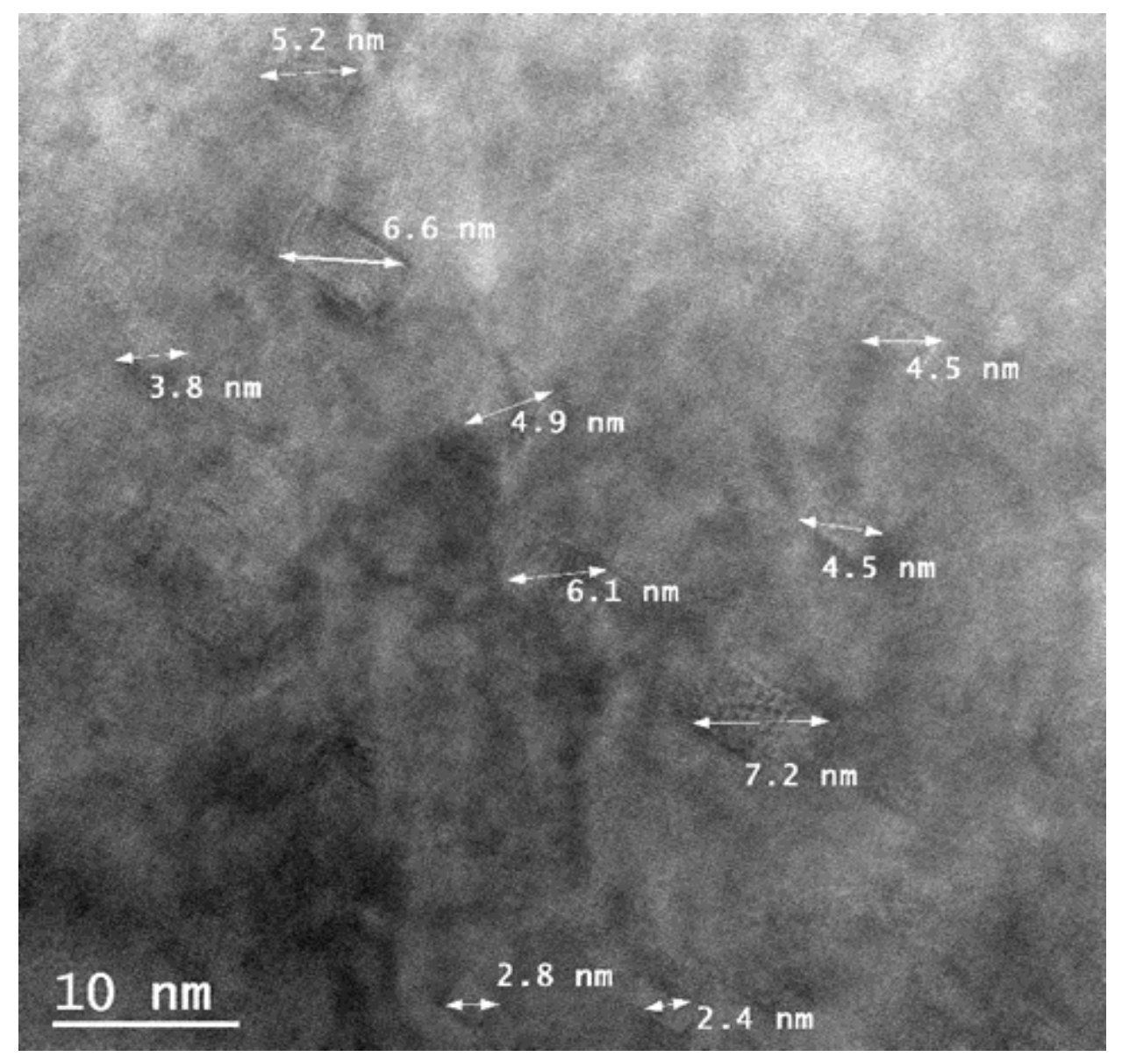


HIPed at 850 ⁰C



Extruded at 850⁰C

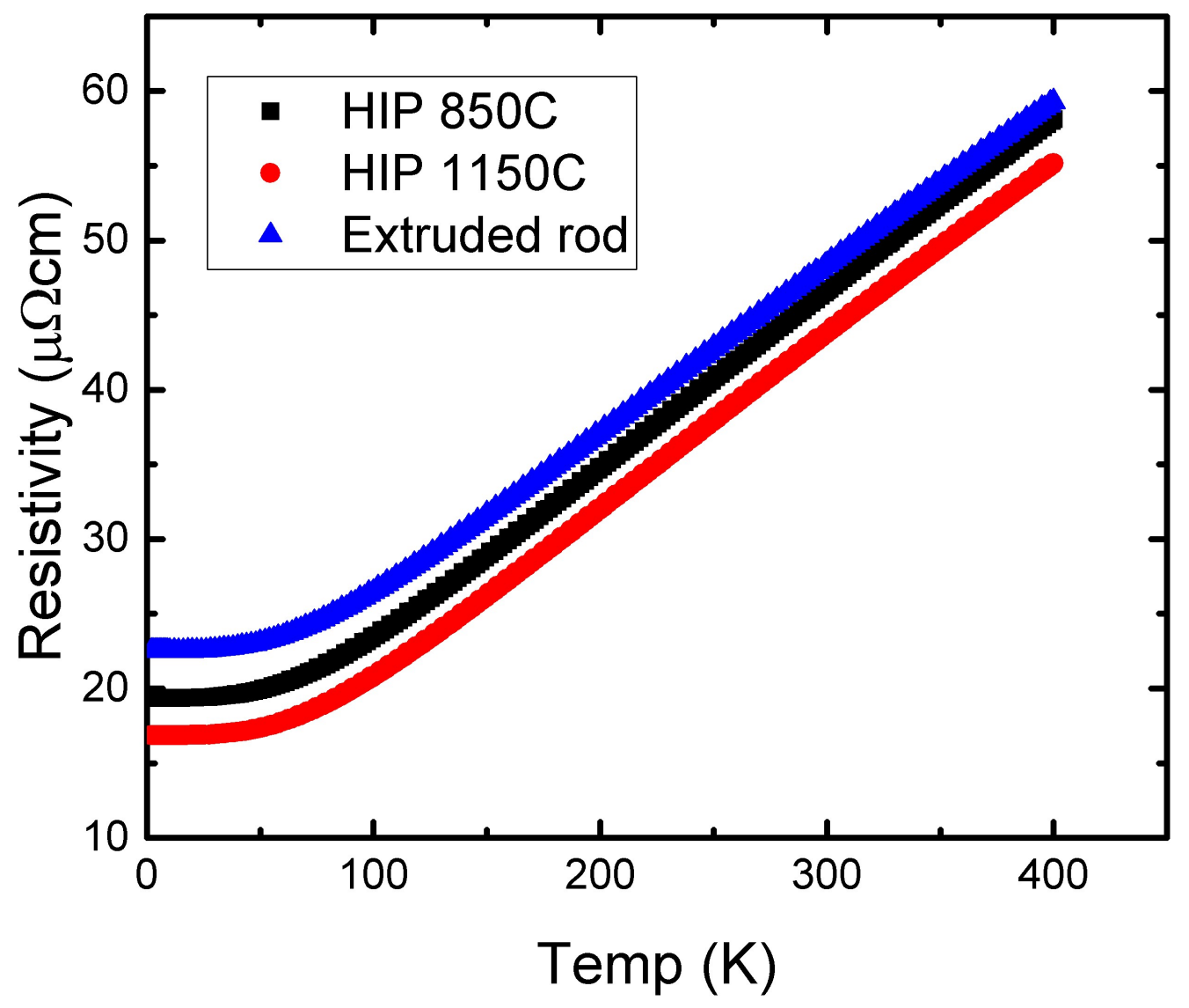




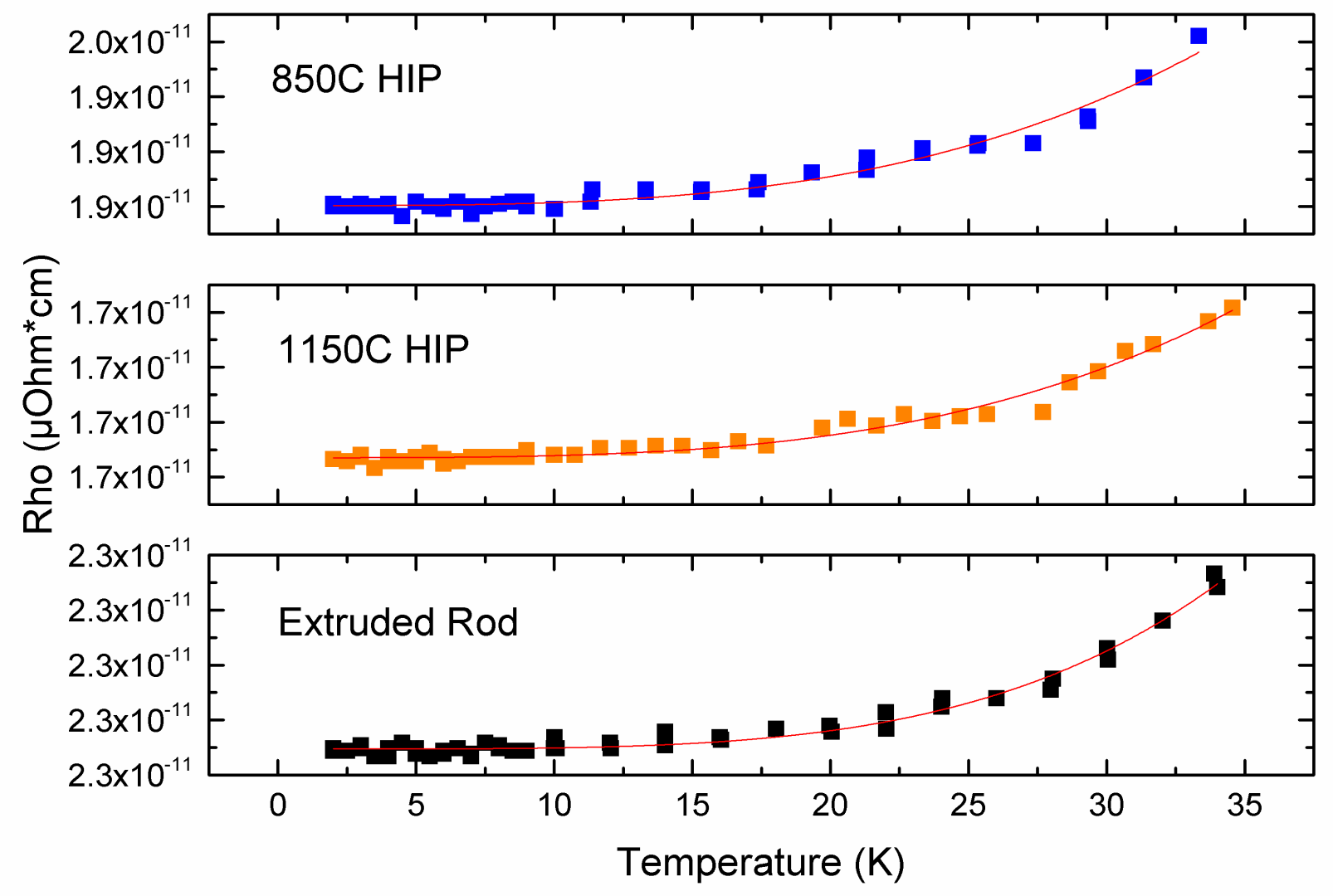
High resolution TEM image showing morphology and size distribution of Y-Ti-O containing NOs.

- Bimodal grain distribution was observed as a result of the three processing methods.
- The density of grains decreases (bigger grains) by increasing the HIP temperature.

Electrical Resistivity



Resistivity of 14YWT varies by processing technique used. Smaller grain size specimens have higher resistivity presumably due to grain boundary (GB) scattering.

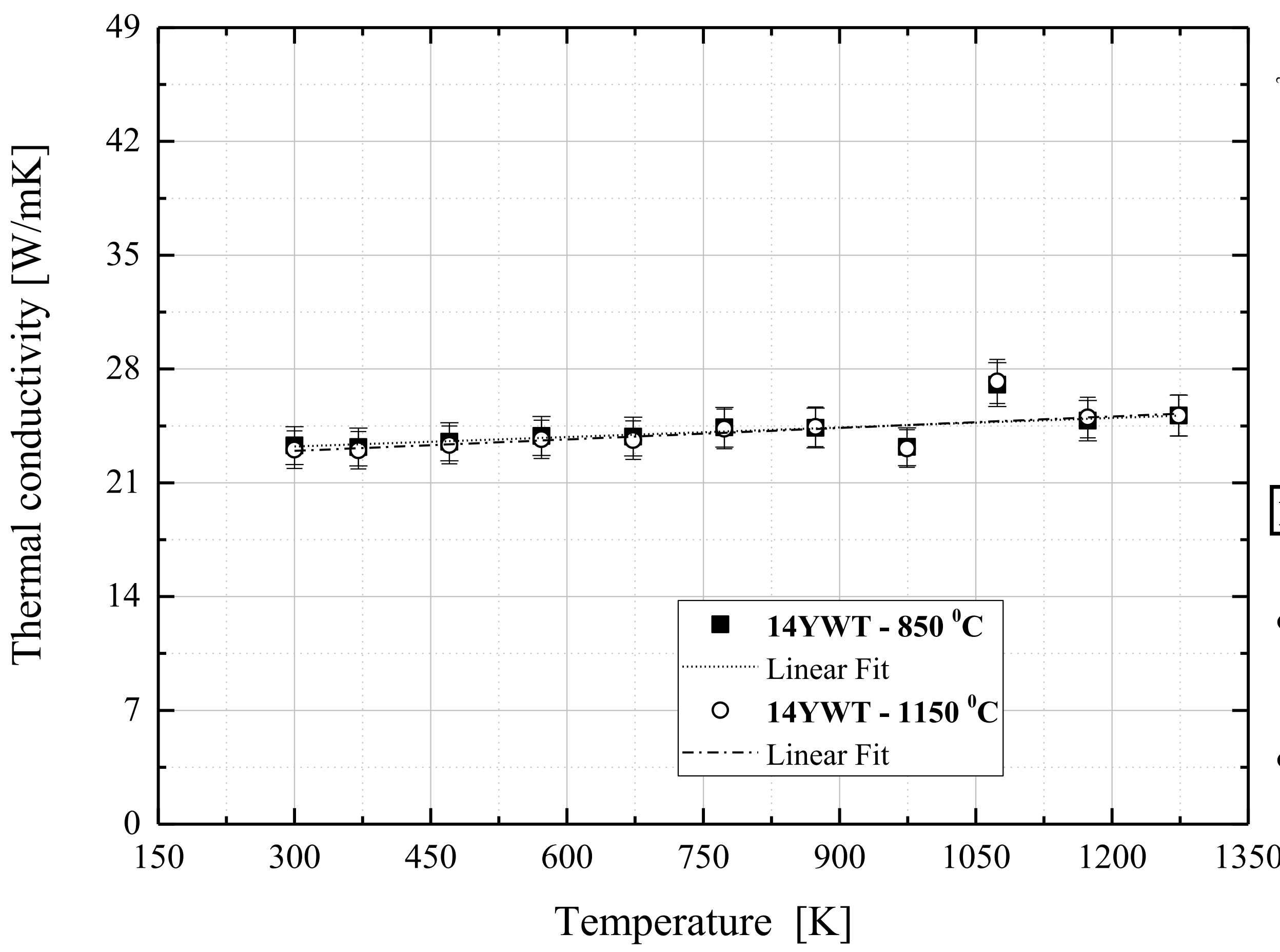


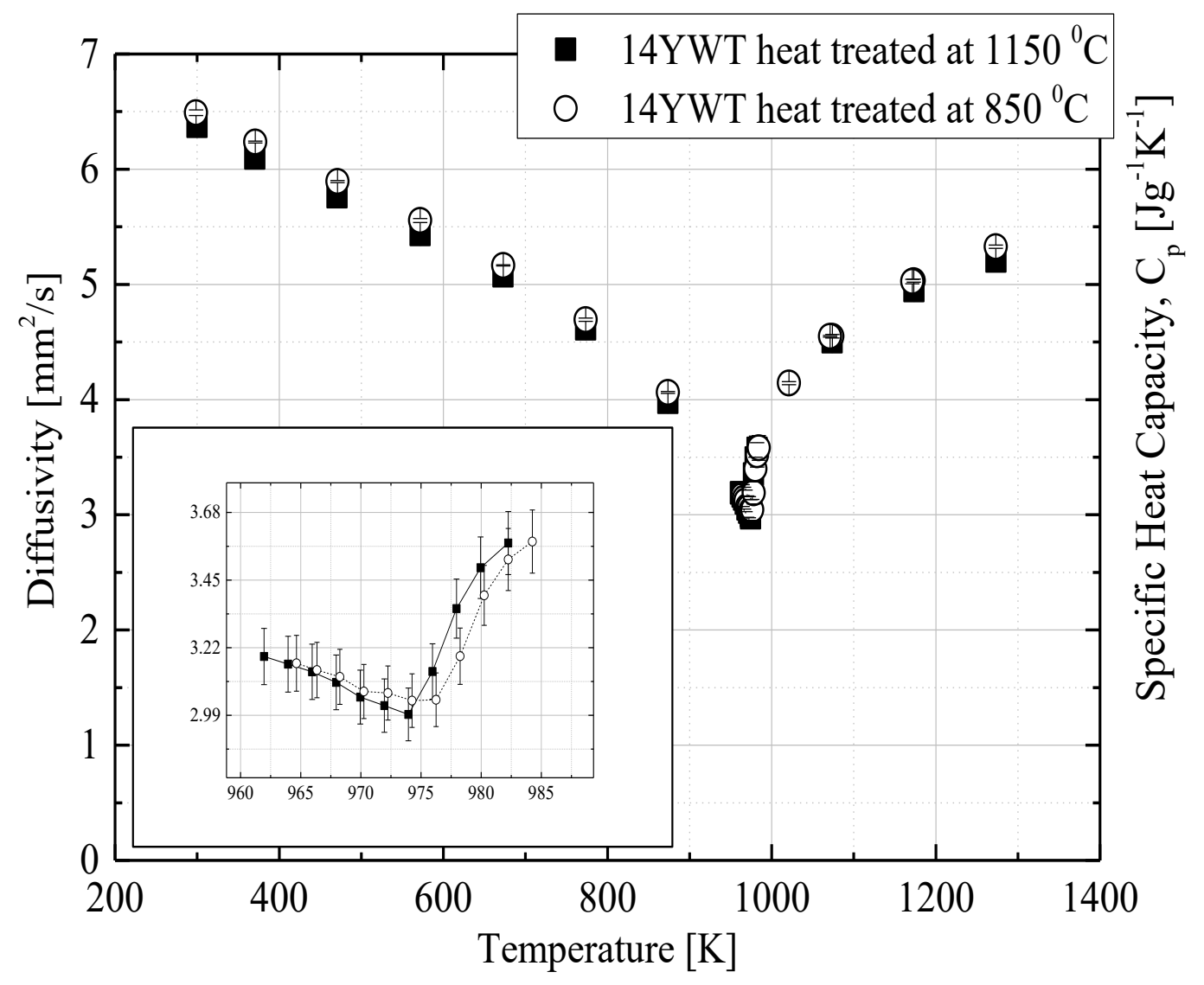
$\rho = \rho_0 + JT^k$ was fit to the low temperature resistivity data above to obtain intrinsic resistivity, ρ_0. Intrinsic resistivity is needed to calculate GB resistivity coefficient.

$$\rho_{total} = \rho_0 + C_g\xi_g + C_p\xi_p$$

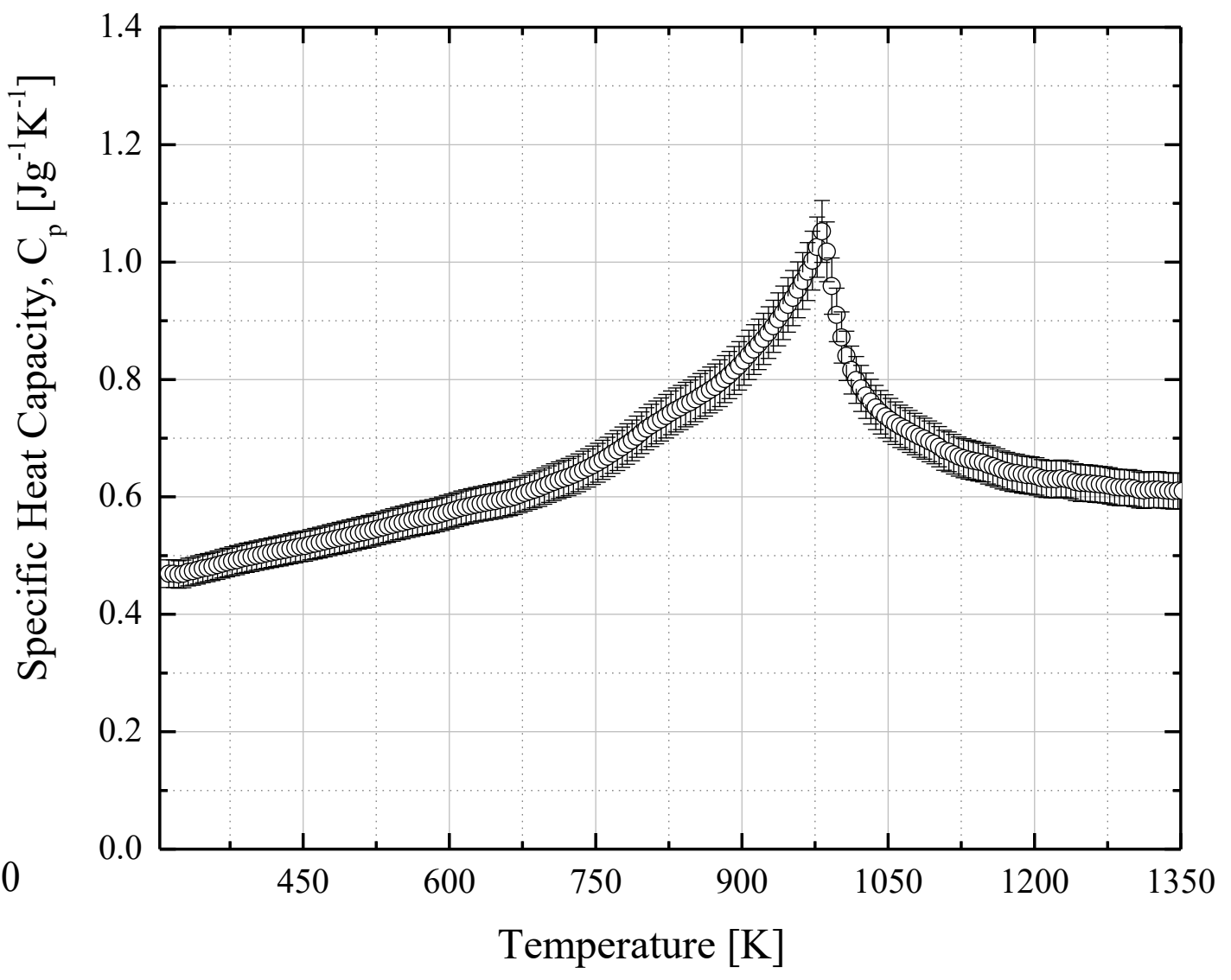
- The grain boundaries and precipitates scatter free electrons that conduct electricity and are related by Matthiessen's rule above at low T.
- The number density of grains per unit area, ξ_g, can be estimated simply by 1/ *d*.
- The precipitates ξ_p, which exist as a second phase, are correlated to density of small grains.
- Since the electrons will encounter more grain boundaries in a metal with smaller grain size, resistivity contribution due to grain boundaries is expected to be highest for ER 850 ⁰C, followed by HIP 850 ⁰C, and least for HIP 1150 ⁰C.

Thermal Conductivity





Inset: Diffusivity near the Curie temperature



Specific heat capacity

- Thermal conductivity of 14YWT remains essentially constant as a function of the processing and temperature that changes microstruture .
- The thermal conductivity of 14YWT has an average value of 24 [W/m.K], which is higher compared to 21 [W/m.K] of contemporary claddings made of Zirconium based alloys.

Summary:

- Grain morphology, electrical, and thermal properties of 14YWT processed using Hot Isostatic Pressing (HIP) and Extruded Rod (ER) were investigated.
- It is observed that the density of grains decreases by increasing the HIP temperature.
- The intrinsic resistivity was found to be highest for ER 850 ⁰C, followed by HIP 850 ⁰C, and least for HIP 1150 ⁰C demonstrating the effect of grain boundary scattering of electrons.
- The thermal conductivity of 14YWT will remain essentially constant as a function of the heat treatment.

Process	Avg. grain size, *d* (μm)	Grain density, ξ_g (cm^{-1})	Resistivity(~4K) (μΩcm)
HIP 850⁰C	0.992	11103.33	19.3±0.1
HIP 1150⁰C	2.131	4692.28	16.9±0.1
ER 850⁰C	1.367	7341.14	22.5±0.1

Future Work:

- The intrinsic resistivity, coefficients due to grain boundary (C_g) and precipitate (C_p) scattering need to be calculated using Matthiessen's rule.
- Investigate effect of grain size on relative hardness using nanoindentation.
- Investigate He embrittlement using ion implantation and nanoindentation.

Acknowledgment:

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