

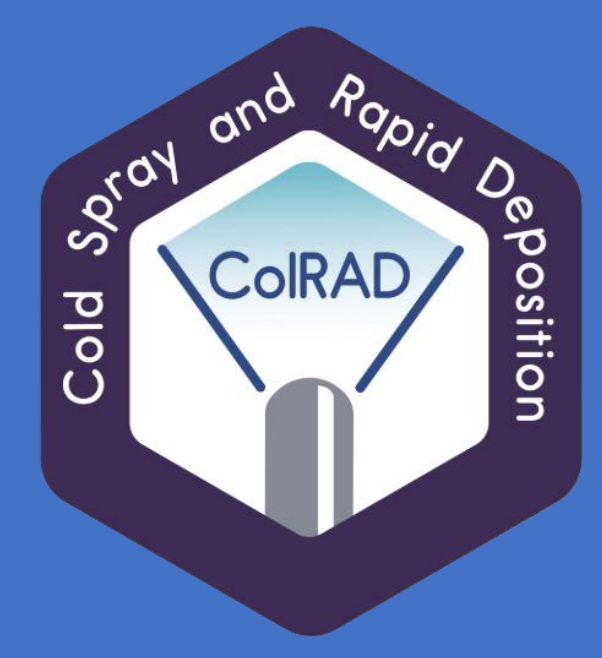
# Thermodynamics and Isochronal Crystallization Kinetics of Poly(ether-ether-ketone)-Boron Nitride Nanoplatelets Structural Layers via Cold Spray Additive Manufacturing



## Nanoplatelets Structural Layers via Cold Spray Additive Manufacturing

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### INTRODUCTION & MOTIVATION

- Polymer coatings support **stealth fighter jets** reduce radar detection.
- PEEK offers high-temperature stability, strength, and chemical resistance.
- Lightweight & corrosion resistant.



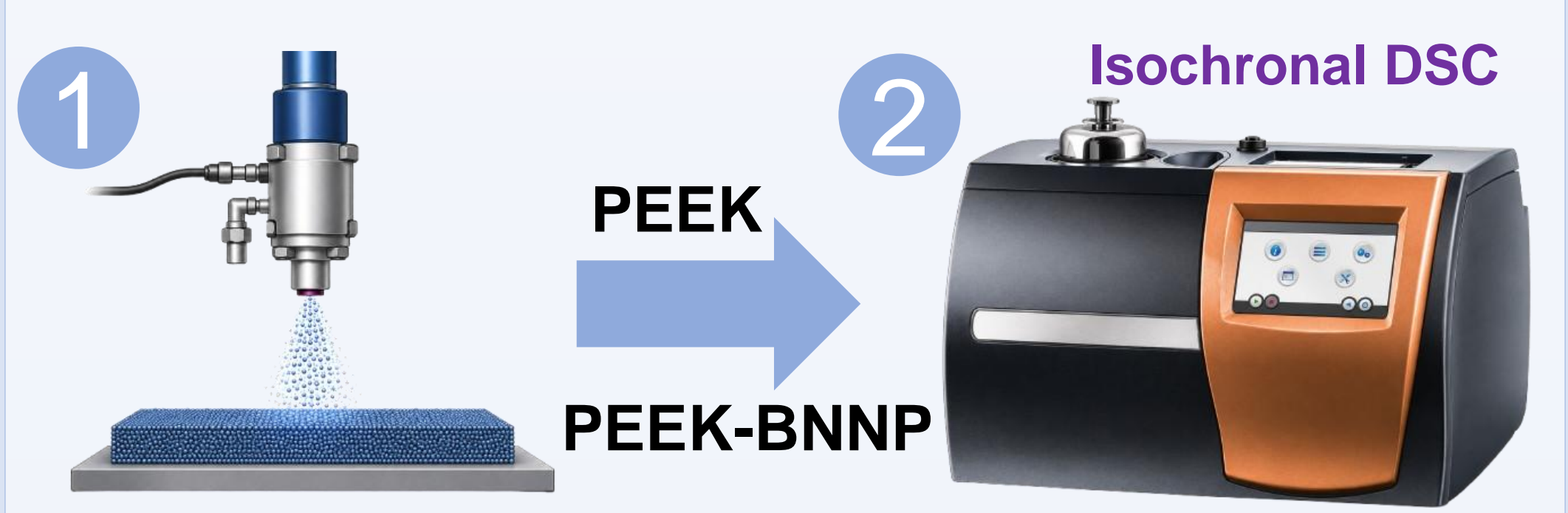
### Challenges

- PEEK has Limited thermal conductivity and stiffness in extreme environment.
- Existing repair methods employ high thermal energy that can cause melting or degradation of polymers.

### Solutions

- Cold spray for solid-state route deposition and repairing without melting or degradation.
- BNNP reinforcement for improved properties.
- Fundamental crystallization analysis to tailor process-structure-property relationship.

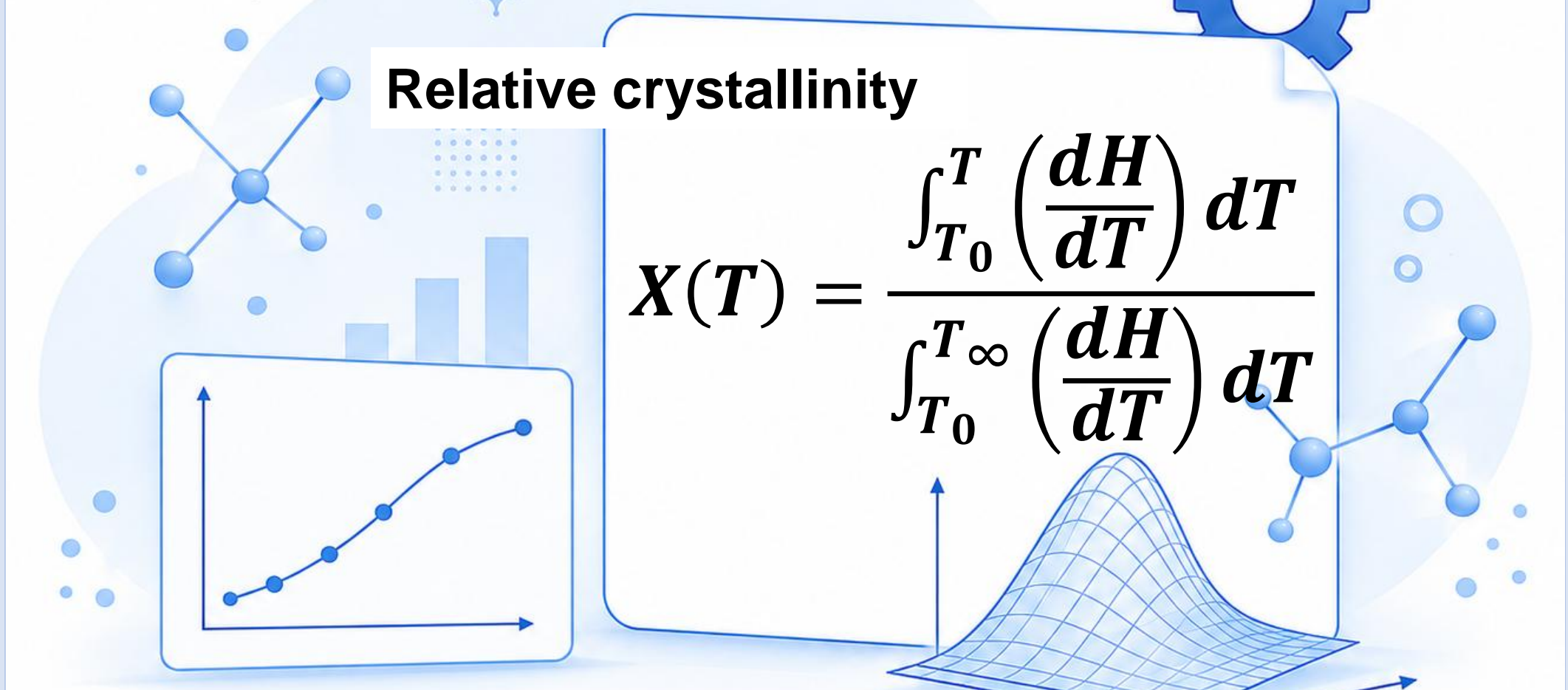
### MATERIALS AND METHODS



- Cold spray structural layers**
- Low pressure system
- Carrier gas; compressed air
- Gas temperature; 350 °C
- Pressure; 6 Bar

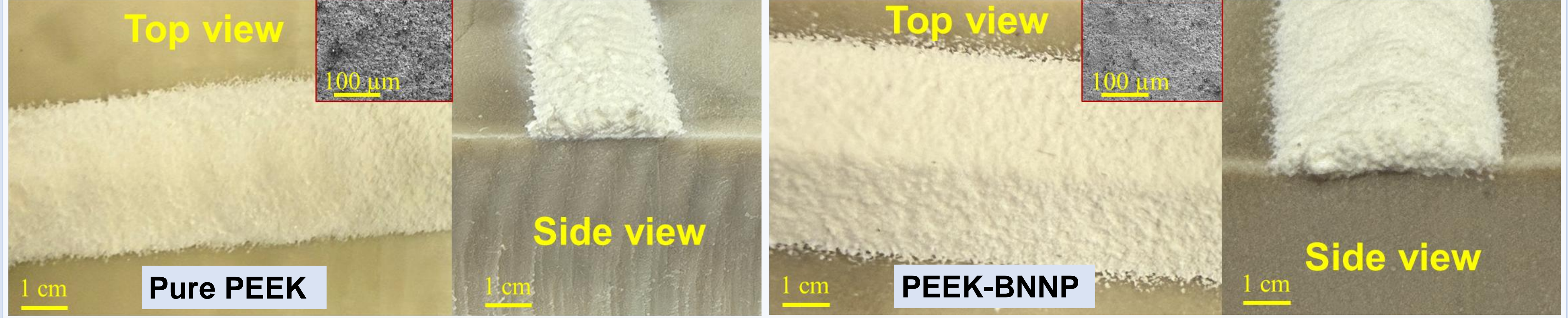
3 X-ray diffraction → Crystalline phase development

4 Fundamental crystallization analysis



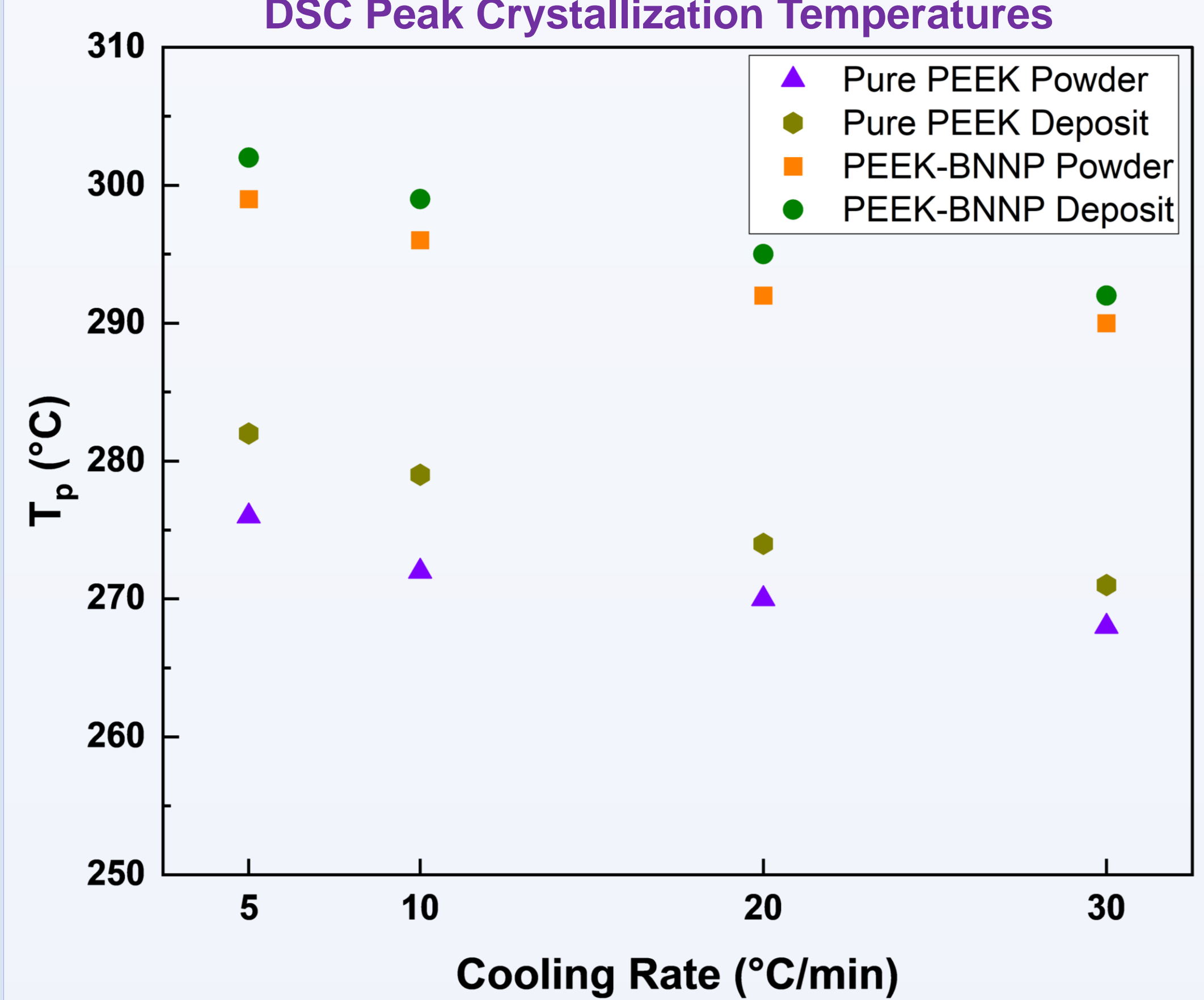
- Jeziorny Modified Avrami Model** - Nucleation and growth mechanism
- Ozawa Model** - Crystal growth mechanism
- Mo's Combined Model** - Combined kinetic response

### RESULTS AND DISCUSSION

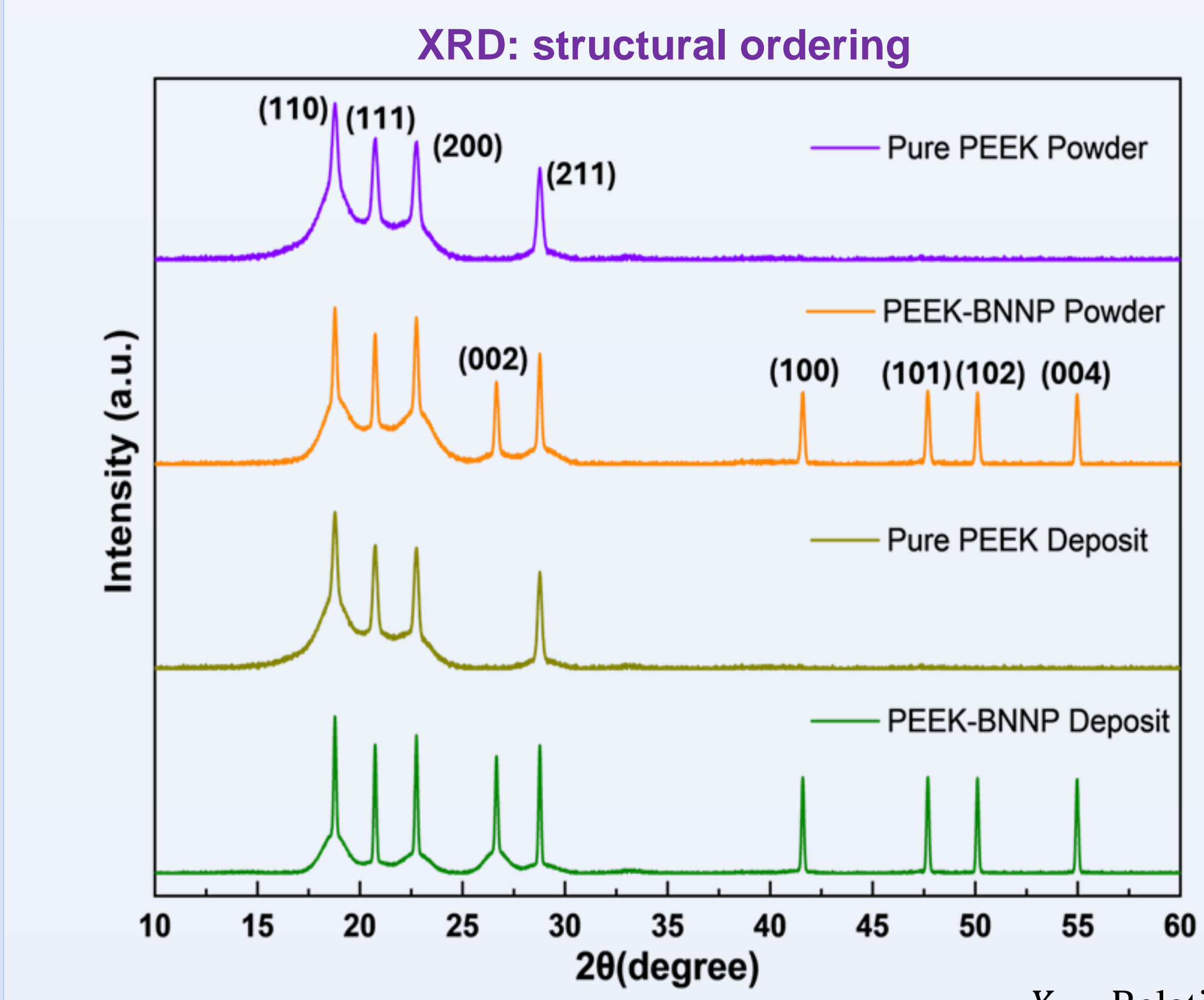


- Continuous ~2 mm thick structural layers.
- Continuous ~3.5 mm thick structural layers.

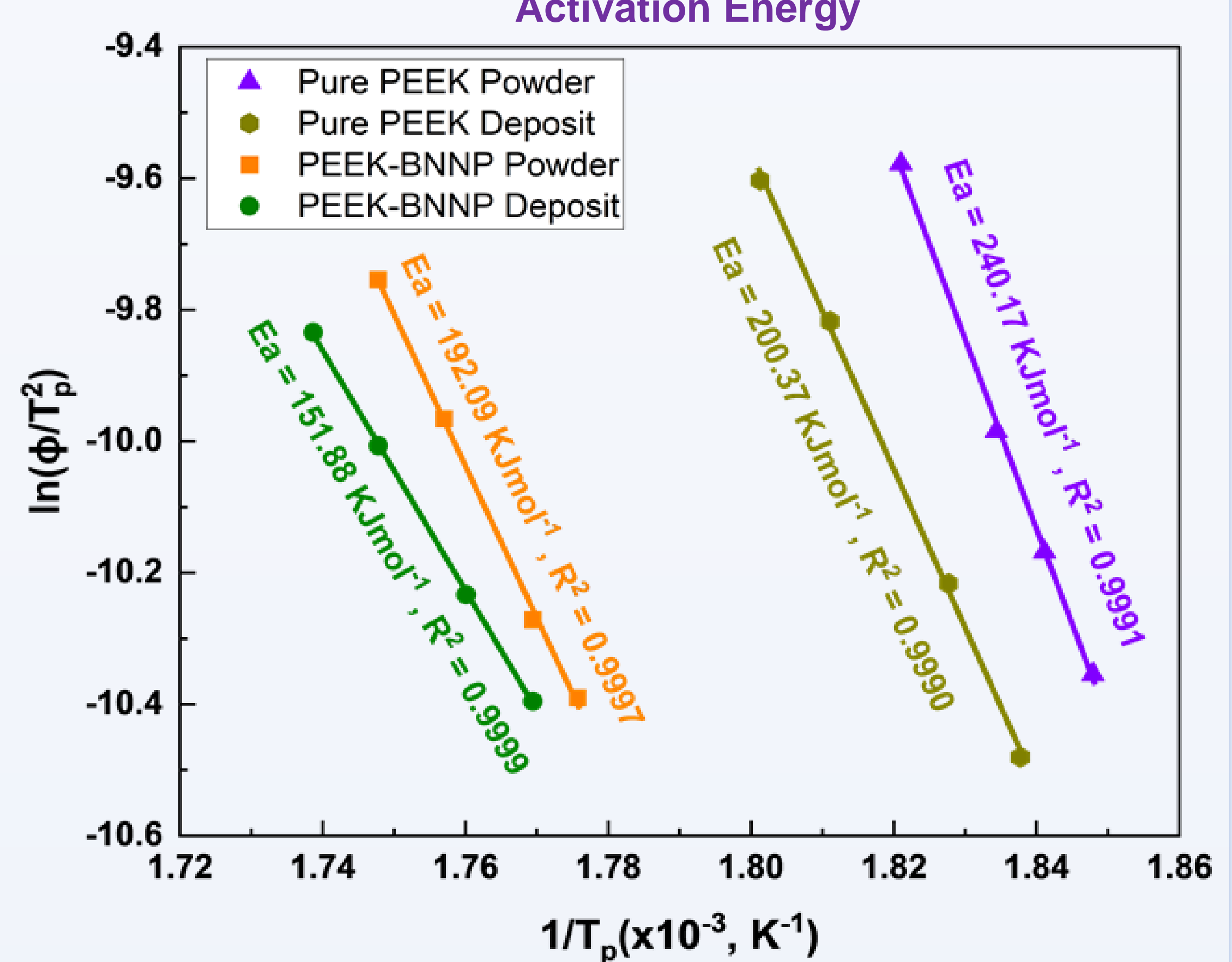
### Crystallization Progression



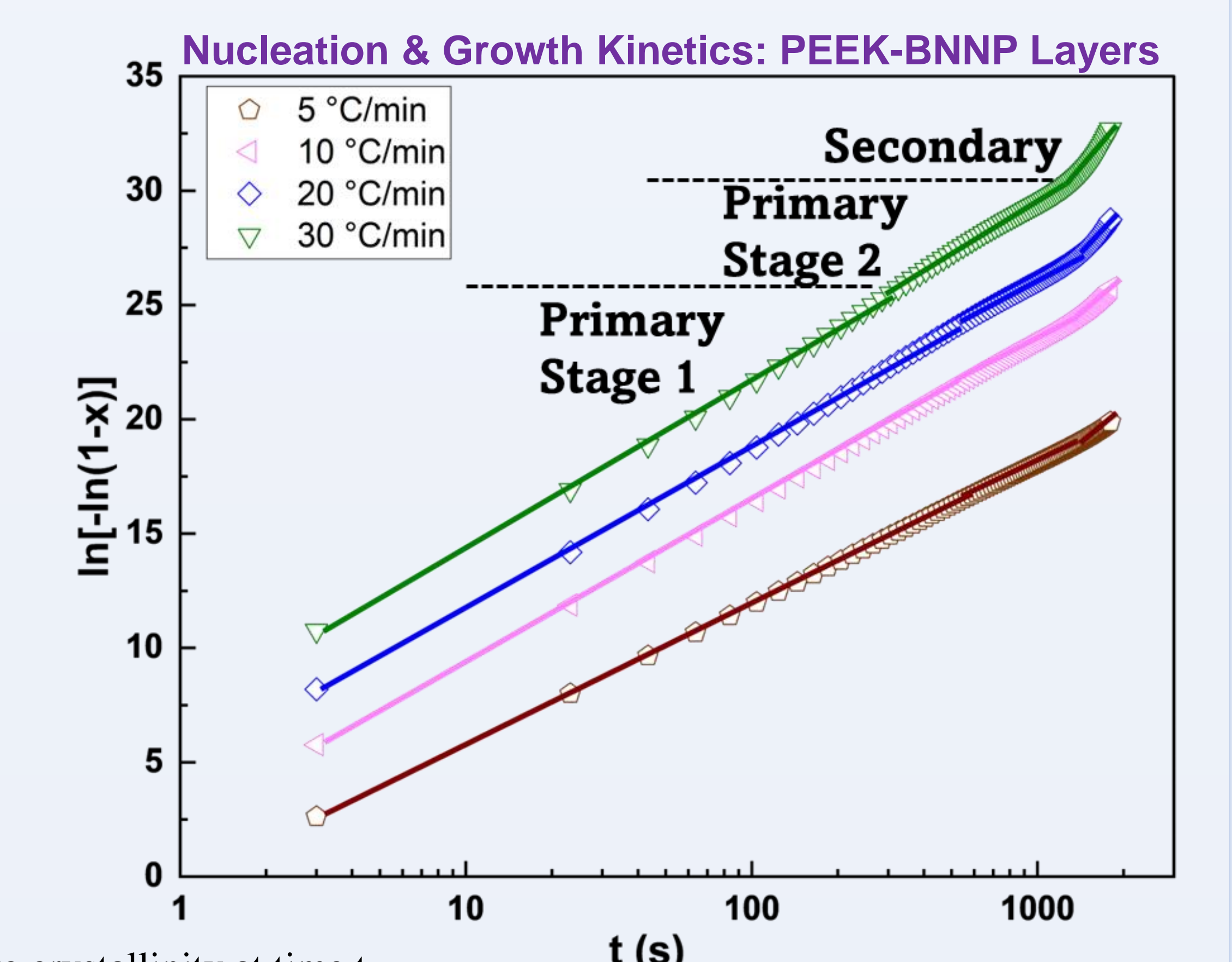
- The combined **cold spray and BNNP effect reduced the activation energy by 37%** compared with pristine PEEK powder.
- XRD confirmed cold spray induced crystallization and BNNP addition increased crystallization by ~32%.
- No phase transformation** in PEEK & PEEK-BNNP, as all samples retained the characteristic PEEK and BN crystalline phase.



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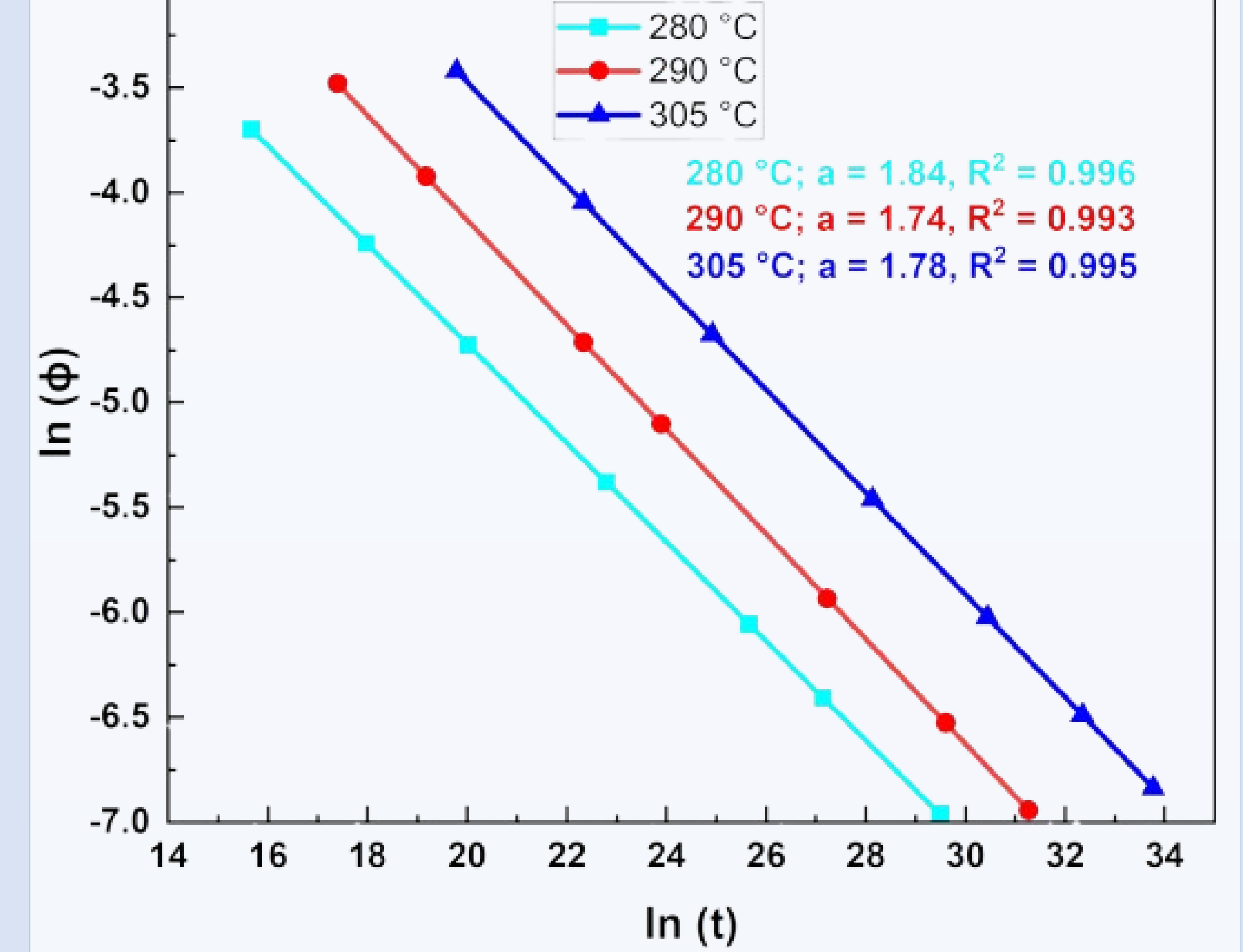


$X$  = Relative crystallinity at time  $t$   
 $Z$  = Crystallization rate constant  
 $t$  = Time,  $T$  = Temperature  
 $\Phi$  = Cooling rate  
 $m$  = Ozawa exponent  
 $K$  = Crystallization function

**Jeziorny Modified Avrami Model**  

$$\ln[-\ln(1-X(t))] = \ln Z_c + n \ln t$$

### PEEK-BNNP Layers: Growth Dimensionality



Ozawa Model  

$$\ln[-\ln(1-X(T))] = \ln K(T) - m \ln \phi$$

Mo's Model  

$$\ln \beta = \ln F(T) - \alpha \ln t$$

### CONCLUSION

- A low pressure cold spray system was used to **successfully deposit** PEEK and PEEK-BNNP structural layers for advanced engineering applications.
- Cold spray strain and nanoplatelet nucleation support significantly transform crystallization from passive thermal relaxation into a mechanically activated kinetic process by **37%**.
- Impact-induced deformation during **cold spray strengthens crystalline order** by **32%**. This promotes mechanical and thermal properties needed in aerospace, automotive and marine applications.
- Thermodynamic-kinetic control of **crystallization provides** a direct pathway for application-driven **cold spray additive manufacturing** of high-performance polymers and composites with tailored layer organization for **extreme environmental applications**.

### REFERENCES

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- Svoboda, R., & Machotová, J. (2025). Polymer crystallization: Universal macroscopic description via the autocatalytic Hoffman–Lauritzen approach. *ACS Omega*, 10, 16602–16619.

### ACKNOWLEDGEMENT

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