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# Microstructure and Mechanical Properties of Direct Laser Metal Deposited GRCop-84 Alloy

**Ajay Bhagavatam, Praveen Sreeramagiri, Guru Dinda***

**6/18/19**

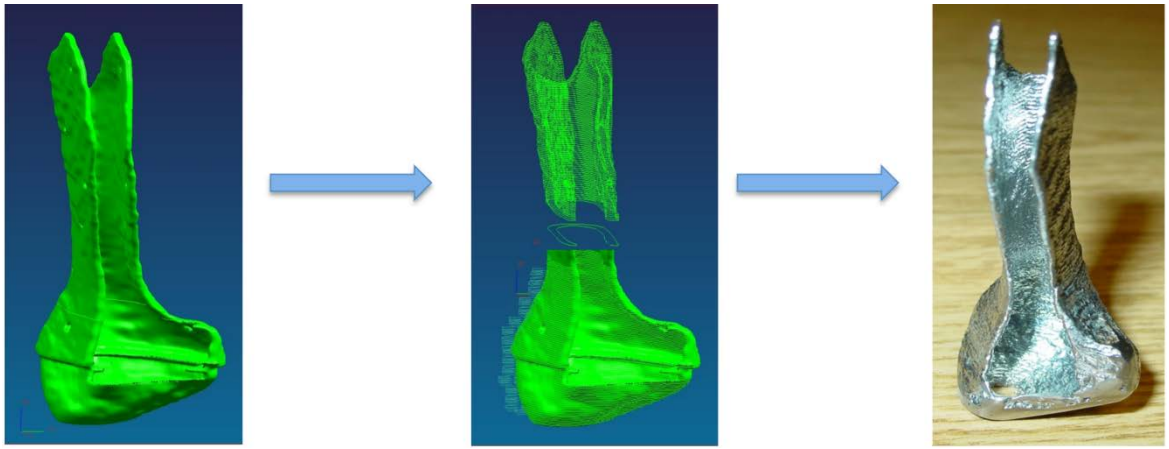

**Wayne State University**

# What is Additive Manufacturing ?

**Additive Manufacturing is a technology where an actual part can be printed accurately using its 3D CAD design. In this process a part is developed by depositing material layer by layer as per its dimensions until the part is created.**

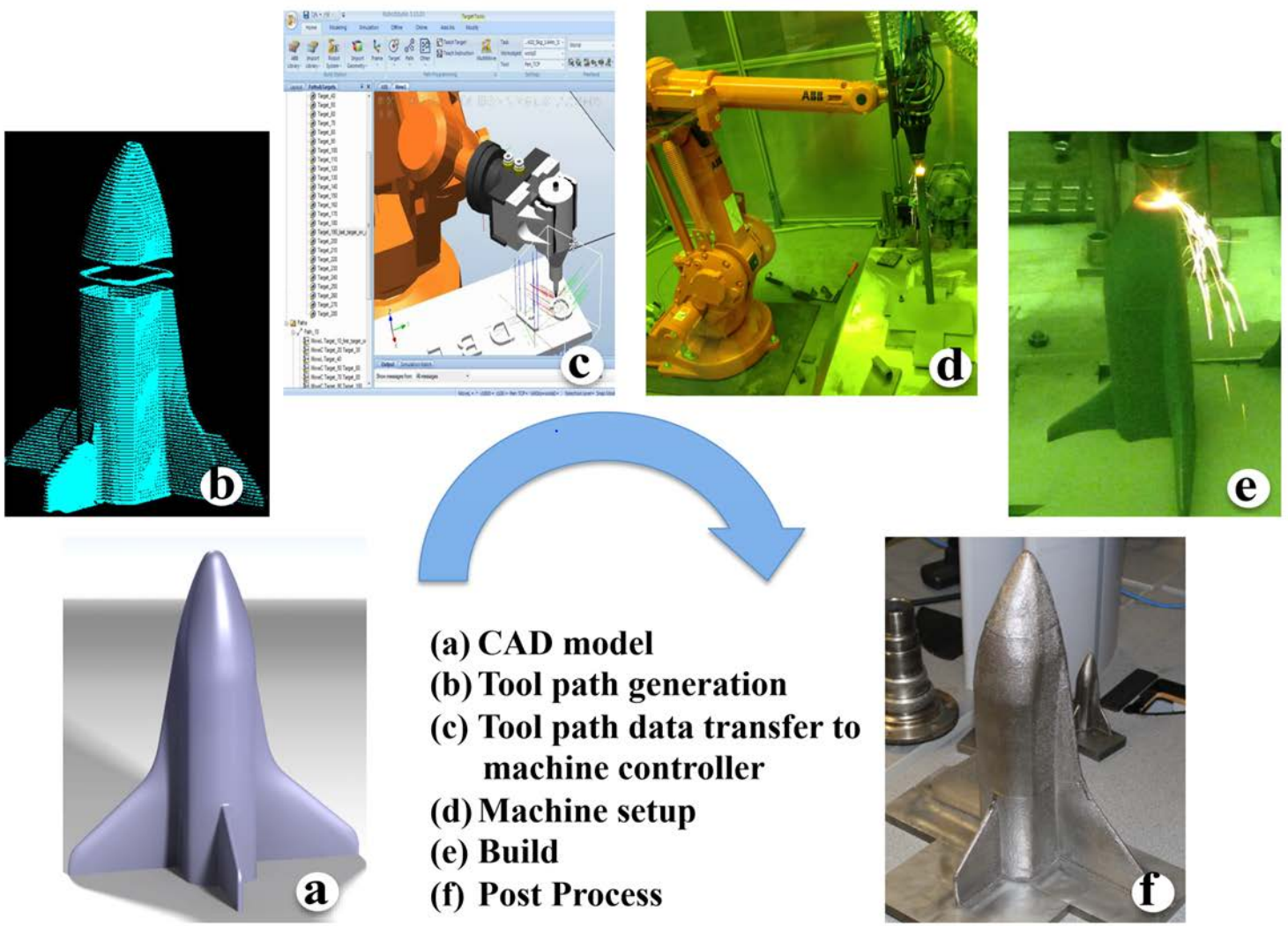
**Different Synonyms for Additive manufacturing are:**

- **3D Printing**
- **Rapid Prototyping**
- **Layer Manufacturing**
- **Direct metal deposition**
- **Solid freeform fabrication**



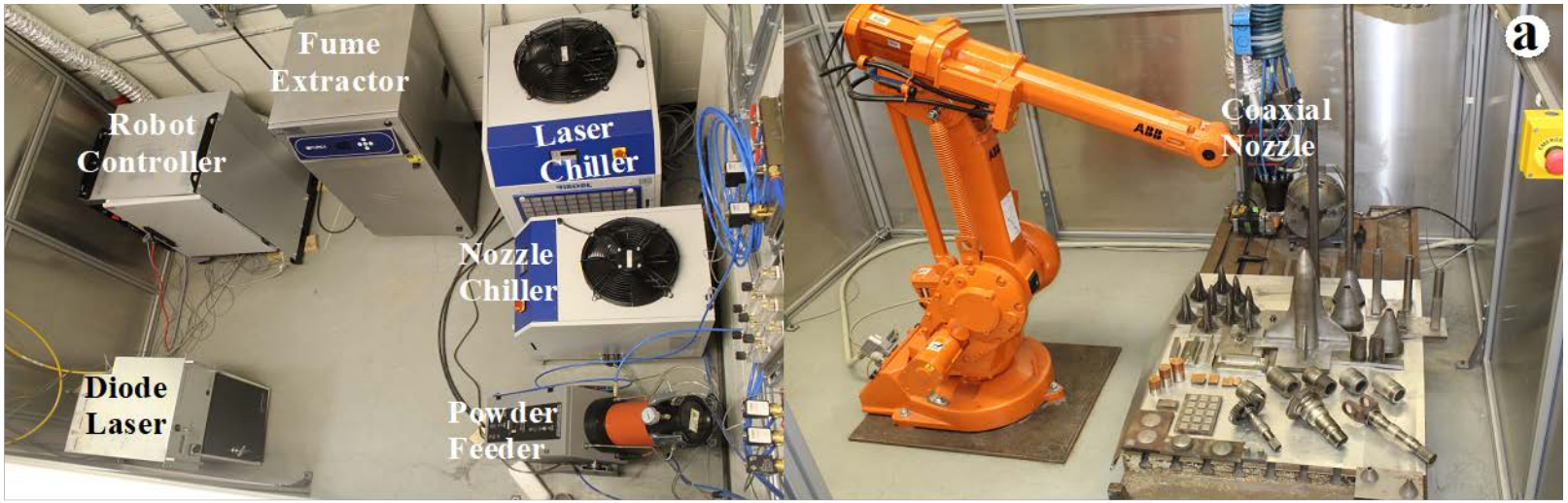
**Ti-6Al-4V scaffold was produced by the DMD process** (Dinda, Song et al. 2008)**.**

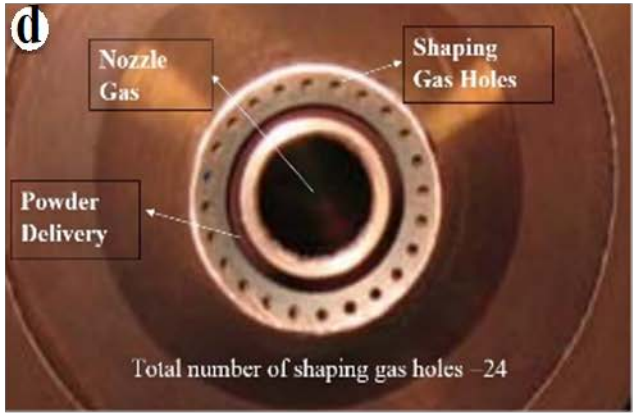
# Additive Manufacturing Process

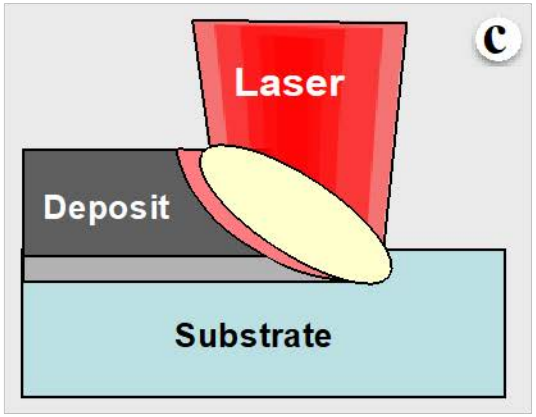


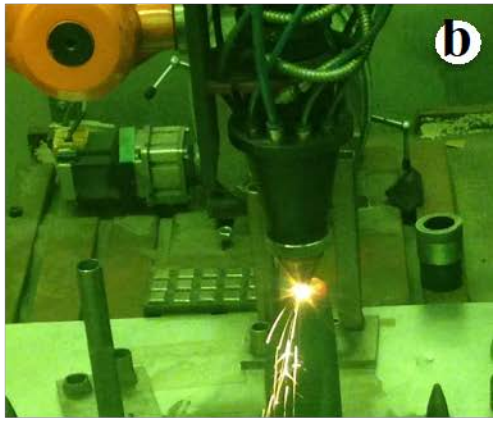

**Laser Metal Deposition Process**

# Laser Metal Deposition Technology Developed at Wayne State University



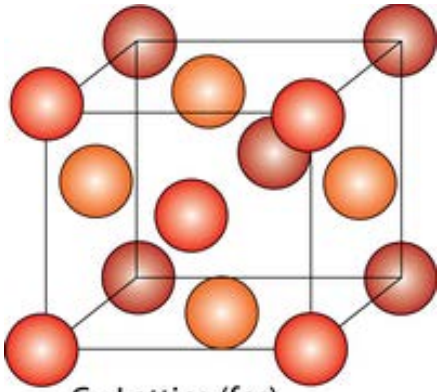




**Laser Metal Deposition at Wayne State University**

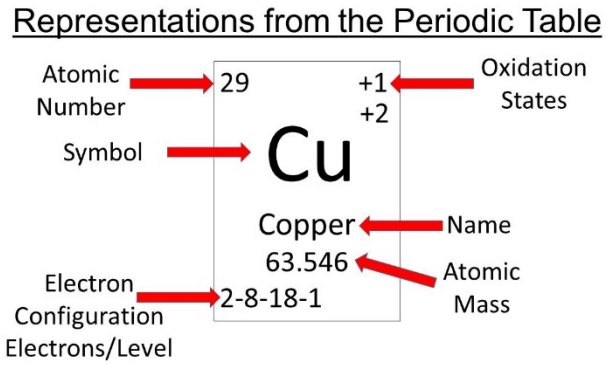
# Copper Alloys with high thermal conductivity

- **Copper is the oldest metal known to man.**
- **Good thermal conductivity 413 W/m k.**
- **Corrosive resistance.**
- **To improve its conductivity and strength at high temperature it is alloyed with Cr, Nb, Zr**(L. Ellis 2005)**.**



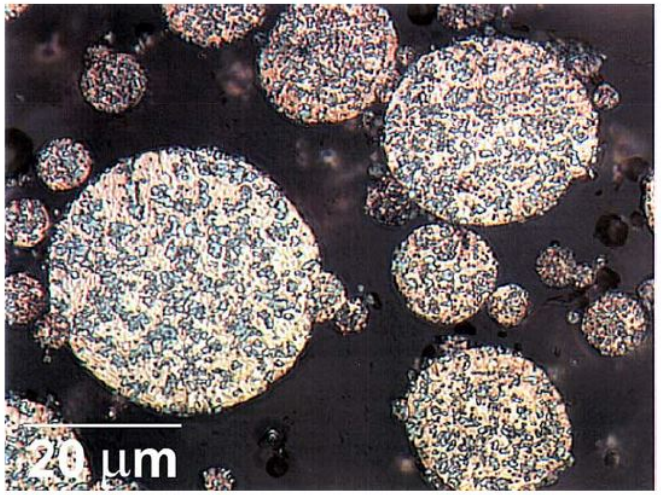

| Alloy | Cr | Nb | Zr | Al | O | Ag |
|---|---|---|---|---|---|---|
| GRCop-84 | 6.65 | 5.85 | | | | |
| AMZIRC (C15000) | | | 0.15 | | | |
| GlidCop Al-15 (C15715) | | | | 0.15 | 0.17 | |
| Cu-0.9Cr (C18200) | 0.9 | | | | | |
| Cu-1Cr-0.1Zr (C18150) | 1.0 | | 0.1 | | | |
| NARloy-Z | | | 0.5 | | | 3.0 |

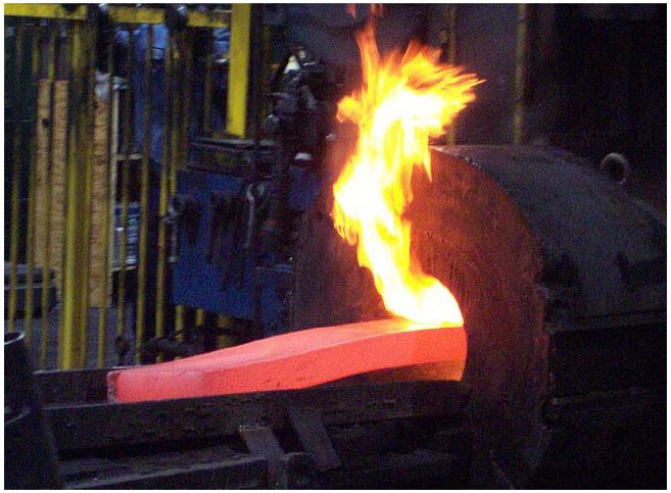
(De Groh, L. Ellis et al. 2008)



# GRCop-84

- **Cu-8Cr-4Nb** is developed by researchers at **NASA's Glenn Research Center** in the 1990's (M.v.Nathal).
- GRCop-84 is most commonly produced in powdered form via **argon gas atomization**.
- **Corrosion resistant** because of Cr and Nb oxide below Cu oxide .
- **Rapid solidification** processes must be used with the material to prevent $Cr_2Nb$ precipitates from growing in size during solidification (L. Ellis 2005).
- **Conventional casting** results in $Cr_2Nb$ precipitates that grow to well over 1 cm in diameter during slow cooling (L. Ellis 2005).



**GRCop-84 extruded from powder. (L. Ellis 2005)**

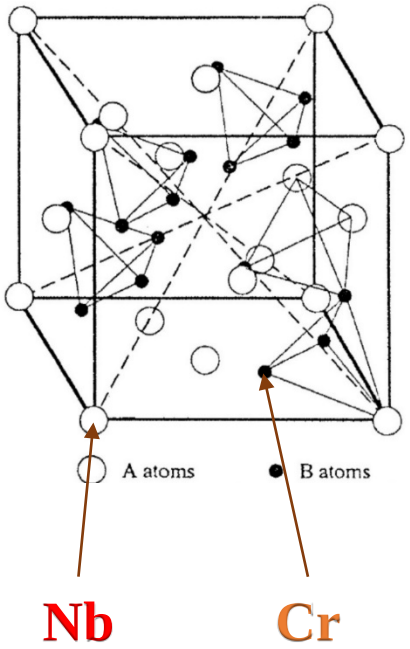
# Properties of GRCop-84

| ALLOY COMPOSITION | | PHYSICAL & MECHANICAL PROPERTIES | |
|---|---|---|---|
| **Component** | **At. %** | Yield Strength 150K | 275MPa |
| | | Yield Strength 1000K | 40MPa |
| Cu | 88% | UTS 150K | 575MPa |
| Cr | 8% | UTS 1000K | 40MPa |
| Nb | 4% | Elongation 150K | 20% |
| | | Elongation 1000K | 20% |
| | | Thermal conductivity 150K | 270 W/mK |
| | | Thermal conductivity 1000K | 290 W/mK |
| | | Electrical resistivity 150K | 1.2 μΩ.cm |
| | | Electrical resistivity 500K | 3.5μΩ.cm |

(MAHALE)

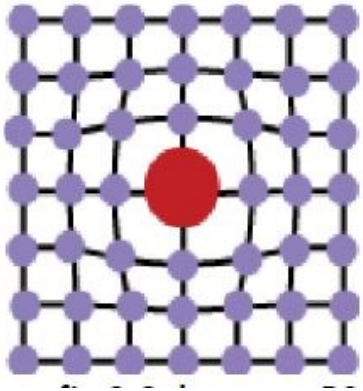
# $Cr_2Nb$ Precipitate

## C15 Laves phase

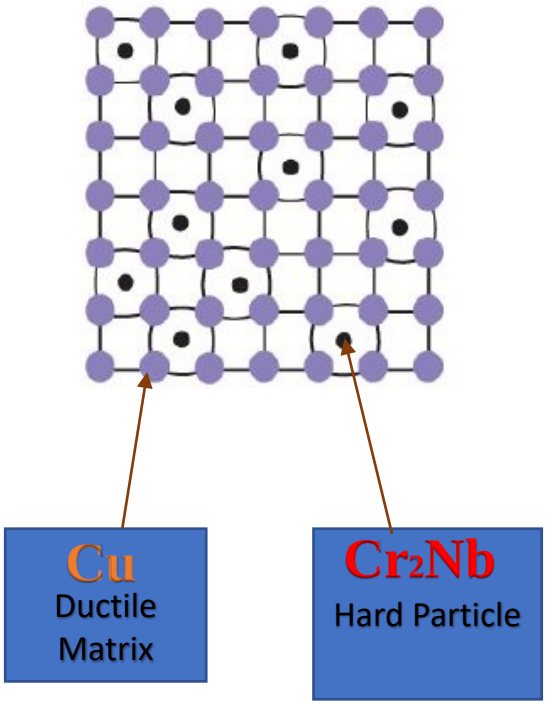



(A. Kellou1)

## Precipitation strengthening



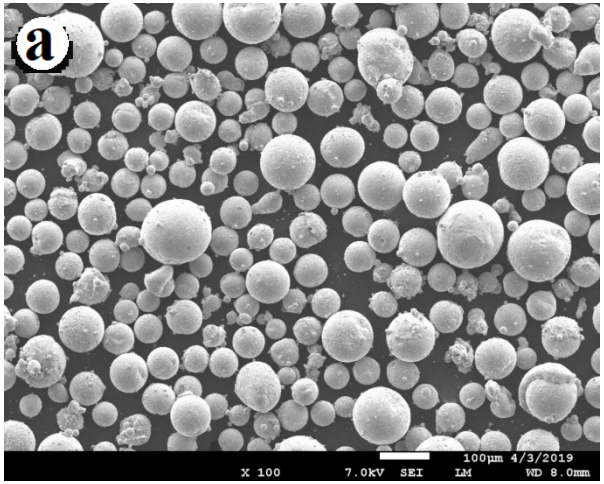
## Dispersion strengthening[3]

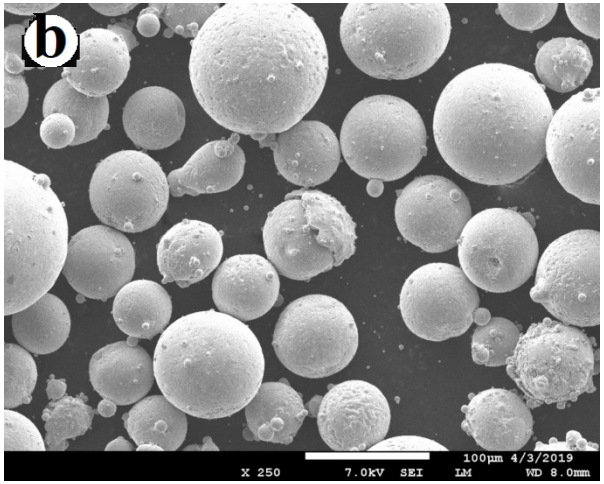


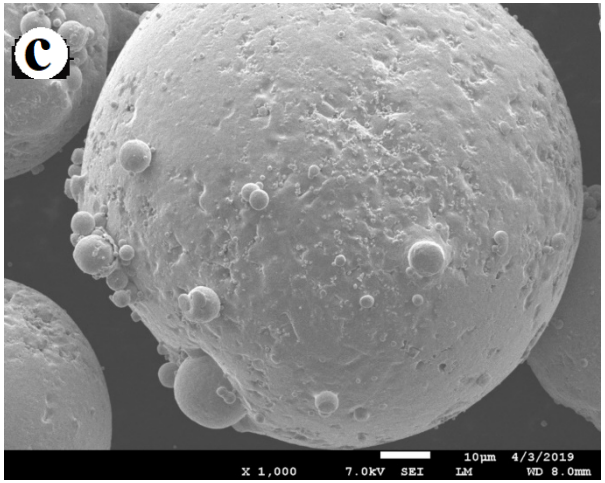
# Objective

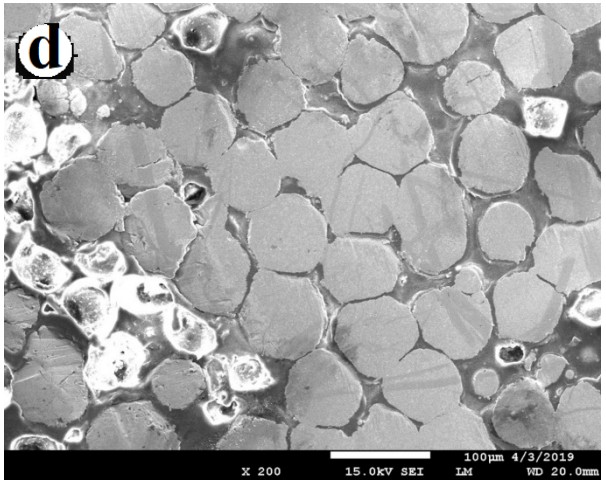
- **To develop parameters for defect free and 100 % dense deposition of GRCop-84 using laser metal deposition process.**
- **Investigate the microstructural properties of the LMD GRCop-84 samples.**
- **Determining the mechanical properties of LMD GRCop-84 sample.**

# Powder Morphology of GRCop-84




**Company – Powder alloy corporation**

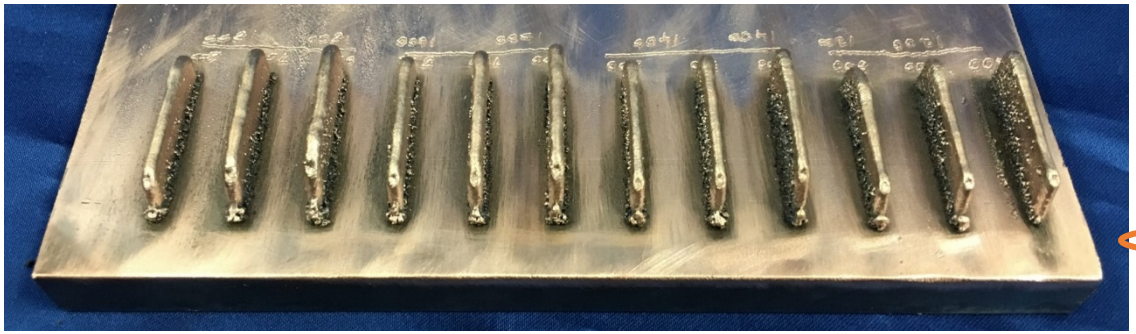
**Mesh Size -140/+325**
**Particle Size: 45 µm – 105 µm**

**Chemical Composition in At.%**

| | Cu | Cr | Nb |
|---|---|---|---|
| GRCop-84 | Bal. | 6.7 | 5.6 |

**GRCop-84 gas atomized powder.**

# Laser Metal Deposition of GRCop-84

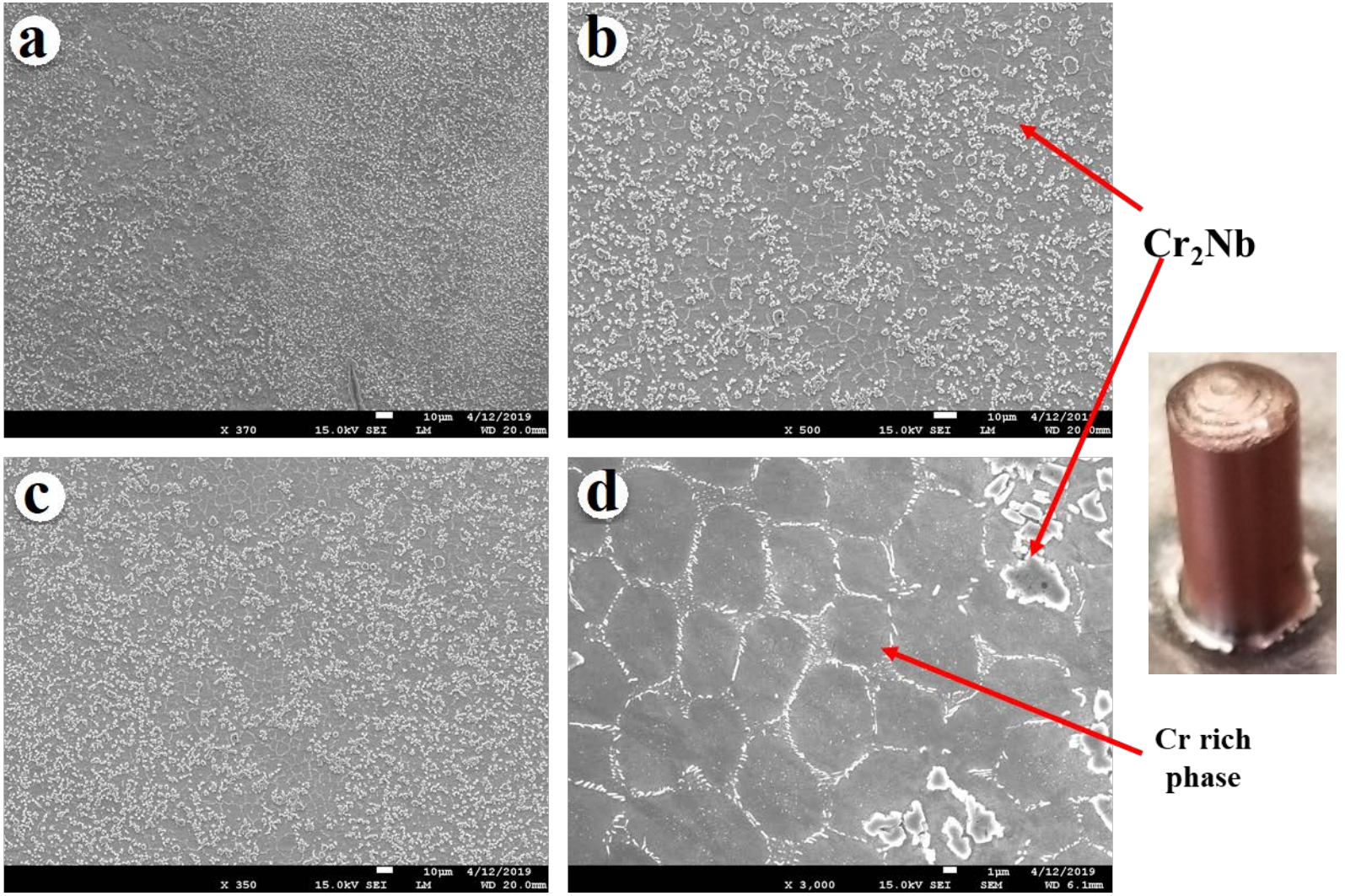


**30 mm x 10 mm GRCop-84 coupons with different process parameters as shown in table deposited on a copper substrate.**

- **Beam Diameter (2 mm)**

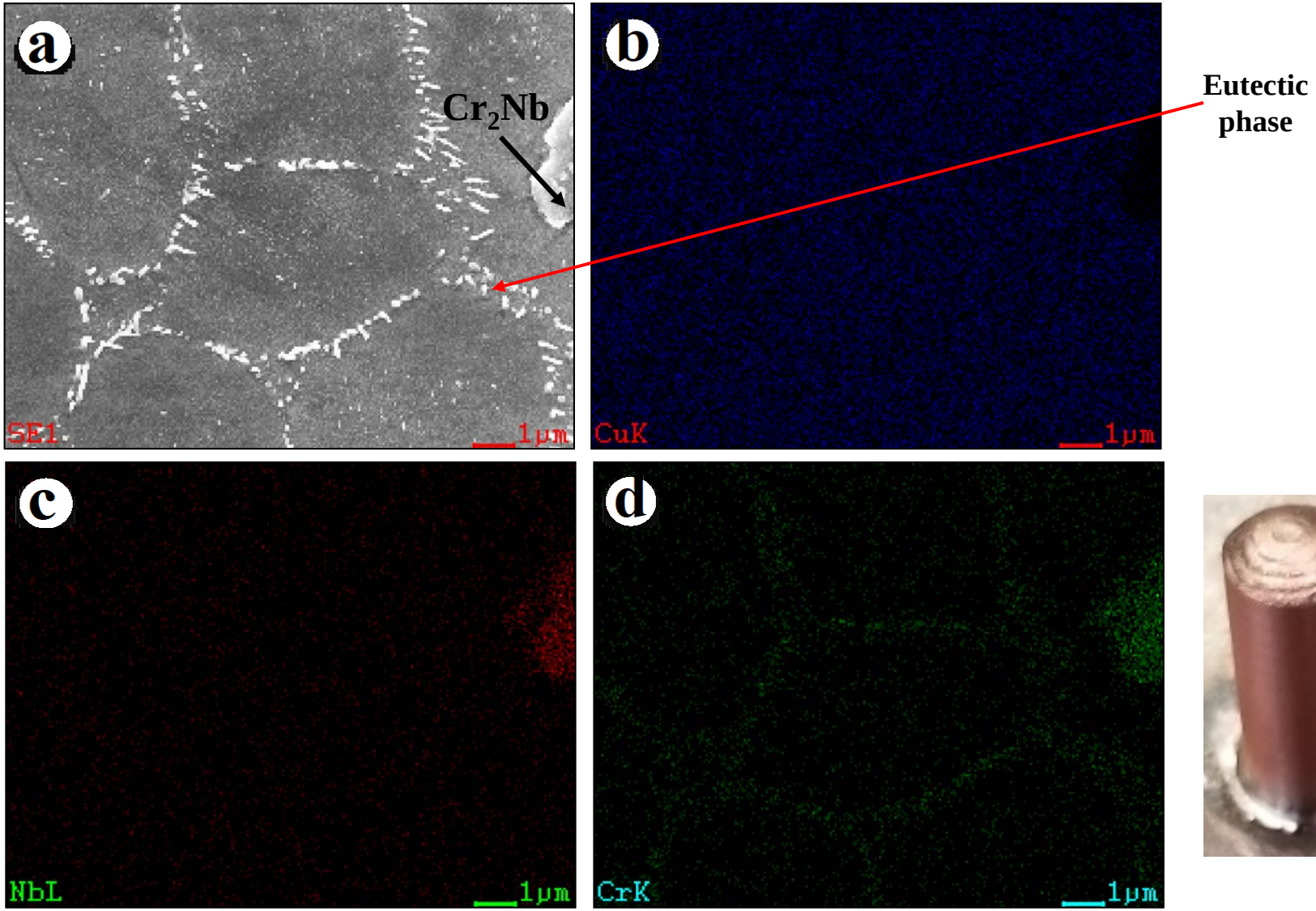
| Sample Number | Laser Power (W) | Travel Speed (mm/min) | Powder Feed (g/min) | Porosity % |
|---|---|---|---|---|
| 1 | 1200 | 600 | 12 | 0.21467 |
| 2 | 1200 | 700 | 12 | 0.21233 |
| 3 | 1200 | 800 | 12 | 0.118 |
| 4 | 1400 | 600 | 12 | 0.0433 |
| 5 | 1400 | 700 | 12 | 0.096 |
| 6 | 1400 | 800 | 12 | 0.112 |
| 7 | 1600 | 600 | 12 | 0. 04095 |
| 8 | 1600 | 700 | 12 | 0.059 |
| 9 | 1600 | 800 | 12 | 0.09267 |
| 10 | 1800 | 600 | 12 | 0.082 |
| 11 | 1800 | 700 | 12 | 0.02167 |
| 12 | 1800 | 800 | 12 | 0.0303 |

# SEM Investigation of GRCop-84 (Cylinder)




**SEM images of as-deposited GRCop-84 cylinder sample. (a) $Cr_2Nb$ precipitates in pure copper matrix with different particle sizes due to different local cooling rate, (b), (c) $Cr_2Nb$, (d) eutectic Cr particles along the interdendritic boundaries.**

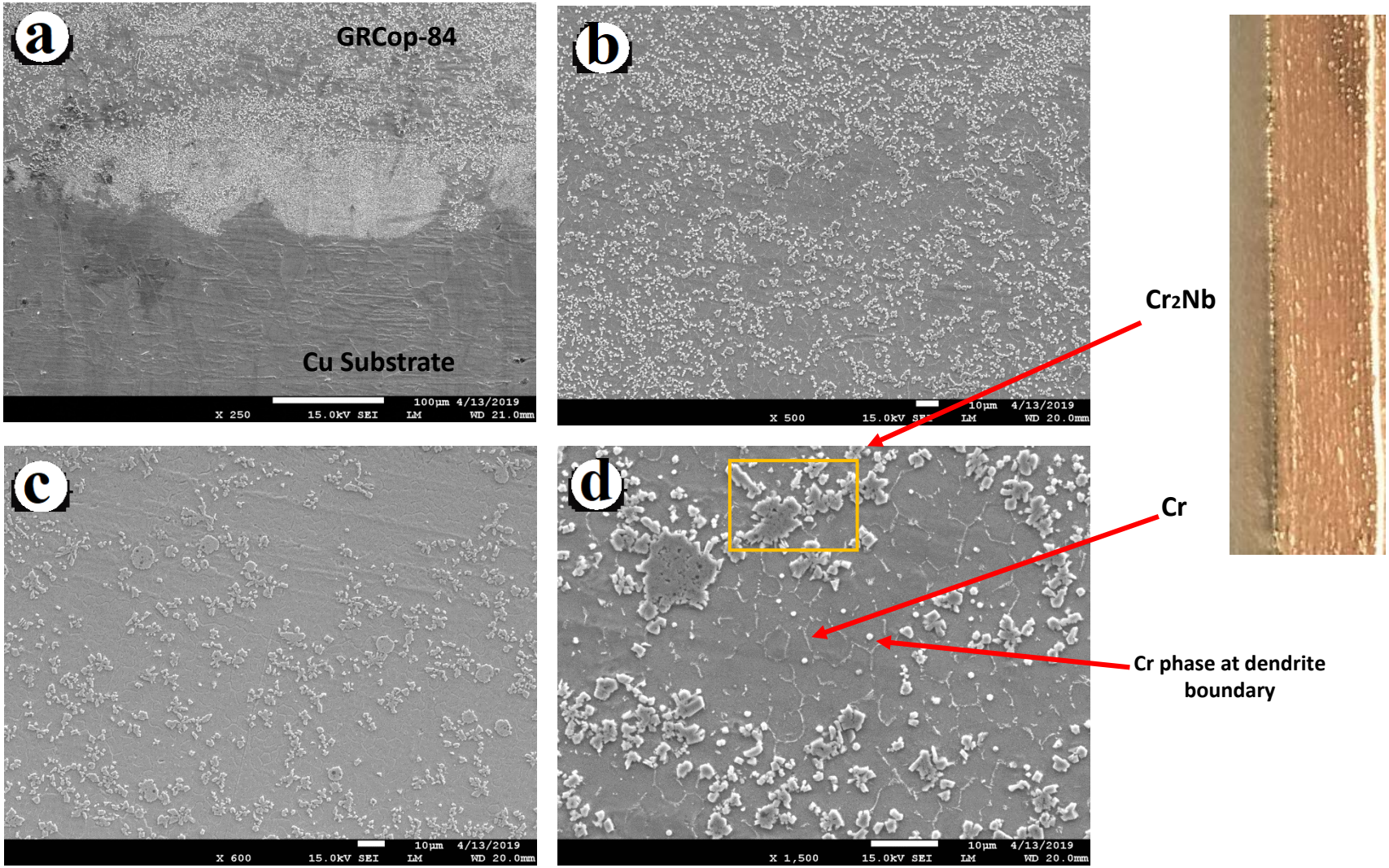
# EDS Investigation of GRCop-84 (Cylinder)





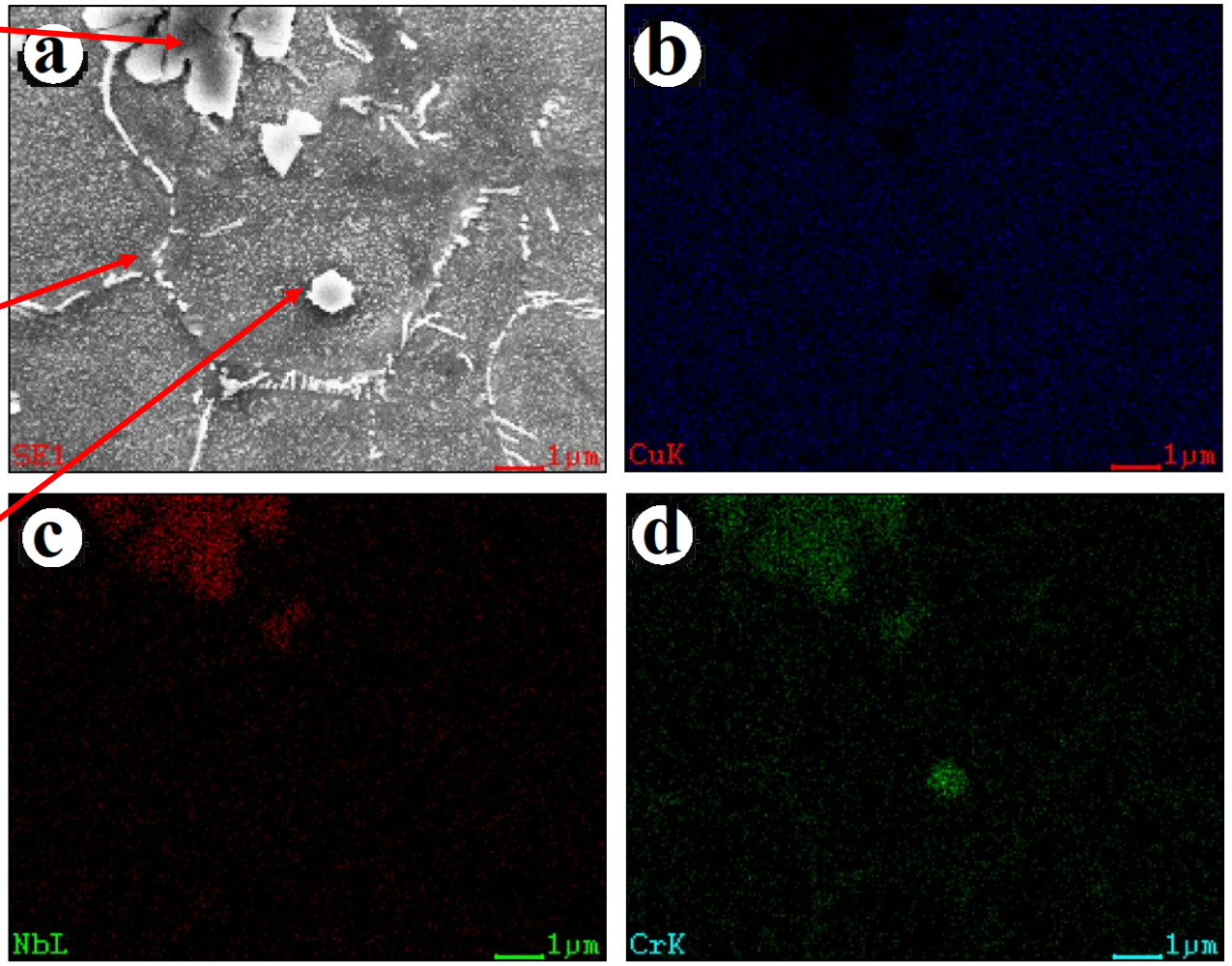

**EDS map of the as-deposited GRCop-84 cylinder sample. (a) eutectic Cr particles along the interdendritic boundaries, (b) Cr, (c) Nb, and , (d) Cr distribution.**

# SEM Investigation of GRCop-84 (Single Wall)



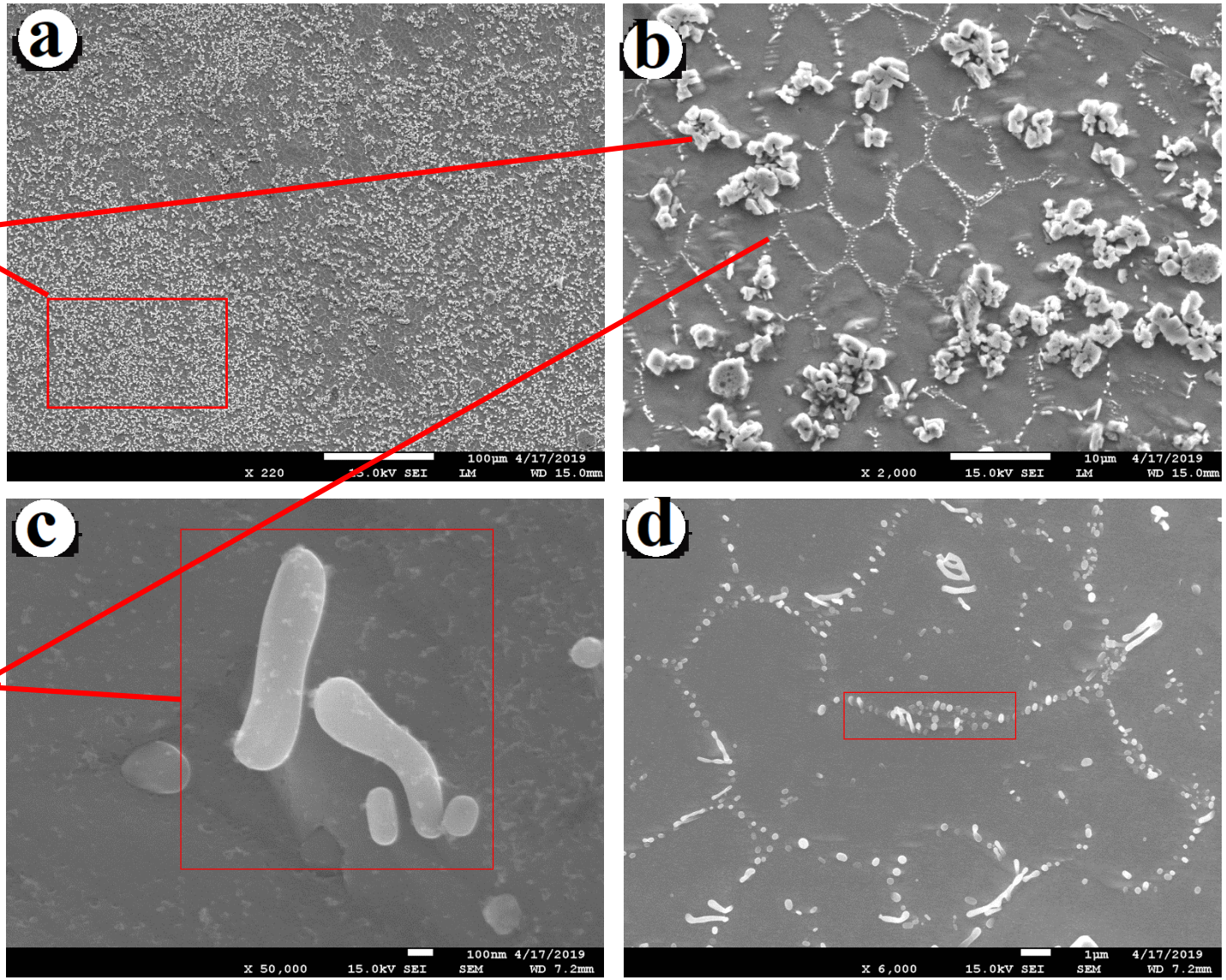

**SEM images of the as-deposited GRCop-84 single wall sample. (a) Copper substrate and GRCop-84 transition region, (b) $Cr_2Nb$ precipitate, (c) $Cr_2Nb$ precipitates in this sample are less dense in region where there is segregation of Cr particle along dendrite boundaries, (d) Cr rich phase particles.**

# EDS Investigation of GRCop-84 (Single Wall)



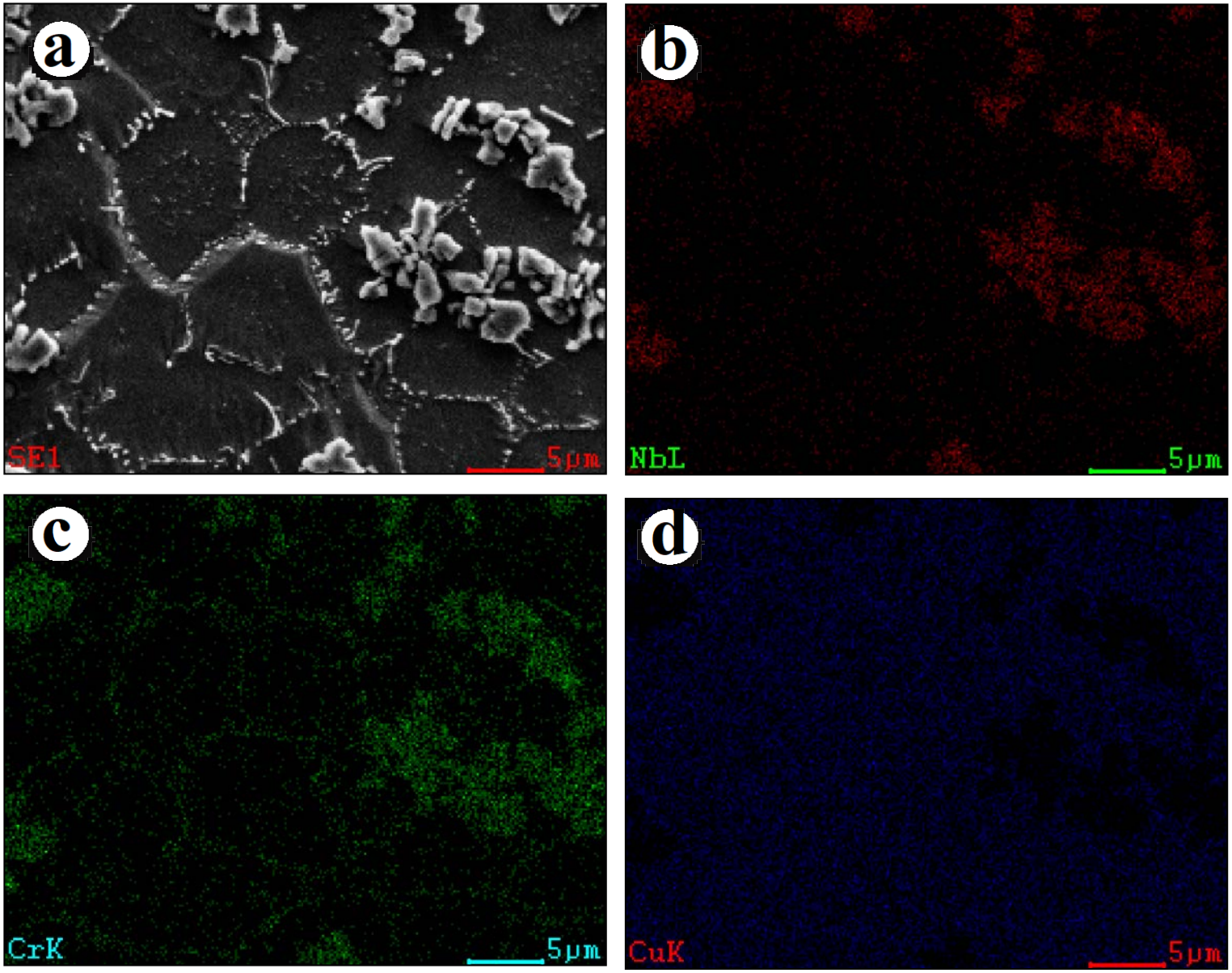

**EDS map of the as-deposited GRCop-84 single wall sample (a) Bright and spherical Cr phase, (b) Cr, (c) Nb, and , (d) Cr distribution.**

# SEM of Heat-Treated (800 $^{o}$C/1h) GRCop-84



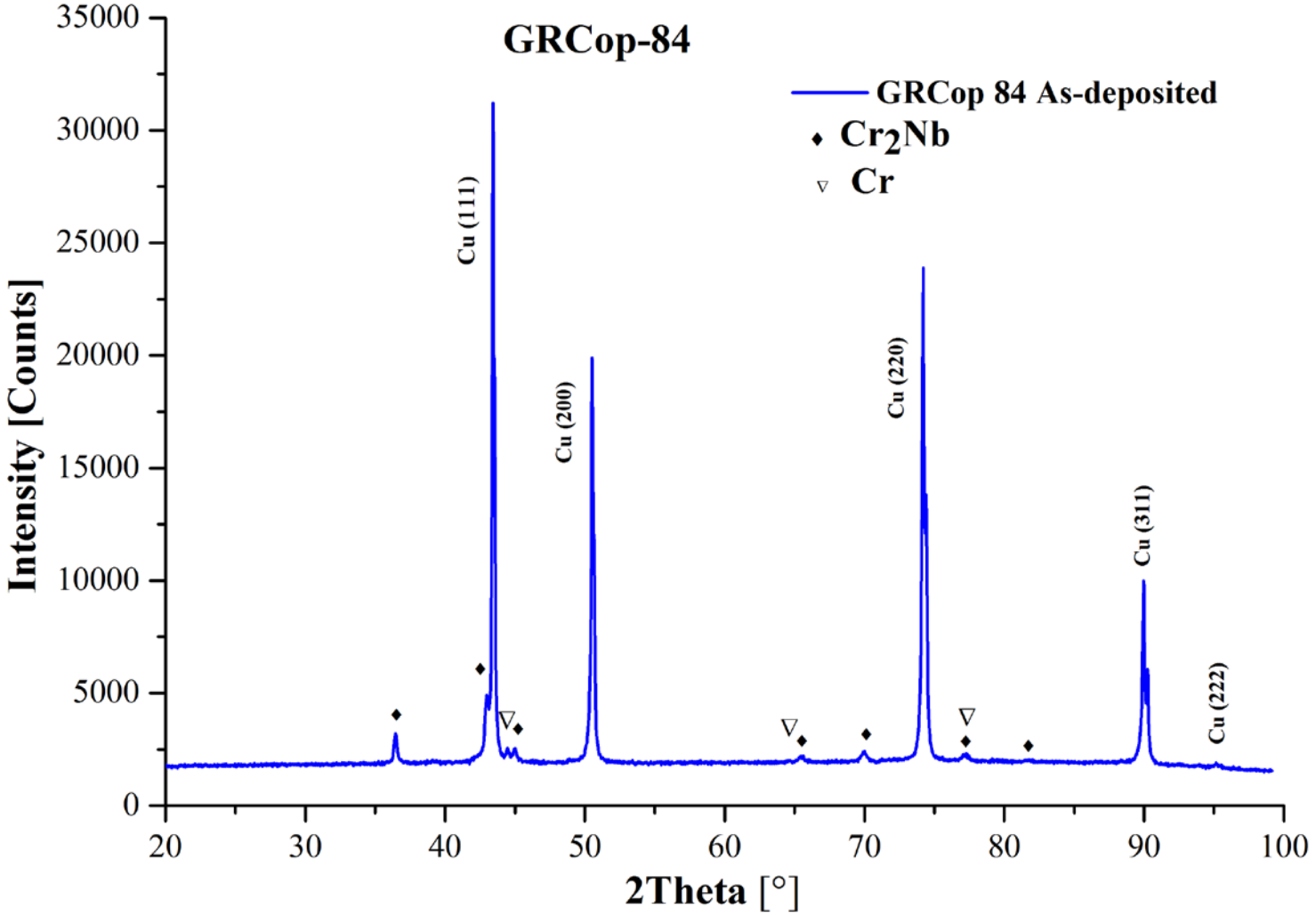

**SEM micrographs of the heat-treated GRCop-84 cylinder sample**

# EDS of Heat-treated (800 °C/1h) GRCop-84



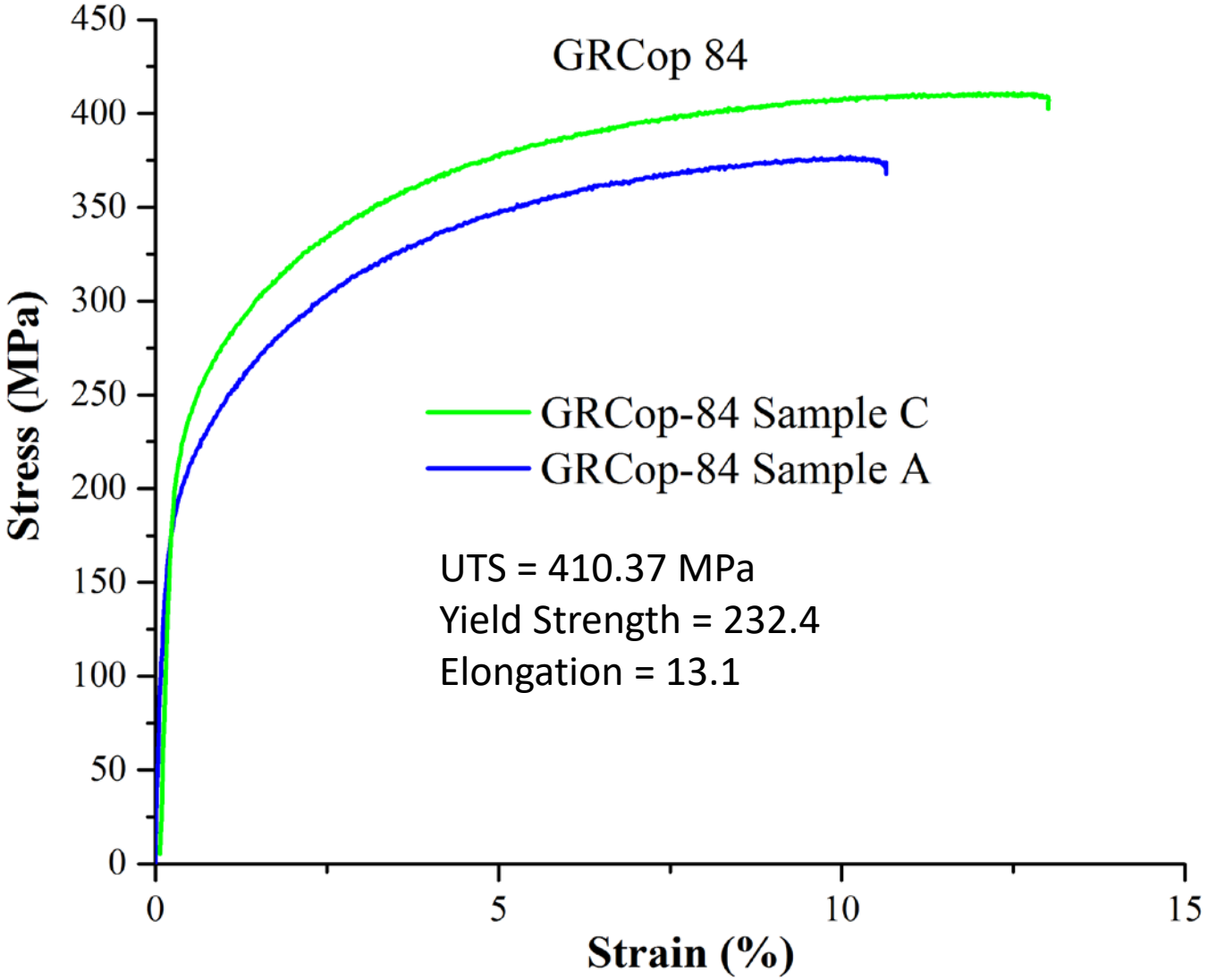

**EDS map of the heat-treated GRCop-84 cylinder sample**

# GRCop-84 X-Ray Diffraction




**XRD plot of the GRCop-84 as-deposited sample.**

# GRCop-84 Tension Test




**Stress vs Strain plot of as-deposited GRCop-84 samples.**

# Conclusion

- **The present investigation demonstrates that GRCop-84 can be successfully fabricated using laser metal deposition techniques.**
- **It is observed that there is no porosity in the as-deposited samples.**
- **SEM and EDS investigation revealed the presence of $Cr_2Nb$ precipitates in the copper matrix.**
- **Cr eutectic particles are observed in the as-deposited and heat treated sample at the dendrite boundary.**
- **There is a decline in the segregation of $Cr_2Nb$ precipitates in the region where Cr particles present at the interdendritic region.**

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# Thank You!