



**HEXAGON**

# **Resistance welding simulation of a thermoplastic composite Lap Shear Coupon**

Presented by **Hexagon**

**Digital Materials Tech Day (September 12, 2024)**

Work Supported by **NASA**

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# Acronyms

- **DSC:** Differential scanning calorimetry
- **DMA:** Dynamic mechanical analysis
- **GRC:** Glenn Research Center
- **TVE:** Thermo-Viscoelastic
- **Tm:** Melting temperature
- **Tg:** Glass transition temperature
- **H-L:** Hoffman Lauritzen
- **QI:** Quasi-isotropic
- **HTC:** Heat transfer coefficient
- **FEA:** Finite element analysis
- **CPU:** Central processing unit

# Study Objective

## Global objective:

- ❖ Resistance welding process modeling
- ❖ Simulate semi-crystalline thermoplastic material microstructure evolution
- ❖ Predict the welded joint mechanical response after welding
- ❖ Predict the bulk material structural response after welding (thermally induced deformation, etc.)

## Project breakdown:

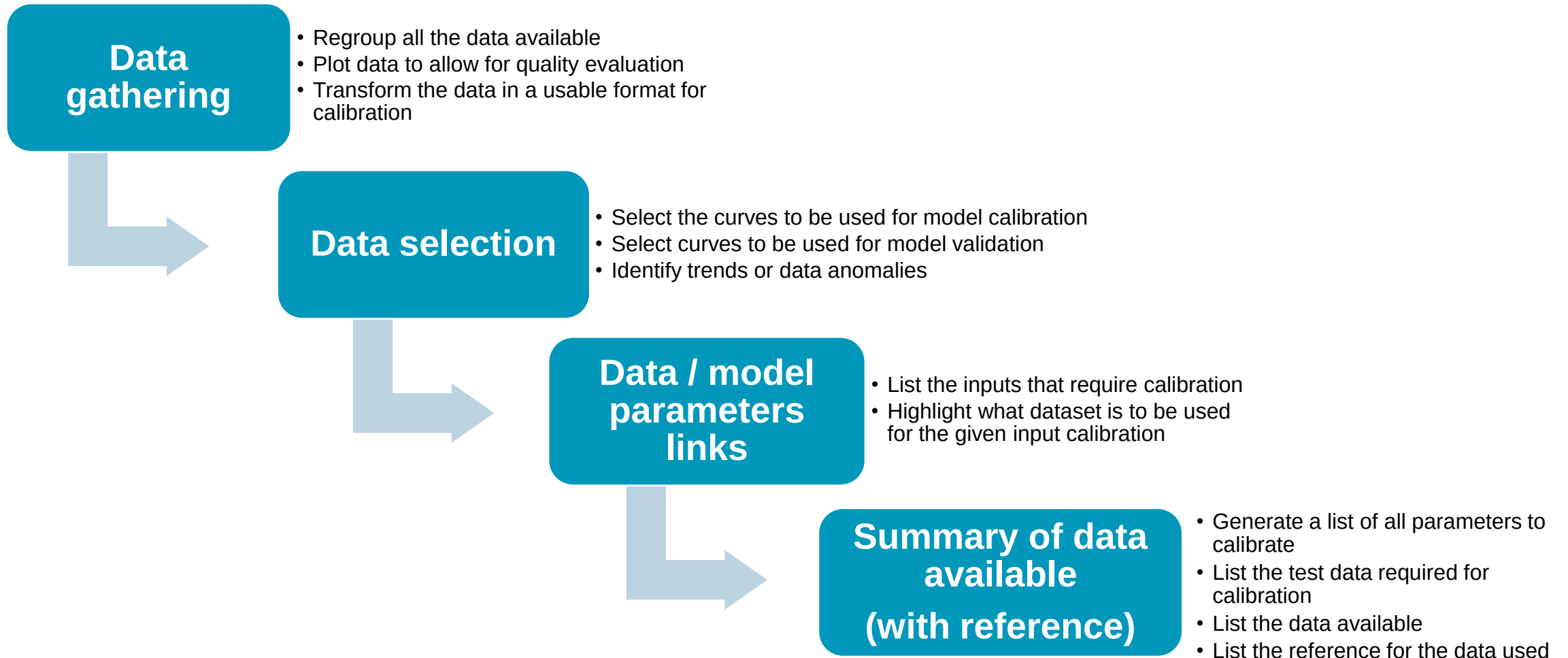
- **Step 1:** Post-Process and analyze the test data available
  - Try to reproduce some of the work performed by Ageorges et al. except for the Consolidation part
  - Assess what data is available in the paper and what data is provided by NASA
- **Step 2:** Calibrate a Digimat crystallinity models
  - Calibrate Crystallization kinetics, Thermal, and Thermo-mechanical behavior (Parameters) using 2 different methods
    - Spreadsheet
    - Script
  - Validate the calibrated model
- **Step 3:** Validate the model at a Coupon Level
  - Creation and simulation of a Current/thermal resistance welding lap-shear coupon
  - Creation and simulation Structural resistance welding lap-shear coupon

## Step 1

*Post-Process and analyze the test data available*

# Step 1 - Post-Process and analyze the test data available

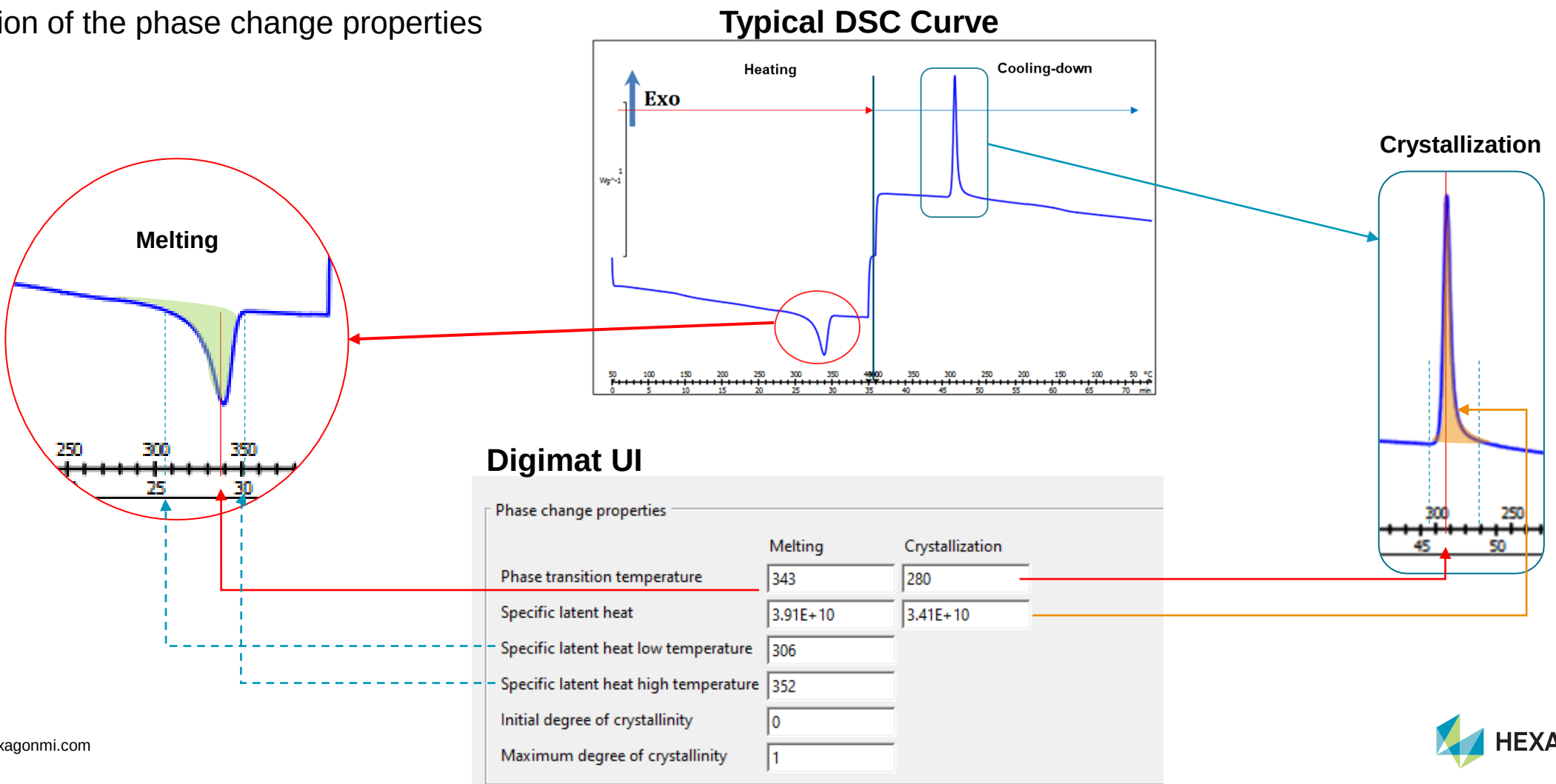
## Workflow



# Differential Scanning Calorimetry (DSC) Data and Connection to Digimat Material Model

## DSC Curve Points of Interest

Definition of the phase change properties



# Conversion of DSC Test Results to Degree of Crystallinity

## DSC Tests – Used for Nakamura model calibration

### Identification of the cure kinetic law

- DSC tests using ASTM-1269-11 on the neat polymer (heat flux computed with respect to the polymer mass)
- Measurement of the Crystallization rate or crystallinity evolution with time to be fitted with the numerical model
- Hoffman Lauritzen or Weibull formulation are both used in this current study

$$\% \text{ Crystallinity} = \frac{[\Delta H]}{\Delta H_c} \cdot 100\%$$

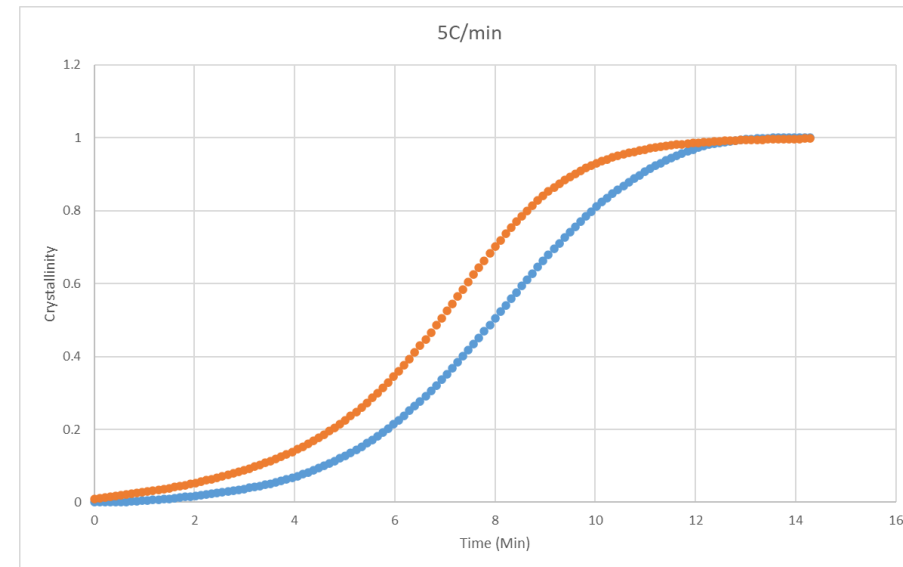
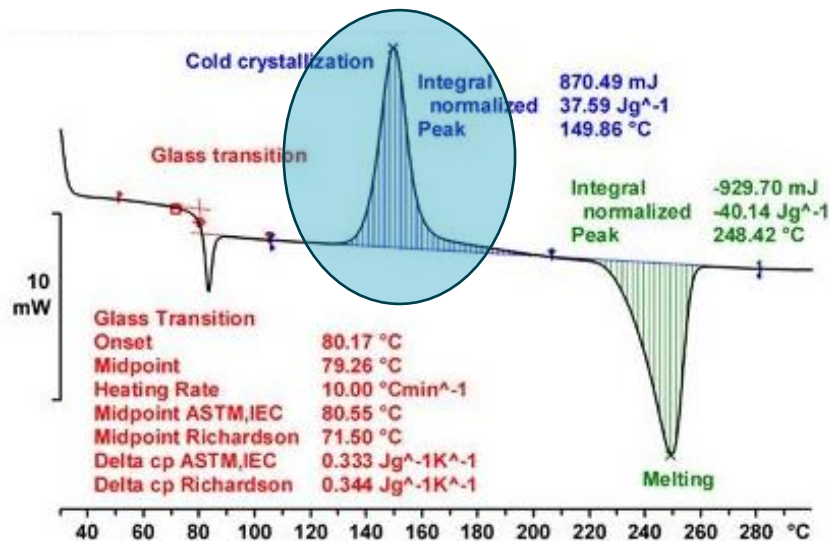


Image taken from

<https://www.surface-science-western.com/analytical-services/differential-scanning-calorimetry-dsc/>

# Curves Selection for Calibration

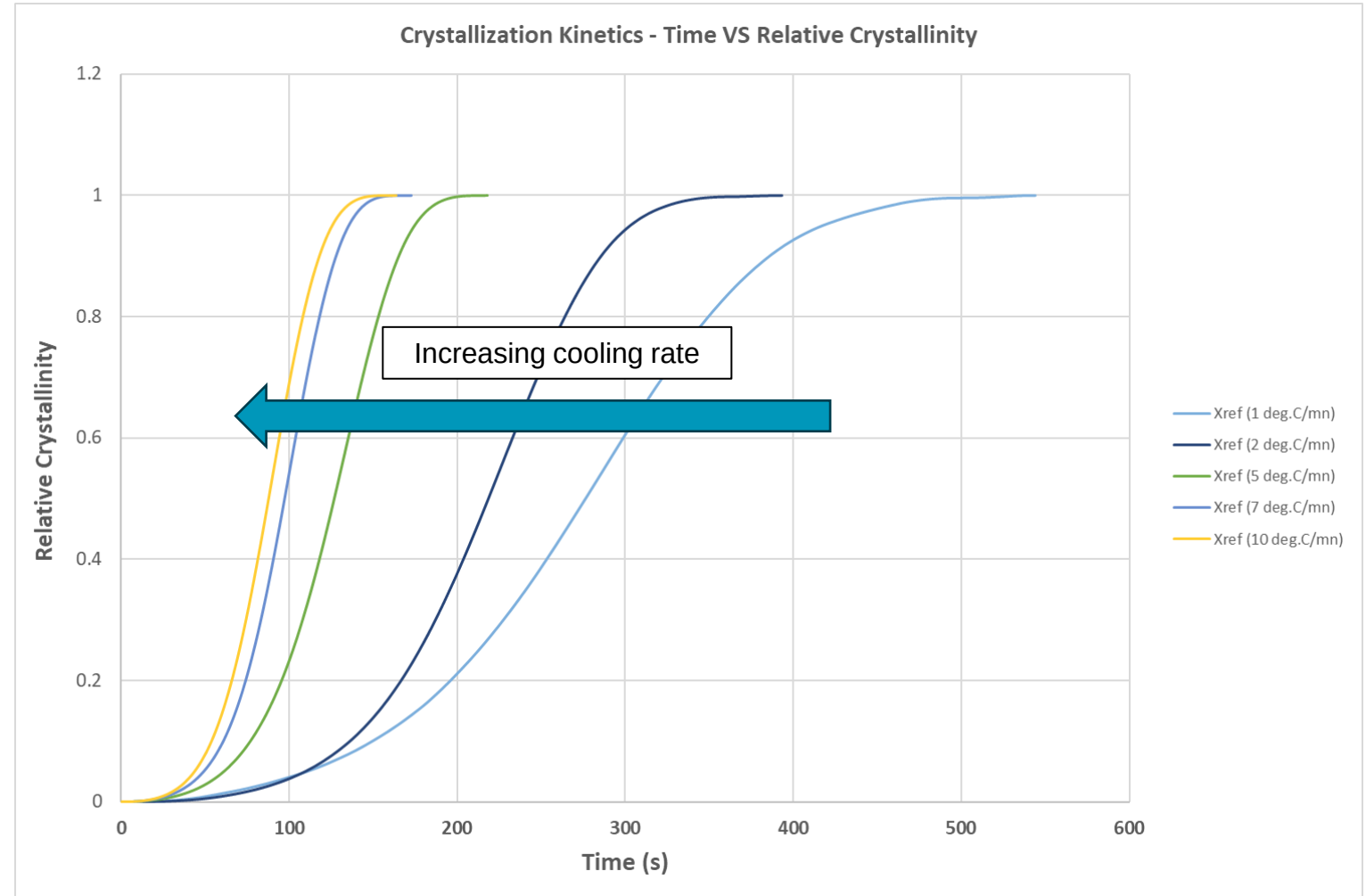
## *Time VS Relative Crystallinity*

### Curve Selection for Calibration:

- 1, 5 and 10 °C/min

### Curve Selection for Validation:

- 2 and 7 °C/min

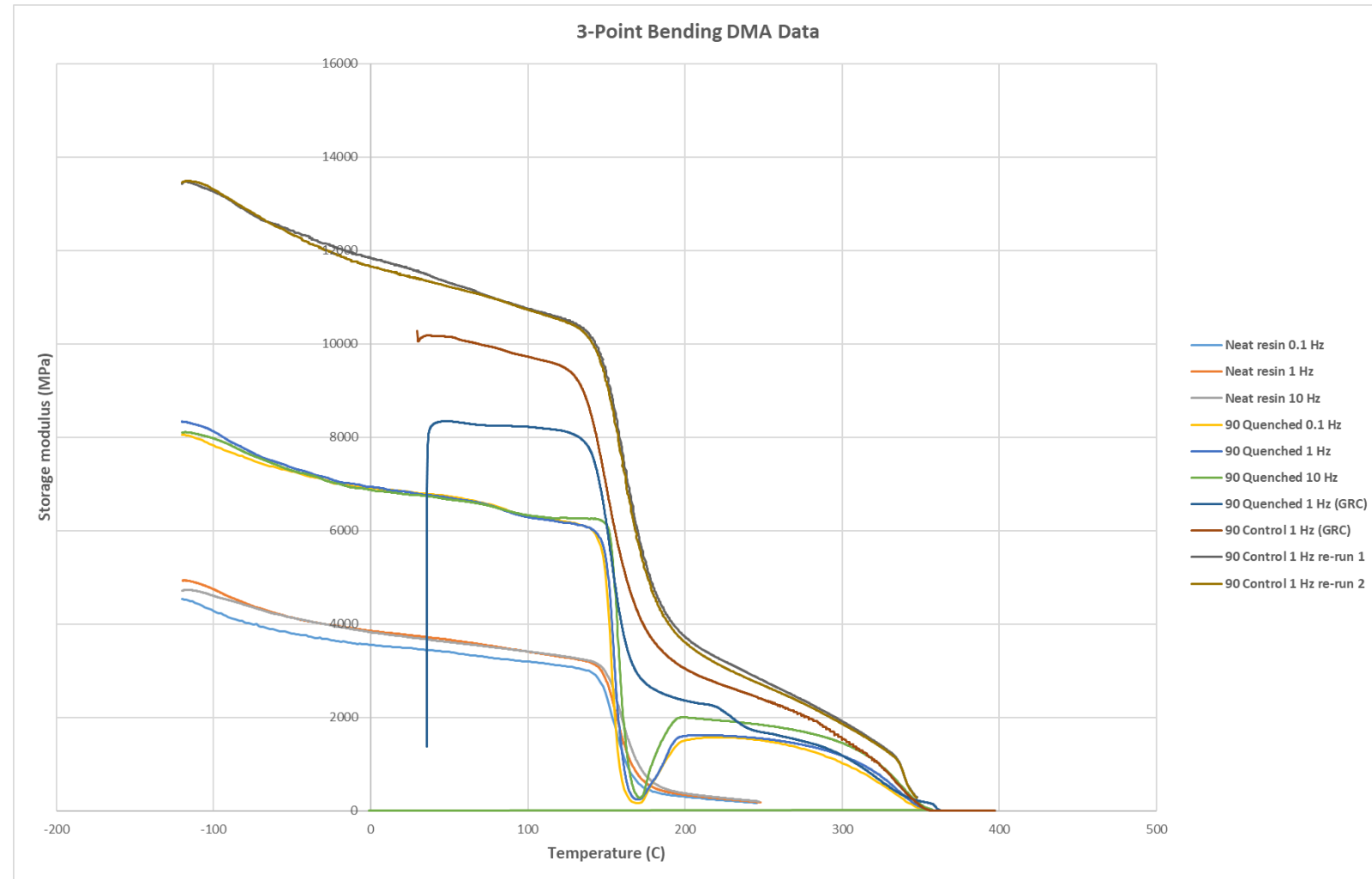


# Dynamic mechanical analysis (DMA) 3-Point Bending Test

*Test data provided by NASA*

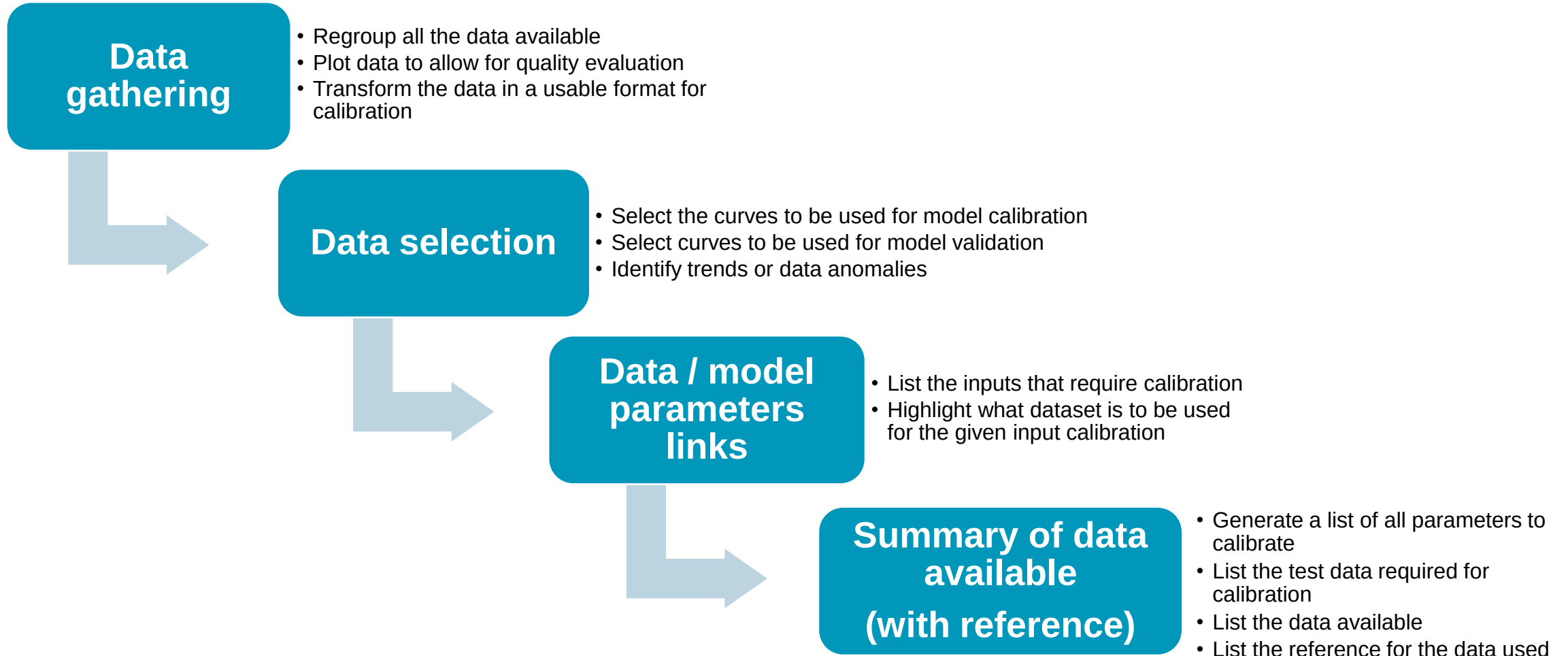
## Initial observations:

- The data include Neat resin and composite DMA data
- The Neat resin data were used for the calibration and the composite DMA data was used for validation
- The data from Glenn Research Center (GRC) show some difference in the storage modulus in the early stage of the DMA test compared to the other test data. For that reason, those curves are excluded from the calibration and validation.



# Step 1

## Workflow

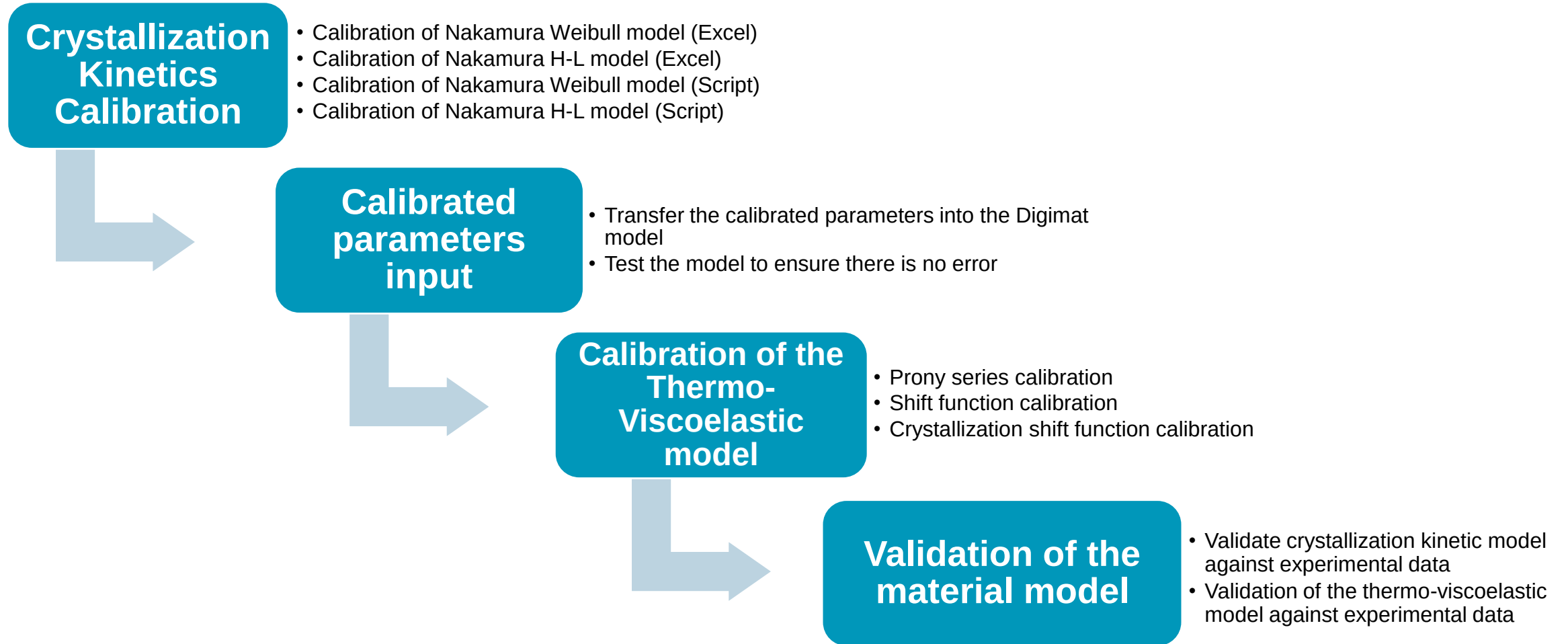


## Step 2

*Calibrate a Digimat crystallinity models*

# Step 2

## Workflow



# Calibration - General Methods

## *Tools and Options*

**Two crystallization kinetic models are available in Digimat:**

- Double Nakamura Weibull
- Hoffman Lauritzen

While there are more models available, those are currently the only two ones implemented in Digimat

### **Calibration Option 1 – EXCEL Solver**

Usage of “Solver” capabilities in Excel to calibrate the numerical model parameters

- In the solver option, use the **Min** objective to find parameter values that minimize the mismatch between experimental and calculated values

### **Calibration Option 2 – Script-based** (Preferred Method)

Usage of a script developed internally

# Crystallization Kinetic Models Available in Digimat

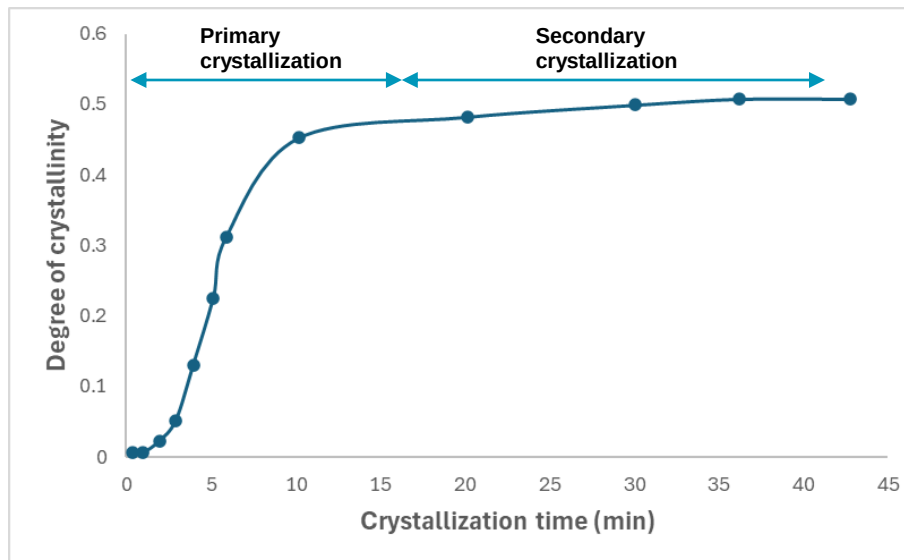
## *Double Nakamura Weibull*

### Pros and Cons:

- Useful for cases where complete crystallization happens during Cooldown
- Model that can capture Primary and Secondary crystallization kinetics
  - The model can be calibrated to capture primary and secondary crystallization or just primary crystallization
- This model can't capture cold crystallization (crystallization that happens when heating the polymer)

### Recommended applications:

- Processes where the whole crystallization happens during cooldown (Molding, Additive manufacturing, ...)
- Cases where secondary crystallization kinetic plays an important role



#### Data taken from:

Baltá-Calleja, F.J.; Ezquerro, T.A. Polymer Crystallization: General Concepts of Theory and Experiments. Encyclopedia of Materials: Science and Technology 2001, 7244–7252, doi:10.1016/B0-08-043152-6/01289-4.

# Crystallization Kinetic Models Available in Digimat

## *Nakamura Hoffman Lauritzen*

### **Pros and Cons:**

- Useful for cases where there is a potential for cold crystallization
- Model that can only capture crystallization kinetics
- The model requires more experimental data for calibration

### **Recommended applications:**

- Processes where there is a potential of heat treatment or consolidation step
  - Heating of the material from room temperature to somewhere below crystallization temperature
- Cases where Double Nakamura Weibull may not be capable of capturing the right crystallization kinetic behavior

# Single Nakamura-Weibull Model Quality Review

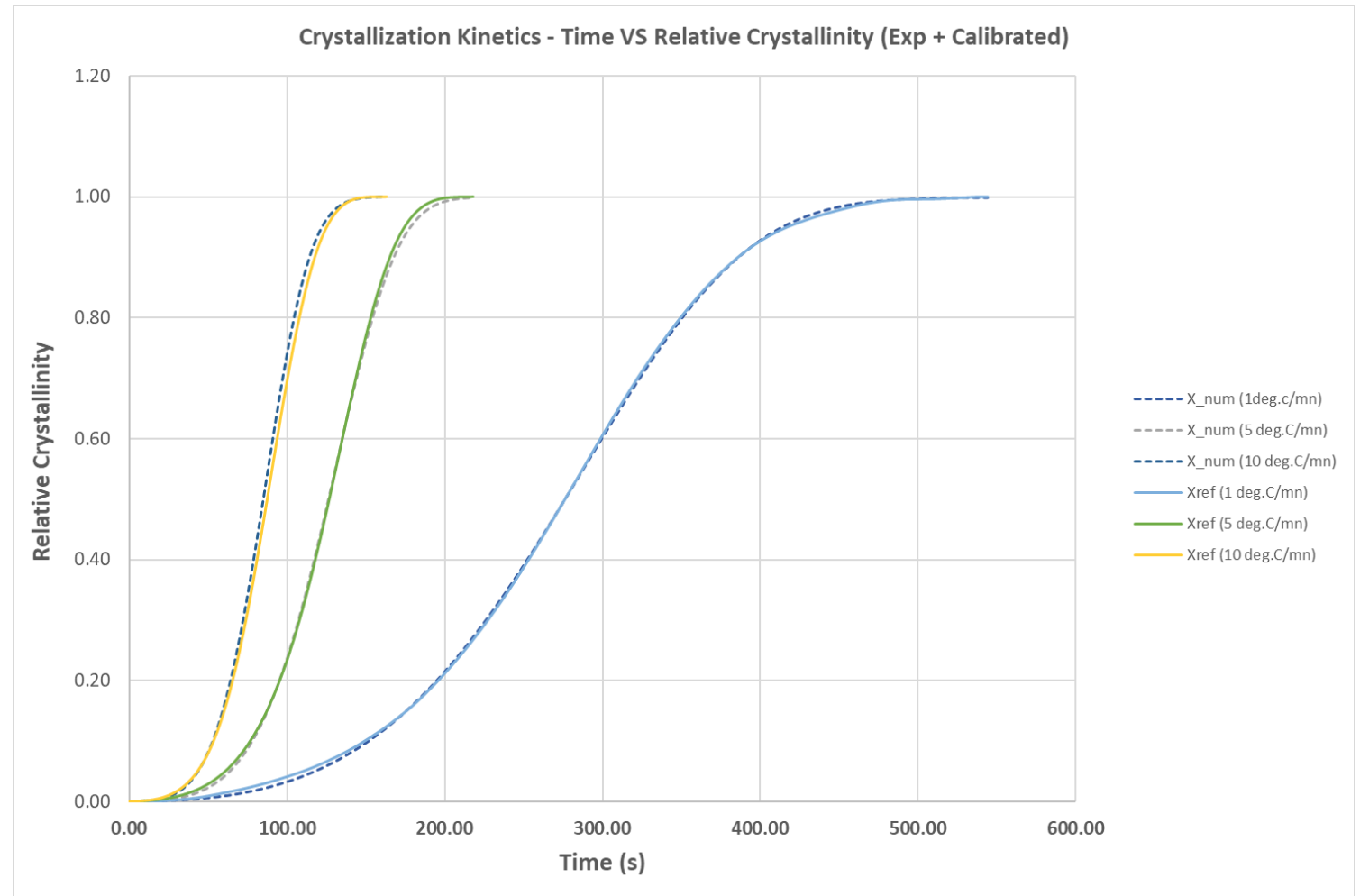
## Calibration Using the Provided Script

Experimental curves selected for the calibration:

- 1, 5 and 10 °C/min

Outcome:

The calibration is very good overall



# Nakamura-Weibull Model Quality Review

## Calibration Using the Provided Script

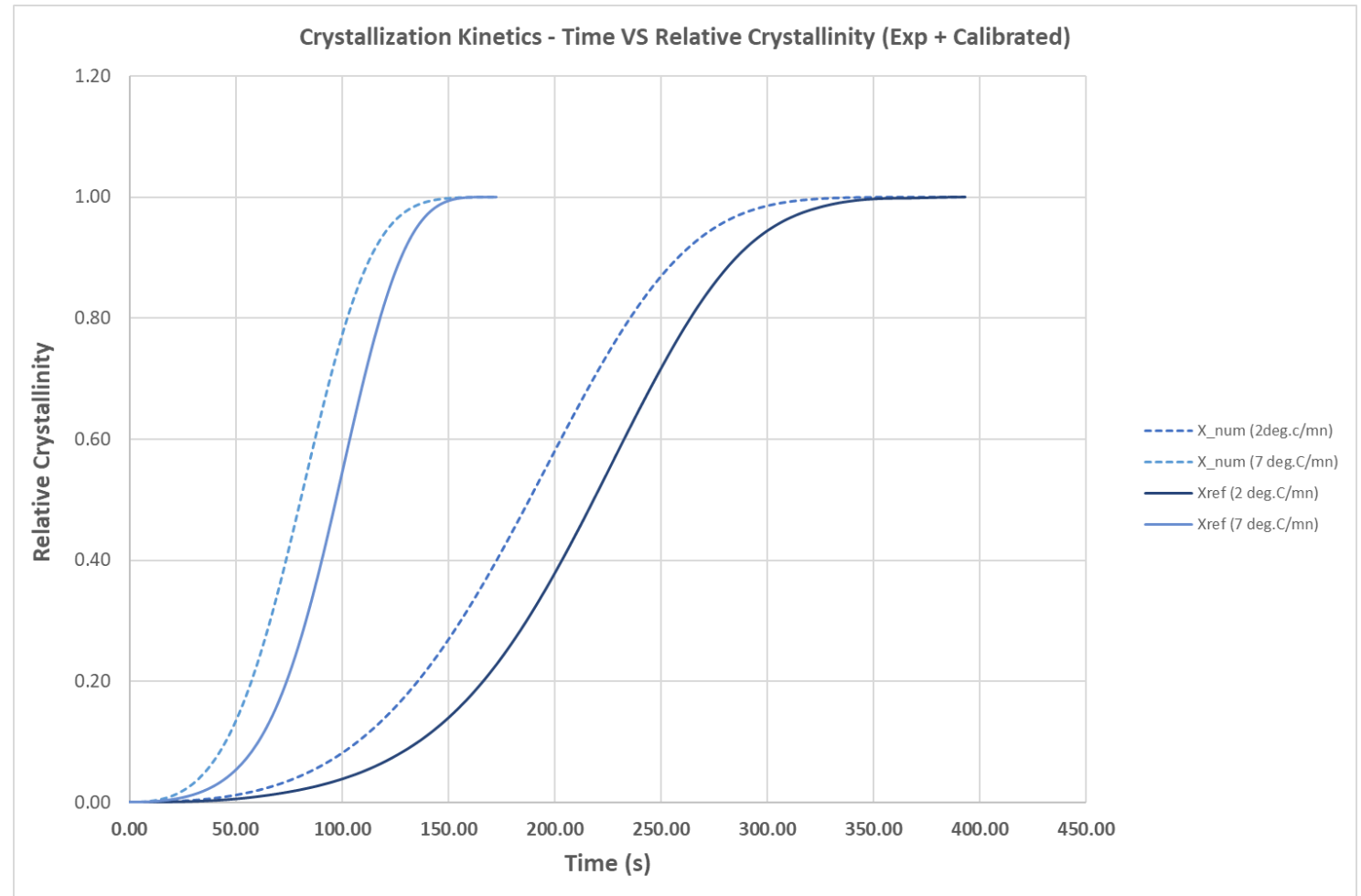
### Experimental curves selected for validation:

- 2 and 7 °C/min

### Outcome:

- The calibrated model capture the speed of the crystallization at both cooling rates
- The model crystallization start earlier for both cooling rates

**COMMENT:** The ideal case would be to include all experimental curves into the calibration process. It may end in a better overall average capture with a less good specific fit.



# Calibration of the TVE Model

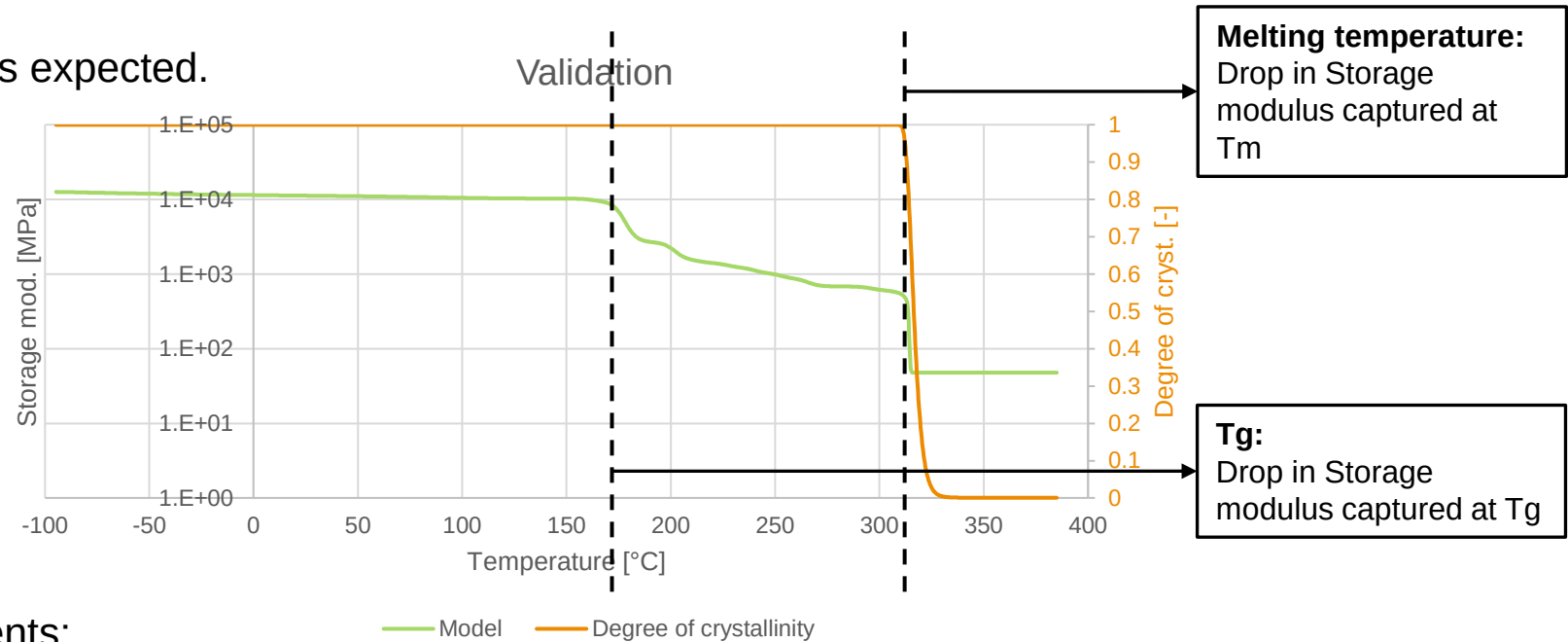
## Strategy

- The temperature shift function is calibrated based on the resin data (Degree of Crystallinity = 1)
- The Prony series is extended (more terms were added) to cover the composite range
- The calibration strategy of the final TVE model is based on a global optimization of the quenched composite DMA data:
  - Adjusting the weight of the Prony series to fit at best the DMA curve
  - Calibrating the crystallization shift function to obtain the typical behavior (stiffness drop around  $T_g$ , stiffening due to crystallization)
  - Fine-tuning the temperature shift function

# Validation of the Storage Modulus with Respect to Crystallinity

## Comparison between Storage Modulus and Different Important Microstructure changes ( $T_m$ & $T_g$ )

- The overall behavior of the model is as expected.

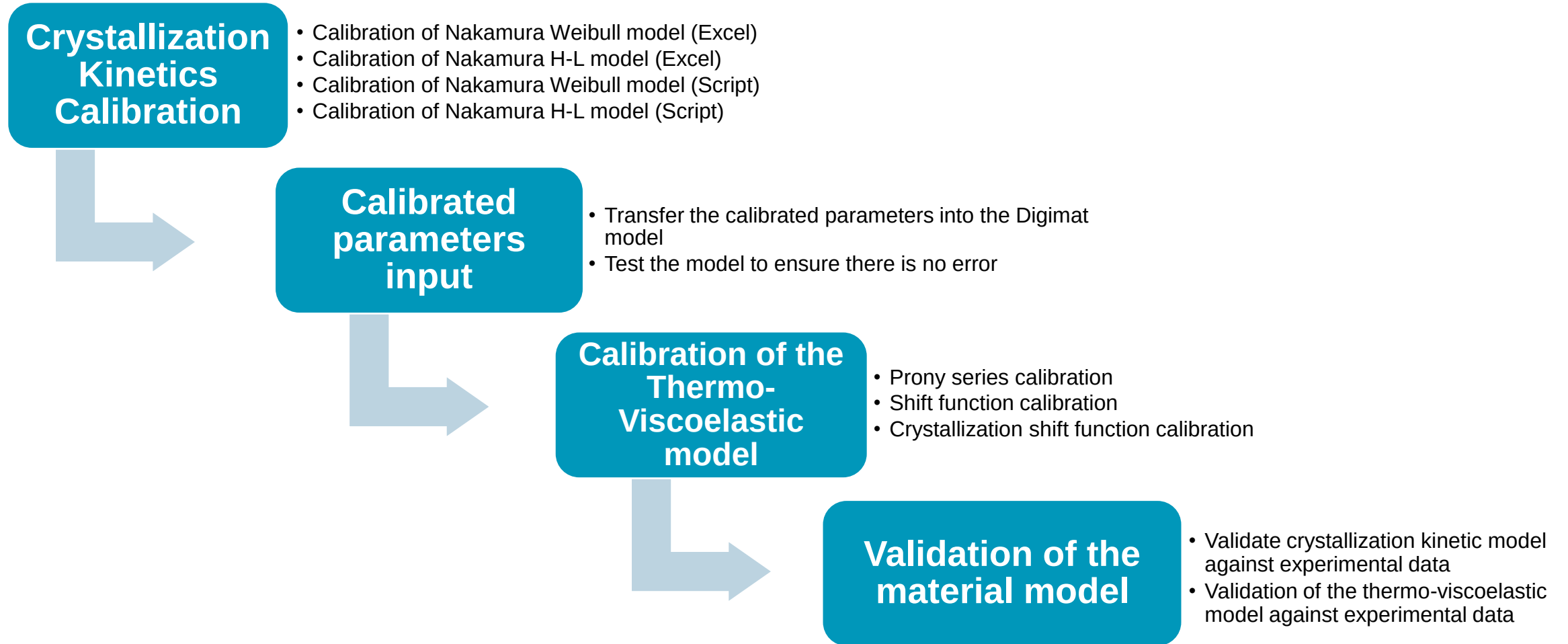


### Limitations, Hypotheses & Improvements:

- Perform static tensile tests on neat resin & composite to fit the VF of fibers and the TVE model
- Perform shear & tensile DMA tests to account for a variable Poisson ratio
- Perform both quenched & crystallized DMA on neat resin (much easier to calibrate)
  - Ideally use the same sample that was quenched by cooling down in the DMA (heat ramp followed by a cooling ramp)
  - Otherwise, the same temperature history can be applied to another sample and then DMA
- Evaluate different heating rates
- Validate the crystallization kinetics model in cold crystallization

# Step 2

## Workflow

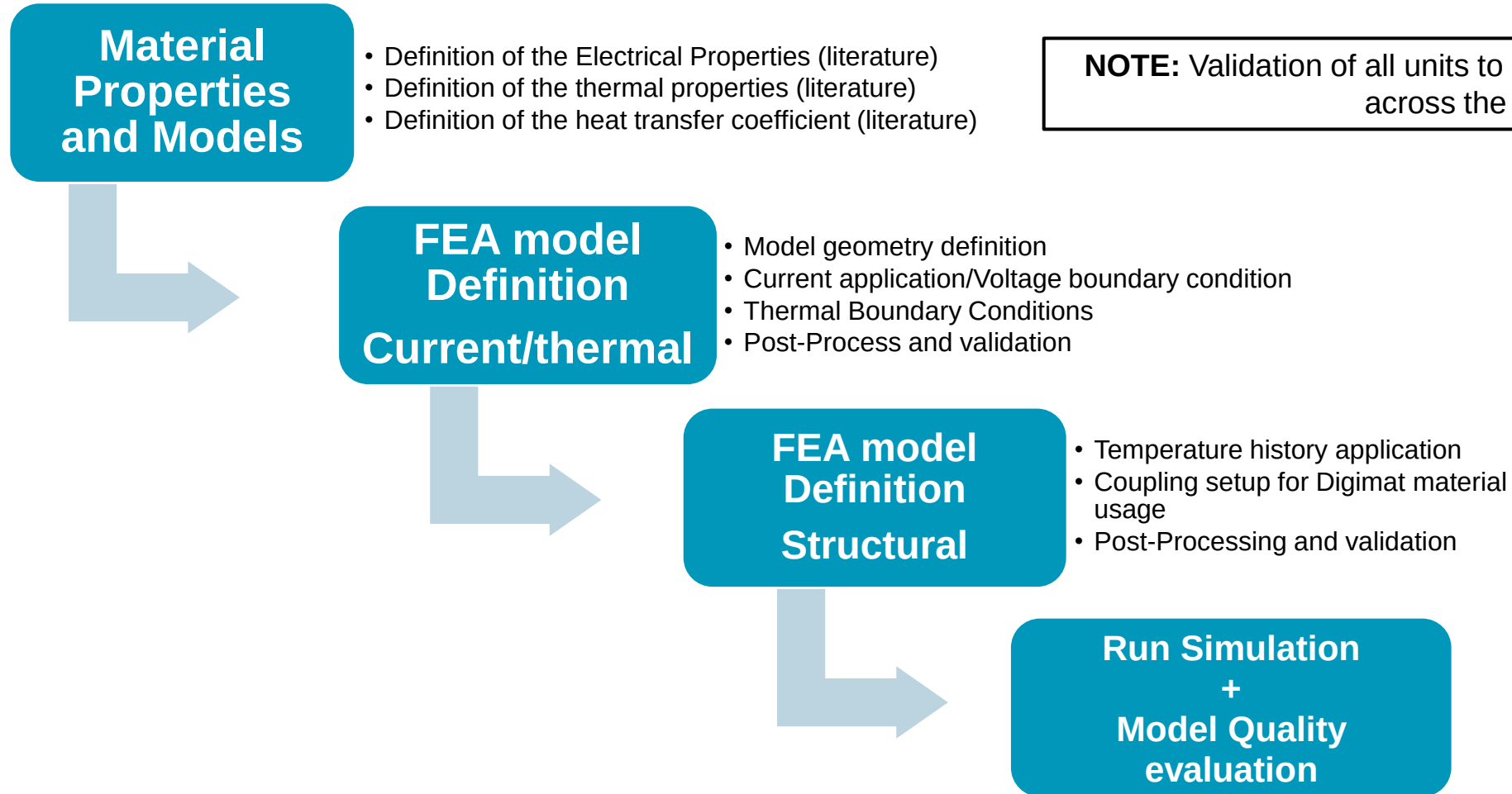


## Step 3

*Validate the model at a Coupon Level*

# Step 3

## Workflow



# Lap Shear Test

*FEA model Definition*

*CURRENT/THERMAL Analysis*

# The Problem

## Resistance Welding

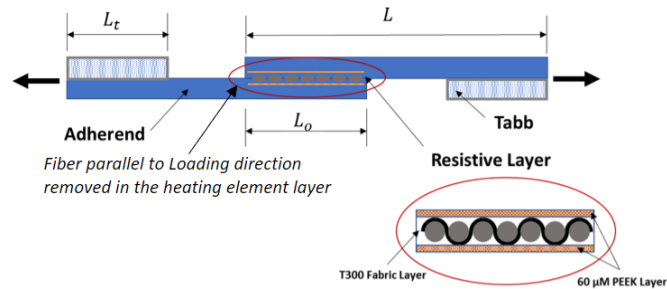
**Objective:** Evaluate the performance of welded joints

### Testing setup:

- **Single lap-shear test**

QI -  $[45/0/-45/90]_{2s}$   
QI0 -  $[0/45/-45/90]_{2s}$

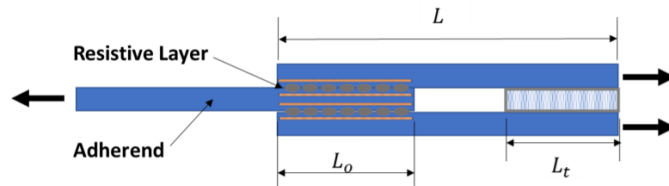
$L_o = 1.0''$   
 $L_t = 1.0''$   
 $L = 4.0''$   
 $W = 1.0''$   
Tab Thickness -  $0.0864''$



- **Double lap-shear test**

QI -  $[45/0/-45/90]_{2s}$

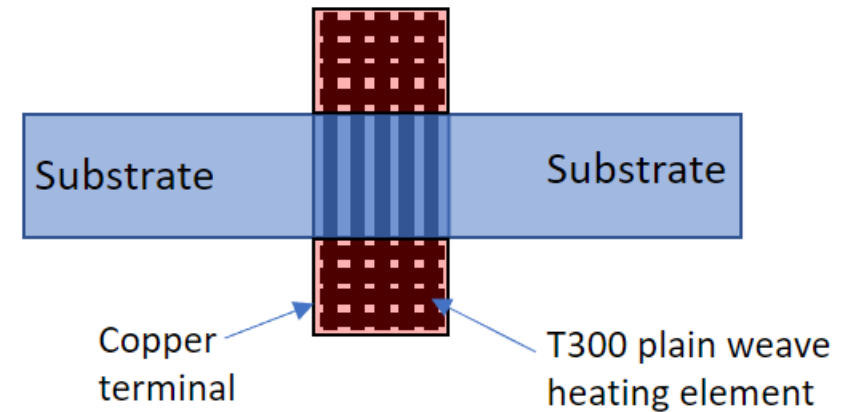
$L_o = 1.0''$   
 $L_t = 1.0''$   
 $L = 4.0''$   
 $W = 1.0''$   
Tab Thickness -  $0.0864''$



### Heating setup:

Top view:

Heating element tows  
oriented in loading direction  
removed over faying surface



# Single Lap-Shear Test

## Overall Model Description – Material and Sections

Picture of the welding setup

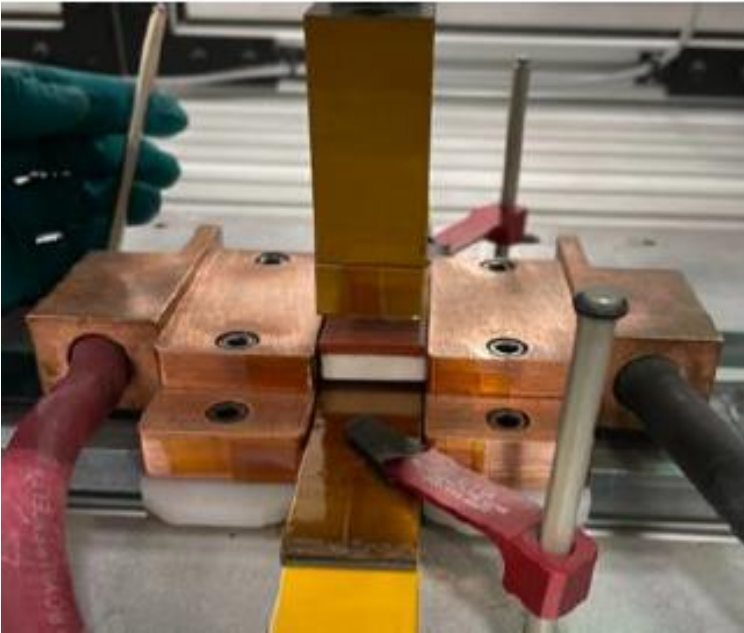
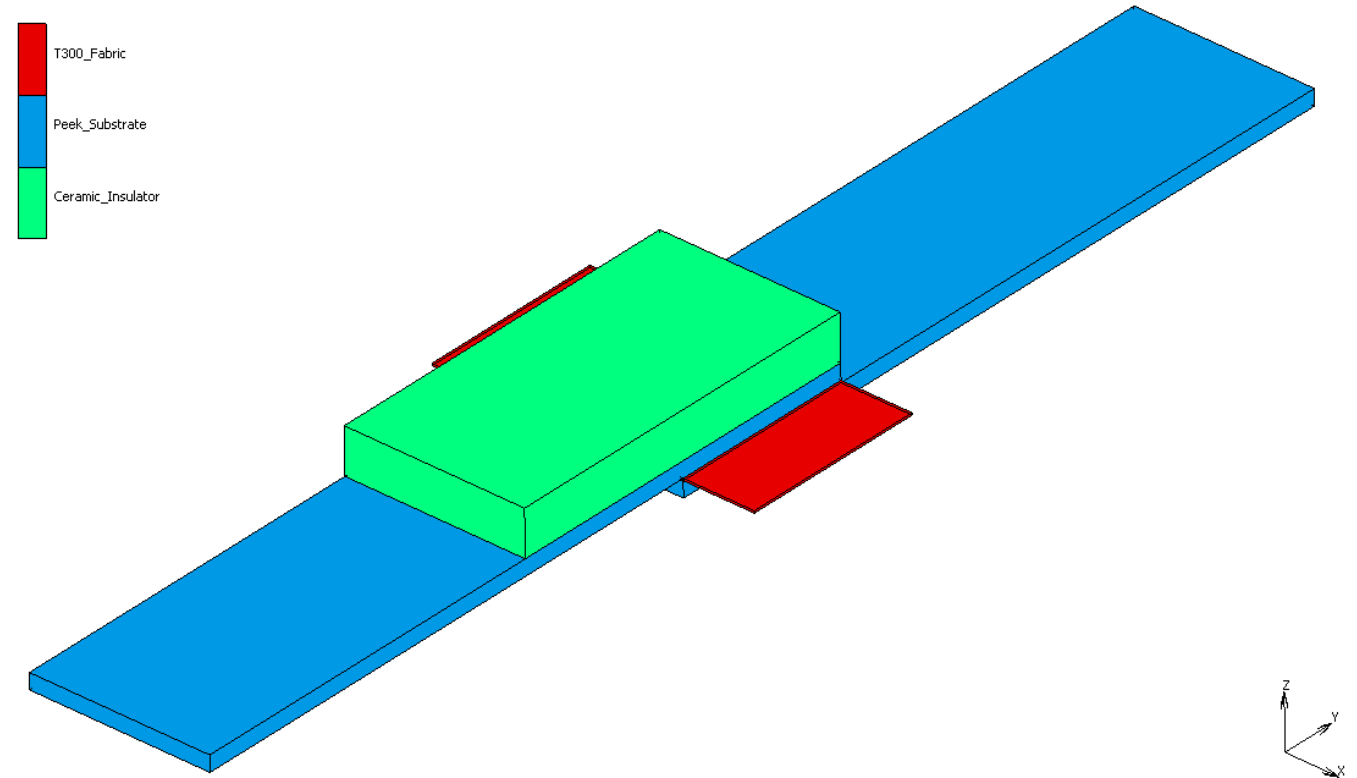


Image of the welding Finite Element Model



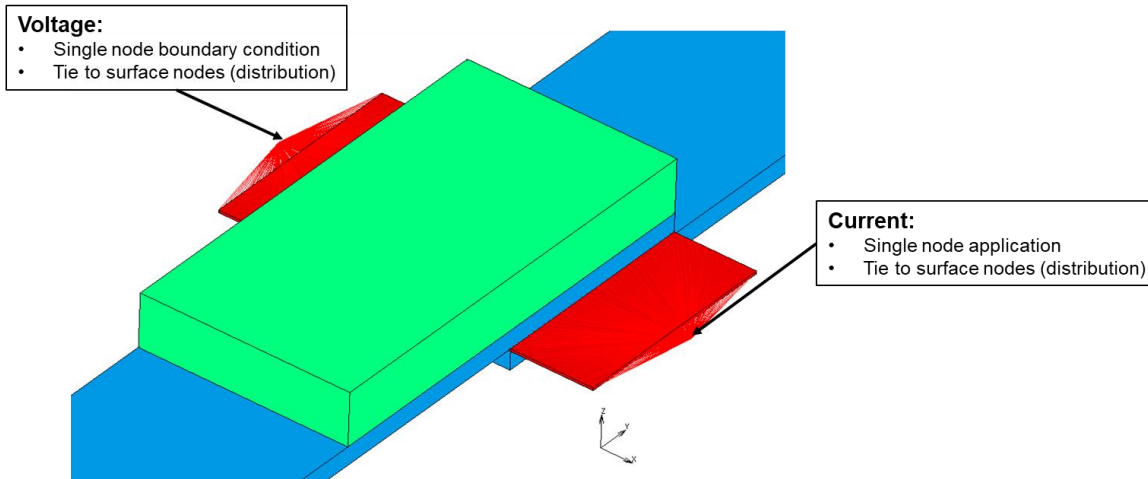
# Single Lap-Shear and Double Lap-Shear Test

## *Current application/Voltage boundary condition*

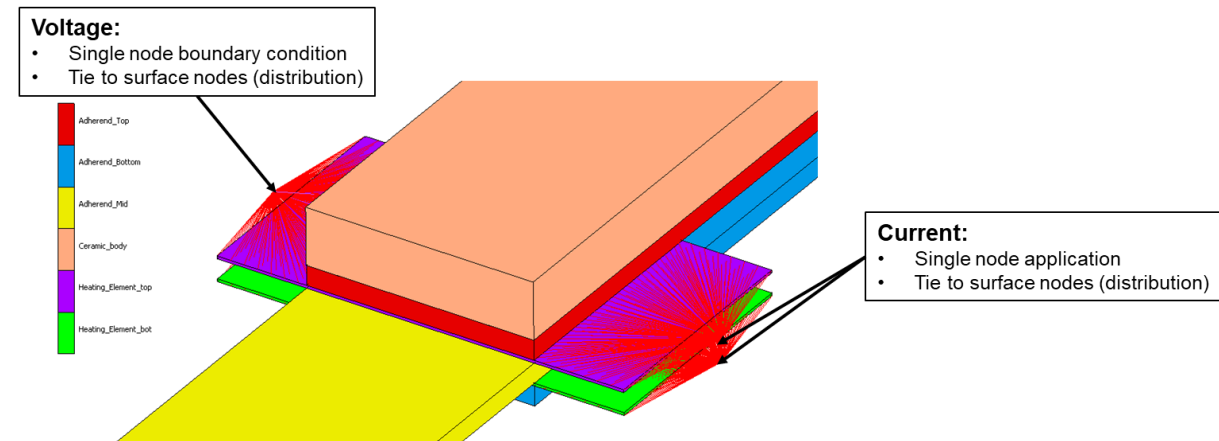
For simplicity, the model doesn't include the copper structure. It instead assumes a convection between the surrounding copper parts and the sample sections

- For the single lap shear test, the current is applied on a node tied to surface nodes like indicated below.
- For the double lap shear test, the current is applied on the bottom heating element and then the top
- The current history is extracted from the experimental data
- The resultant Voltage is compared to the experimental measurements

### Single lap shear test



### Double lap shear test



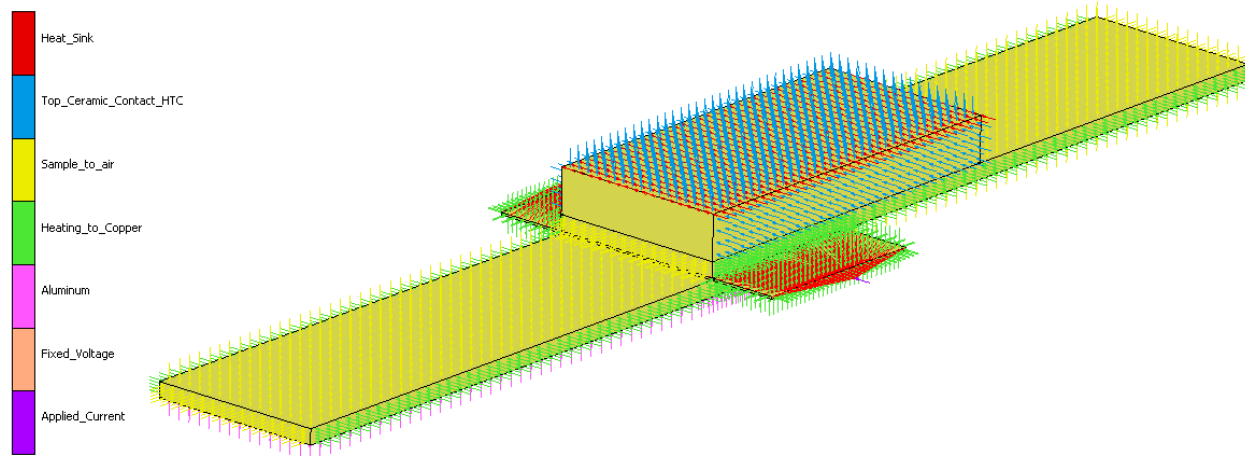
# Single Lap-Shear and Double Lap-Shear Test

## *Thermal Boundary Conditions*

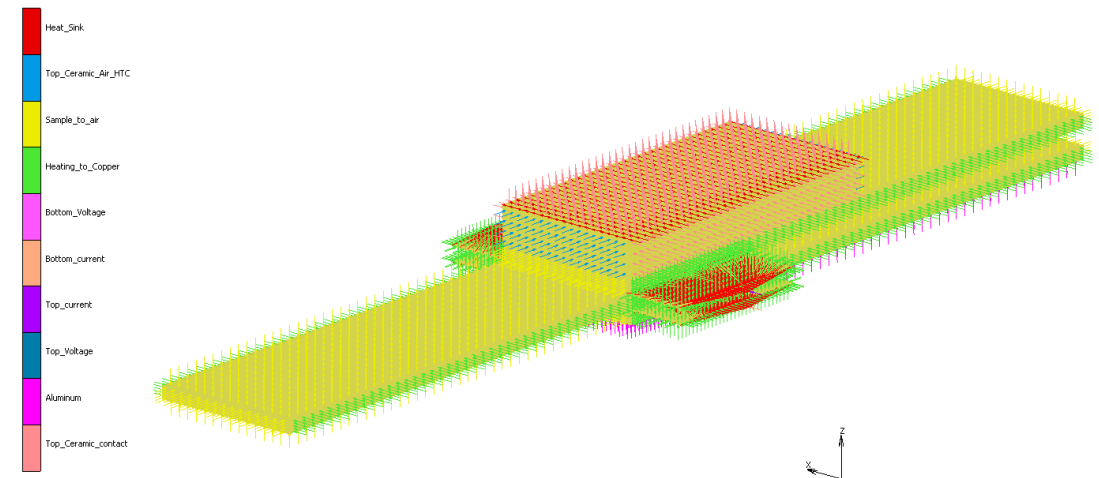
The image below presents all the different thermal Boundary Conditions applied on the Lap-Shear Test:

- The Heat Sink boundary condition is a fixed temperature of 20 °C
- Fixed voltage is applied opposite to the heating element (Value = 0)
- All the remaining boundary conditions are Heat transfer coefficients (HTC) that varies depending on the type of surface considered or if it's a contact surface.

### Single lap shear test



### Double lap shear test

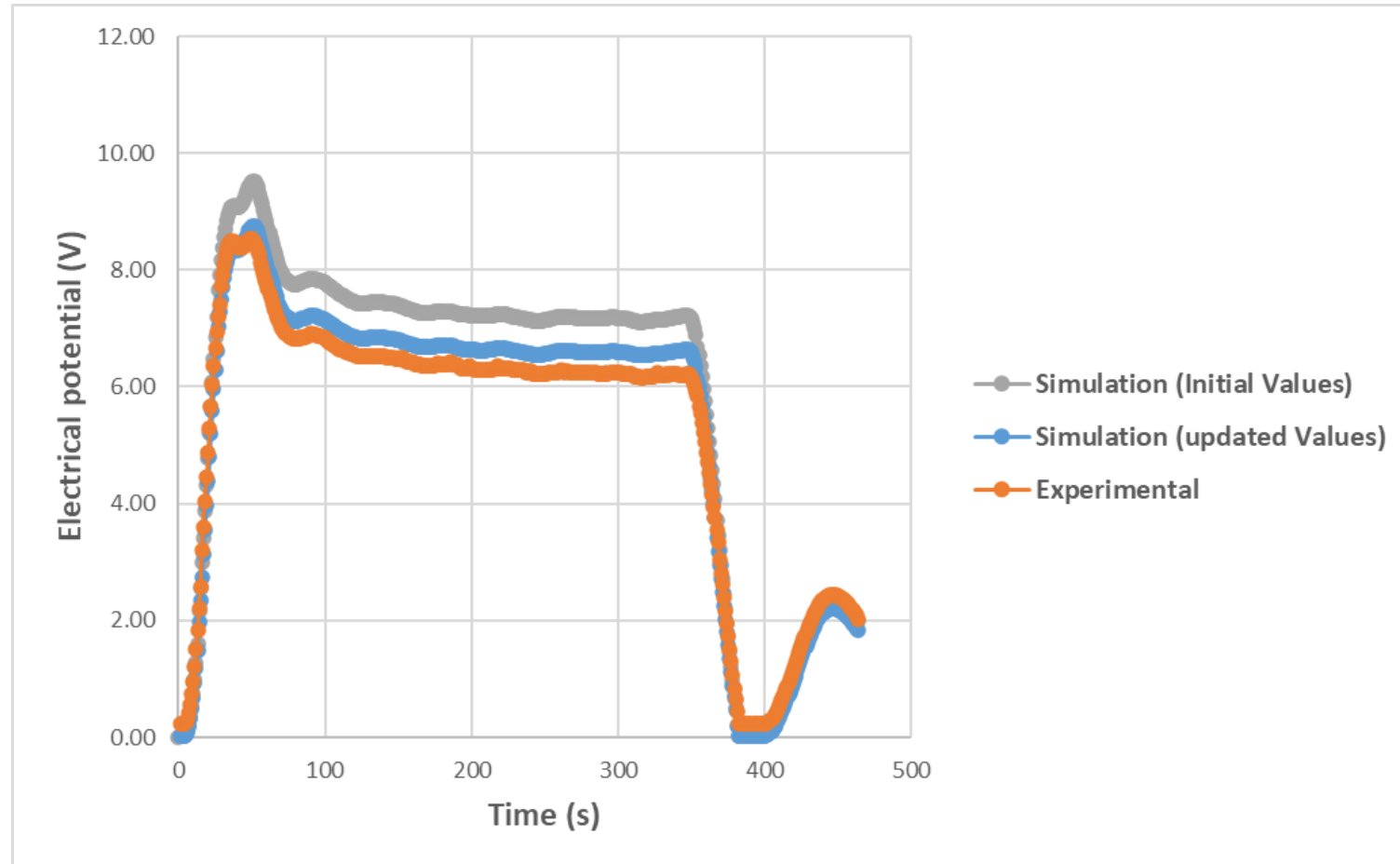


# Double and Single Lap-Shear Test Voltage Validation

## Electrical Properties Validation

- The simulation results (Initial Values) are outputs from a model using electrical properties found in the literature
- The simulation results (updated values) are results using electrical properties that have been increased by less than 10%
- With the updated electrical properties
  - Resultant electrical potential in the simulation match very well the electrical potential measured

**NOTE:** It would be relevant to physically inspect the testing setup and then modify the finite element analysis (FEA) model accordingly.

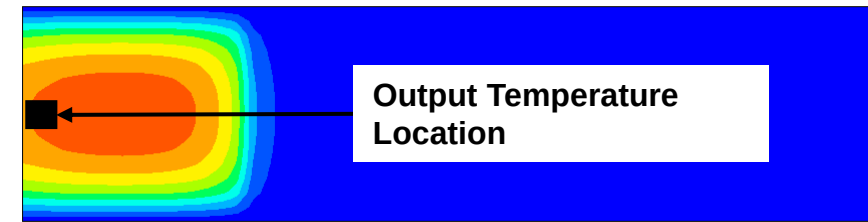


**Obtaining the right electrical potential means that the electrical properties match the current surface application and other electrical boundary conditions**

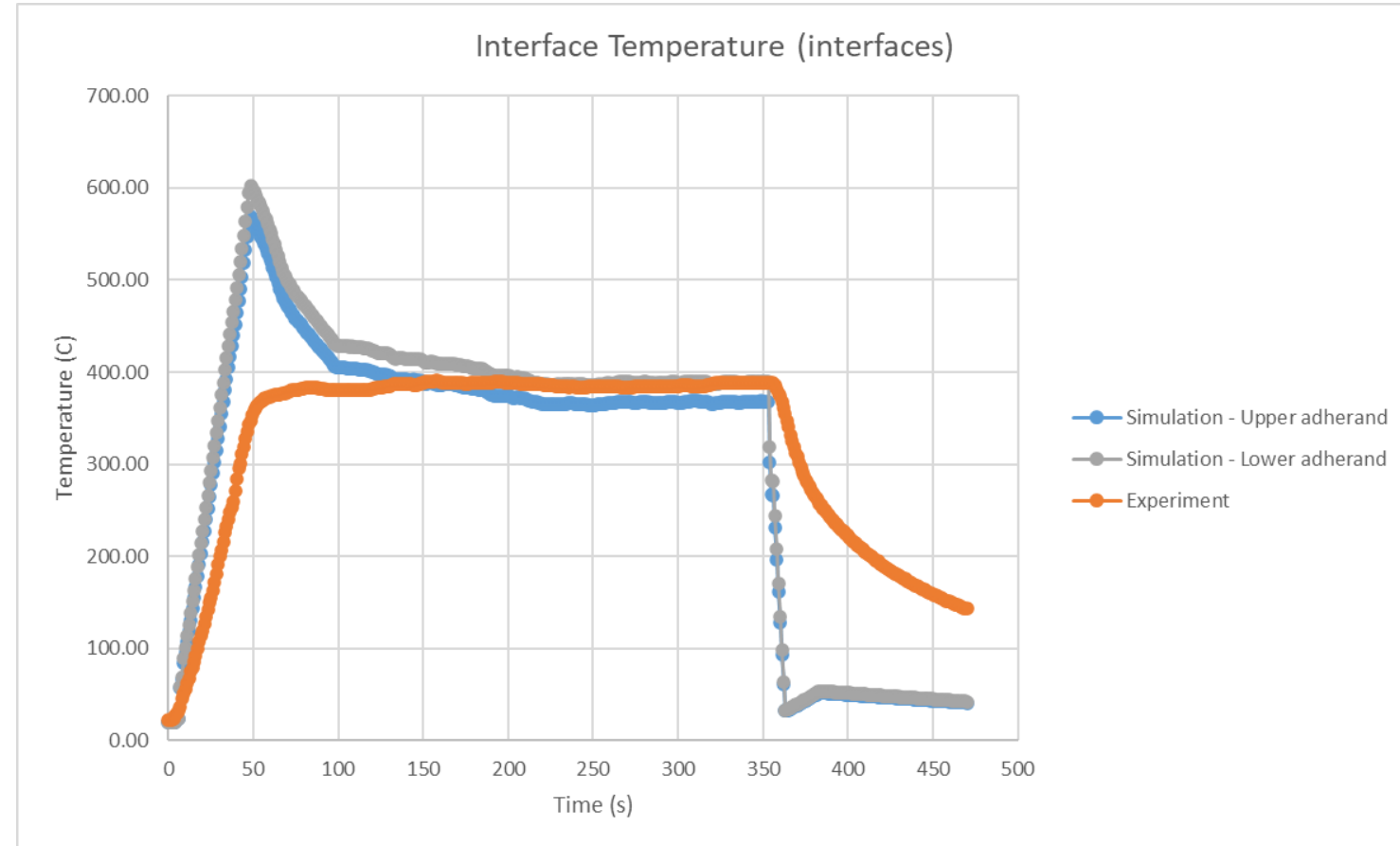
NOTE: Changing the current application surface could slightly affect the results match

# Single Lap-Shear Test Temperature Profile

## *Simulation Temperature at Surface of Adherends*



- The temperature during the hold matches the measured temperature
- Initial and final temperature evolution closely follow the Electrical Voltage/Current Application
- Cooling rate at 350s drastically faster than measured cooling rate



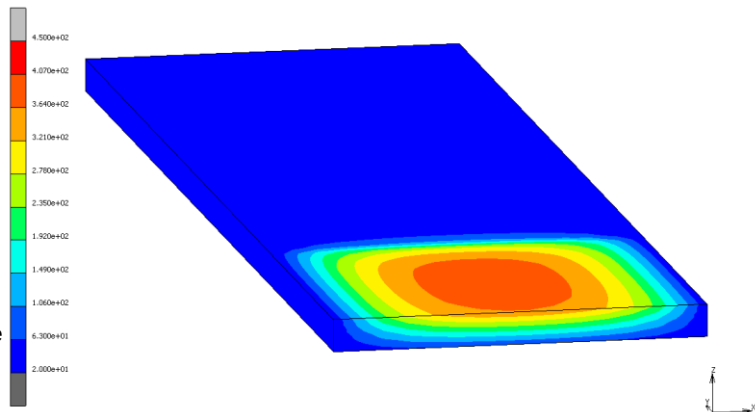
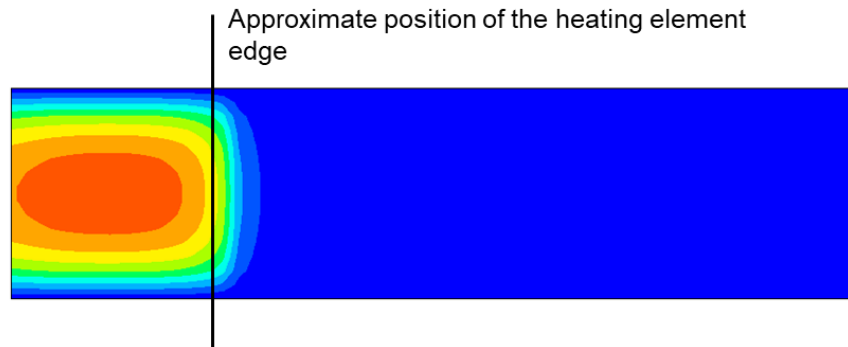
The results highlight a more efficient Current/Temperature match where for the experimental, there seems to be a lag between the current application and the temperature increase.

# Single Lap-Shear Test Temperature Profile

## *Heat affected zone in the lower and upper adherend*

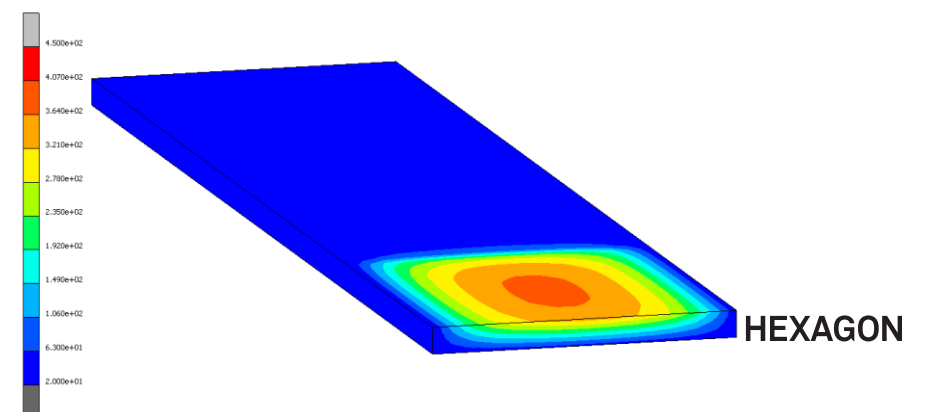
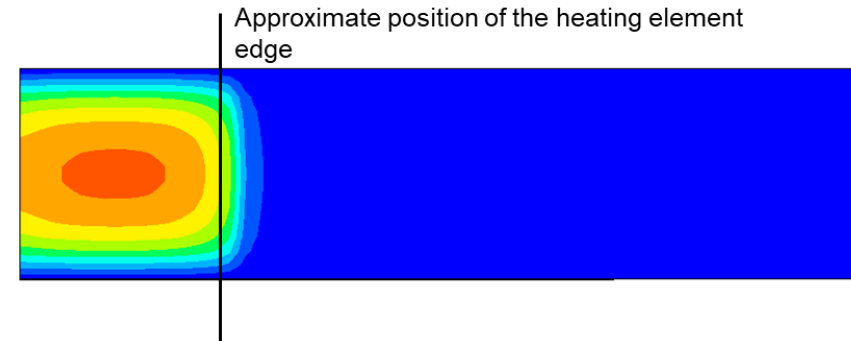
Qualitative evaluation of the heat affected zone in the lower Adherend once the temperature has stabilized (at 250s):

- Temperature in the middle reach values around  $\sim 380$  °C
- Temperature on the edge reach values ranging between  $[100, 300]$  °C



Qualitative evaluation of the heat affected zone in the upper Adherend once the temperature has stabilized (at 250s):

- Temperature in the middle reach values around  $\sim 380$  °C
- Temperature on the edges reach values ranging between  $[100, 300]$  °C



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# Double Lap-Shear Test Temperature Profile

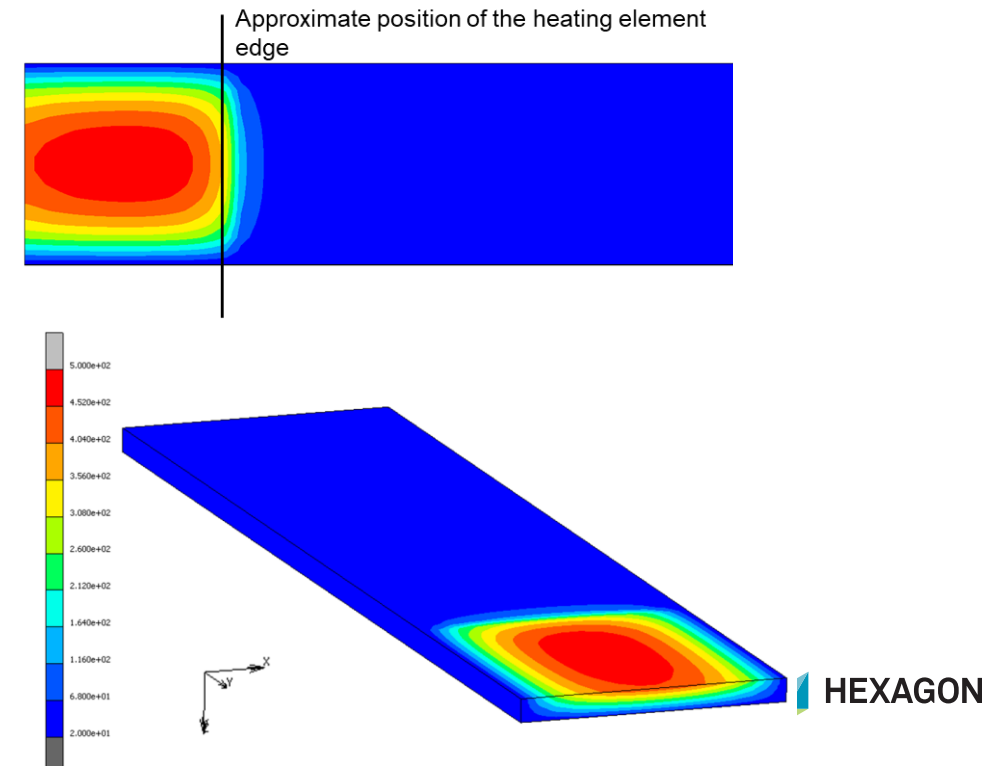
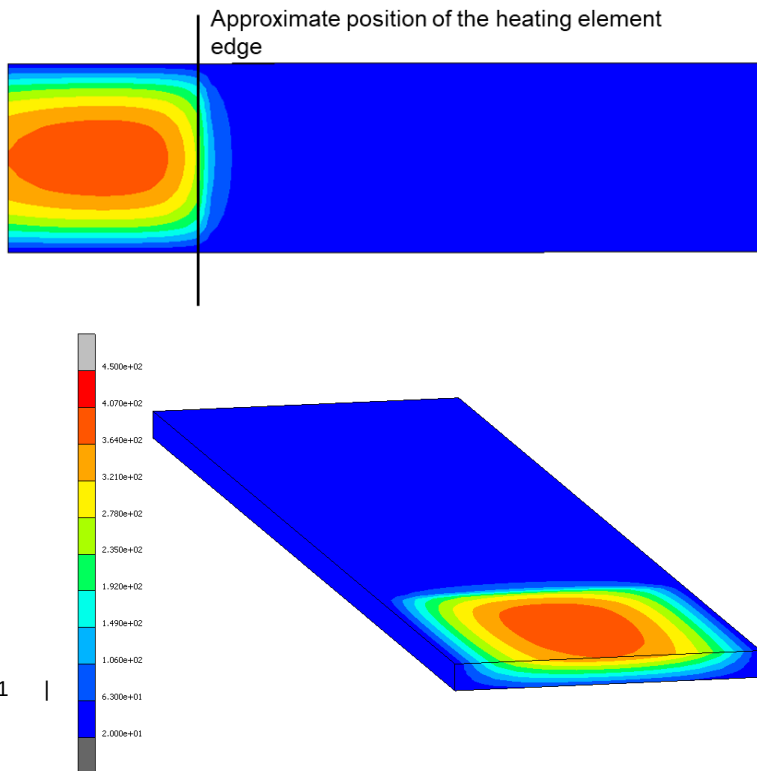
## *Heat affected zone in the Lower Adherend*

Qualitative evaluation of the heat affected zone in the lower Adherend once the temperature has stabilized (at 250s):

- Temperature in the middle reach values around  $\sim 380$  °C
- Temperature on the edge reach values in the range of  $[100, 300]$  °C

Qualitative evaluation of the heat affected zone in the lower Adherend once the temperature has stabilized (at 250s):

- Temperature in the middle reach values around  $\sim 475$  °C
- Temperature on the edge reach values in the range of  $[160, 450]$  °C



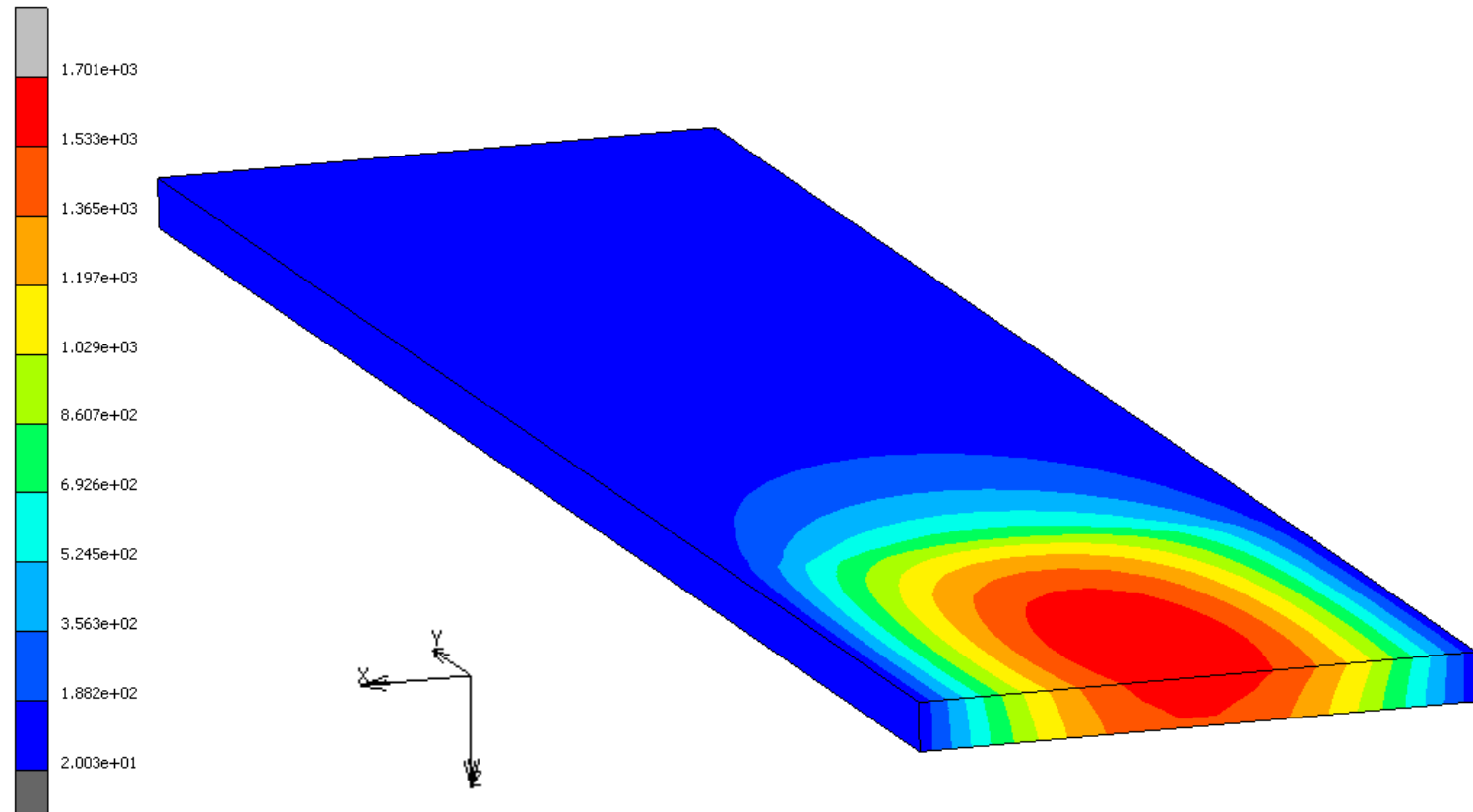
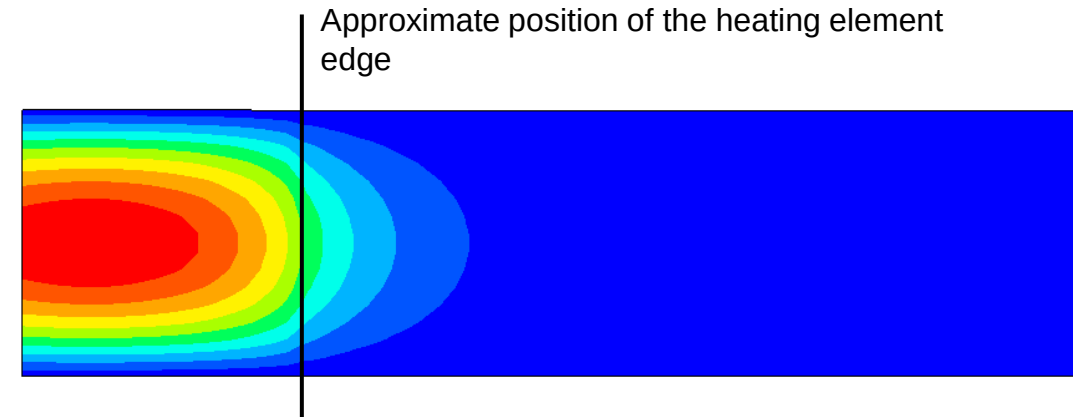
# Double Lap-Shear Test Temperature Profile

## *Heat affected zone in the Middle Adherend*

Qualitative evaluation of the heat affected zone in the lower Adherend once the temperature has stabilized (at 250s):

- Temperature in the middle reach values around  $\sim 1701^{\circ}\text{C}$  (unrealistic)
- Temperature on the edges reach values in ranging between  $[180, 1200]^{\circ}\text{C}$

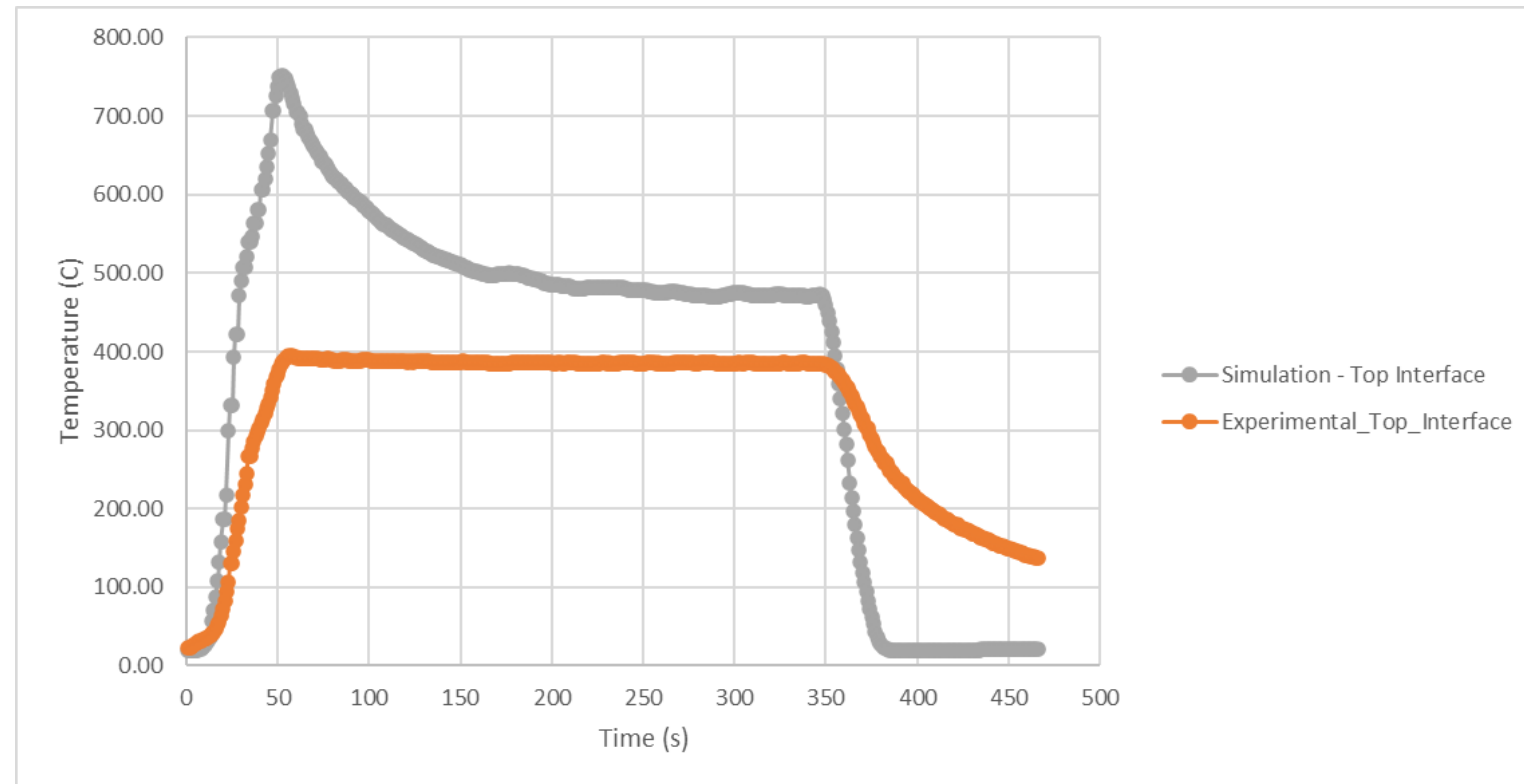
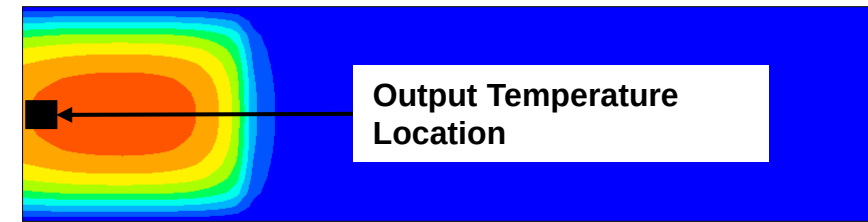
**The temperature reached in the middle adherend are another indicator that the current model is not fully representative of the actual welding process**



# Double Lap-Shear Test Temperature Profile

## *Simulation Temperature at Surface of the top adherend*

- The temperature during the hold is higher in the case of the Simulation
- The initial and final temperature evolution closely follow the Electrical Voltage/Current Application

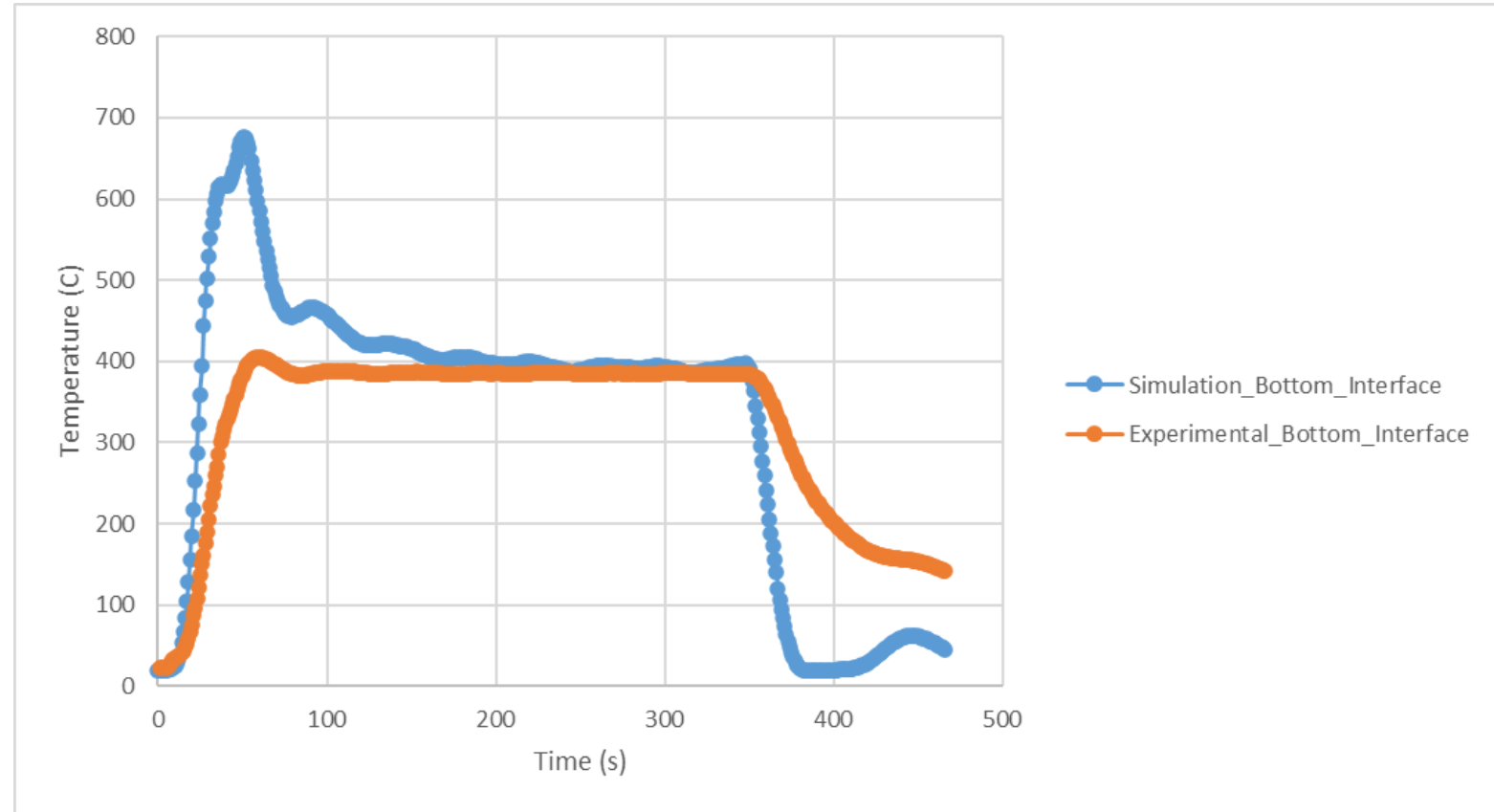
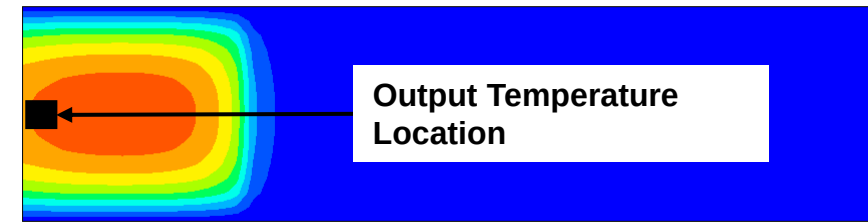


The results highlight a more efficient Current/Temperature match where for the experimental, there seems to be a lag between the current application and the temperature increase.

# Double Lap-Shear Test Temperature Profile

## *Simulation Temperature at Surface of the Bottom Adherend*

- The temperature during the hold matches the measured temperature
- The initial and final temperature evolution closely follow the Electrical Voltage/Current Application



The results highlight a more efficient Current/Temperature match where for the experimental, there seems to be a lag between the current application and the temperature increase.

# Future Model Considerations

## *Current/Thermal*

- **Better identifications of the HTC between the different materials may help identifying what simplifications are acceptable**
  - HTC evaluation can be challenging
- **Experimental characterization of the different Electrical properties for the heating element**
- **Accurate current application seems to have a non-negligeable impact on the temperature profile**
  - This is perhaps the biggest potential source of error. Based on the current application, the response of the heating element is too efficient in comparisons to the experimental values. While the current applied reaches a peak, the temperature doesn't reach that same peak which highlights a lag between the current applied and the temperature measured.

# Lap Shear Test

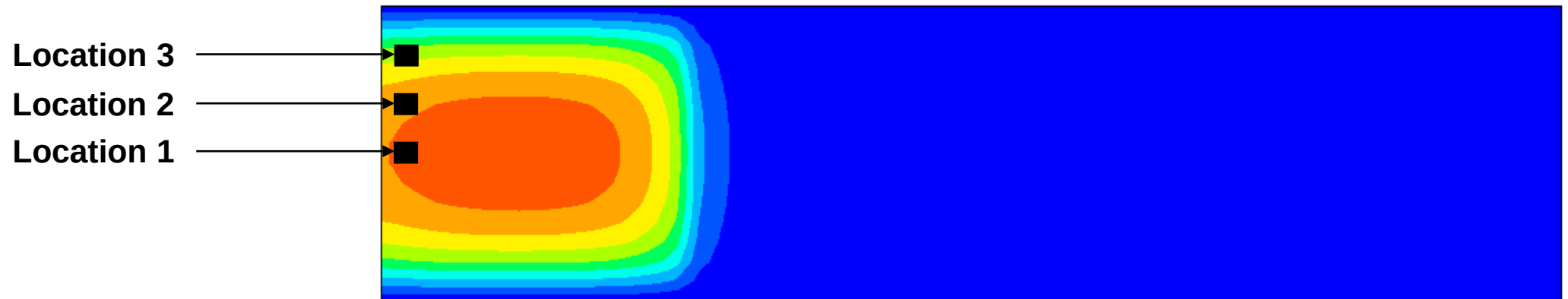
*FEA model Definition*

*STRUCTURAL Analysis*

# Degree of Crystallinity Profiles

*Initial Degree of Crystallinity of 1 (All Layers are starting at 100% crystallinity)*

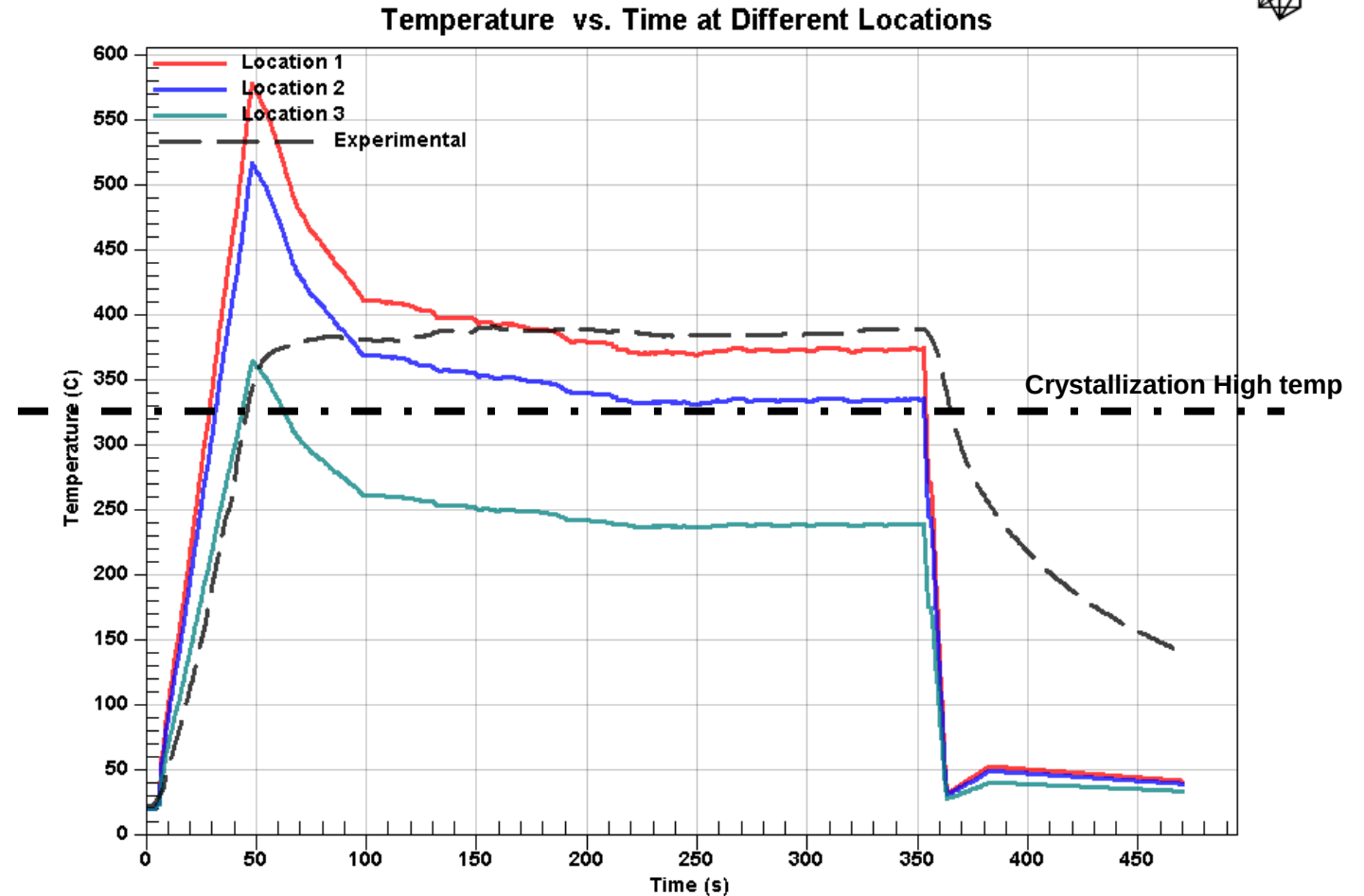
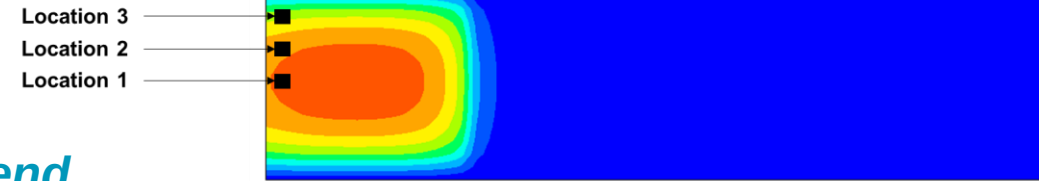
- A history of the degree of crystallinity will be extracted on each adherend at the contact between adherend and heating element
- Below is a location approximation where the degree of crystallinity history is extracted



# Single Lap-Shear Tests

## *Temperatures at the Different Locations in the Lower Adherend*

- Temperature in location 1 and 2 remain above crystallization for the entire duration of the welding process
- Temperature at location 3 drops below crystallization after around 75 seconds
- The cooling rates in the simulation are way higher than the cooling rate measured during the experiments



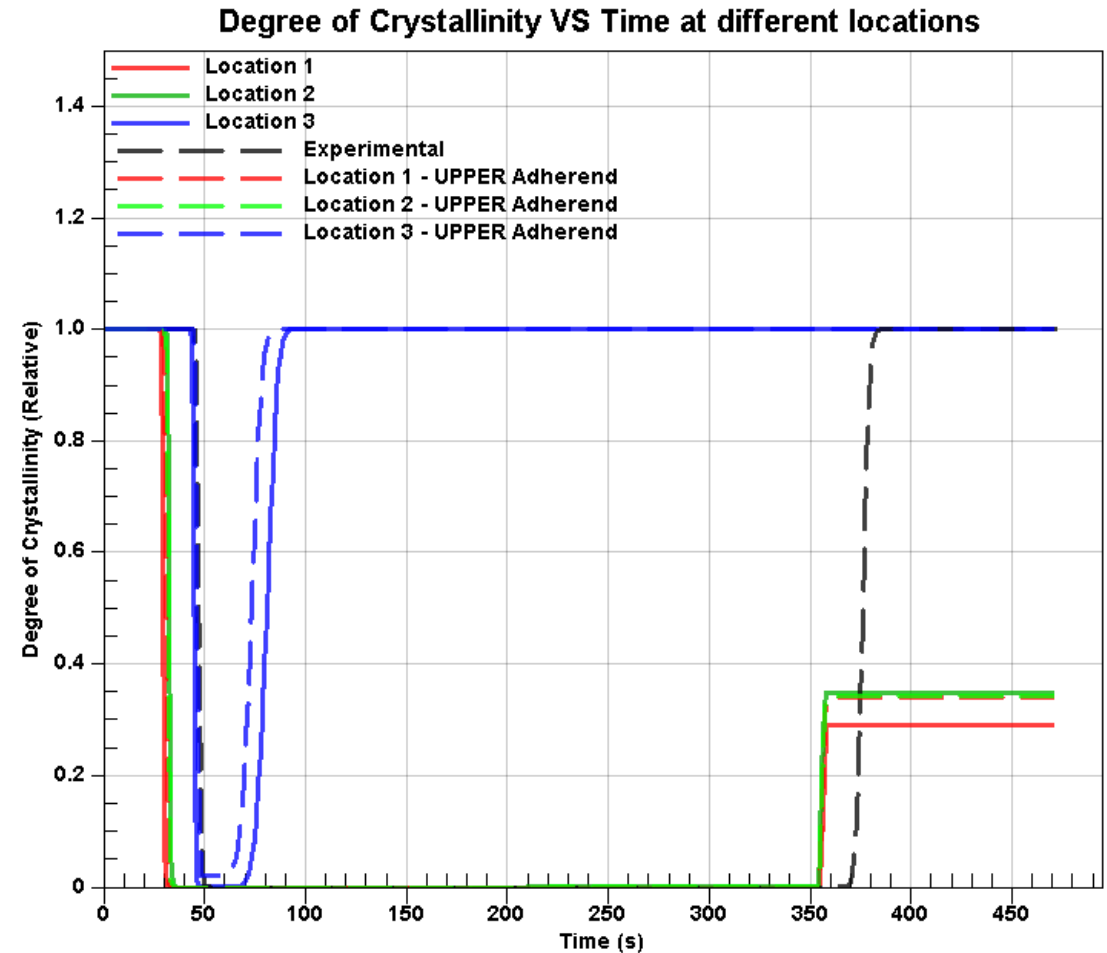
# Single Lap-Shear Tests

## *Degree of Crystallinity at the Different Locations in the both Adherends*

Location 3  
Location 2  
Location 1

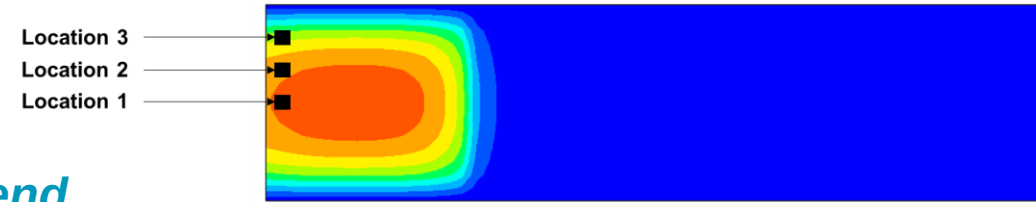


- Melt is total at all locations
- Re-crystallization happens early at location 3
- Due to faster cooling rates in the simulation, the re-crystallization is partial at location 1 and 2 as opposed to full re-crystallization in the experiment

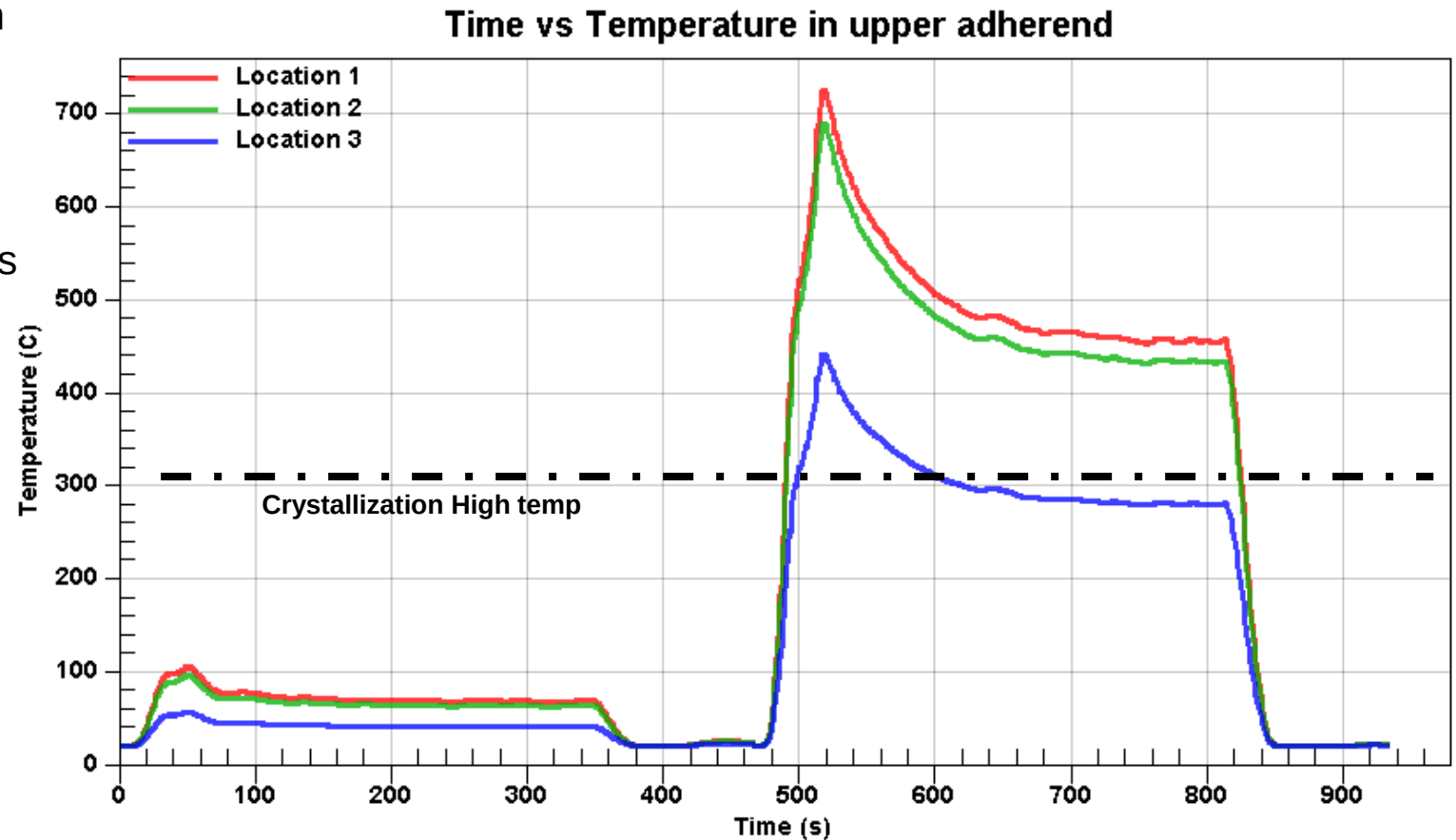


# Double Lap-Shear Tests

## *Temperatures at the Different Locations in the Upper Adherend*

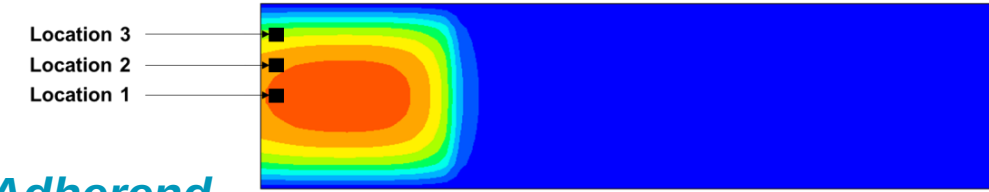


- Temperature in location 1 and 2 remain above crystallization for the entire duration of the welding process
- Temperature at location 3 drops below crystallization after around ~75 seconds
- The cooling rates in the simulation are way higher than the cooling rate measured during the experiments

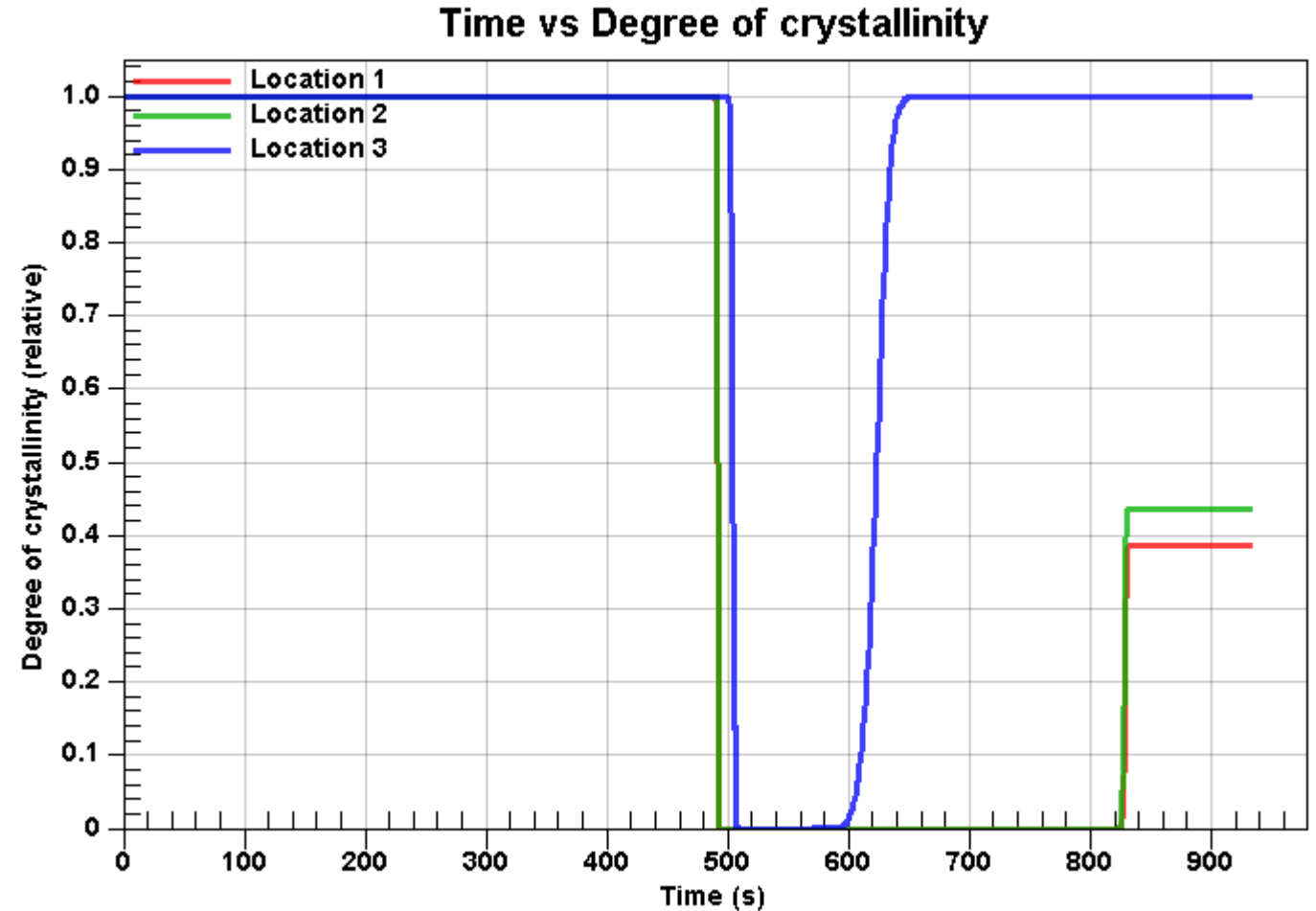


# Double Lap-Shear Tests

## *Degree of Crystallinity at the Different Locations in the Upper Adherend*



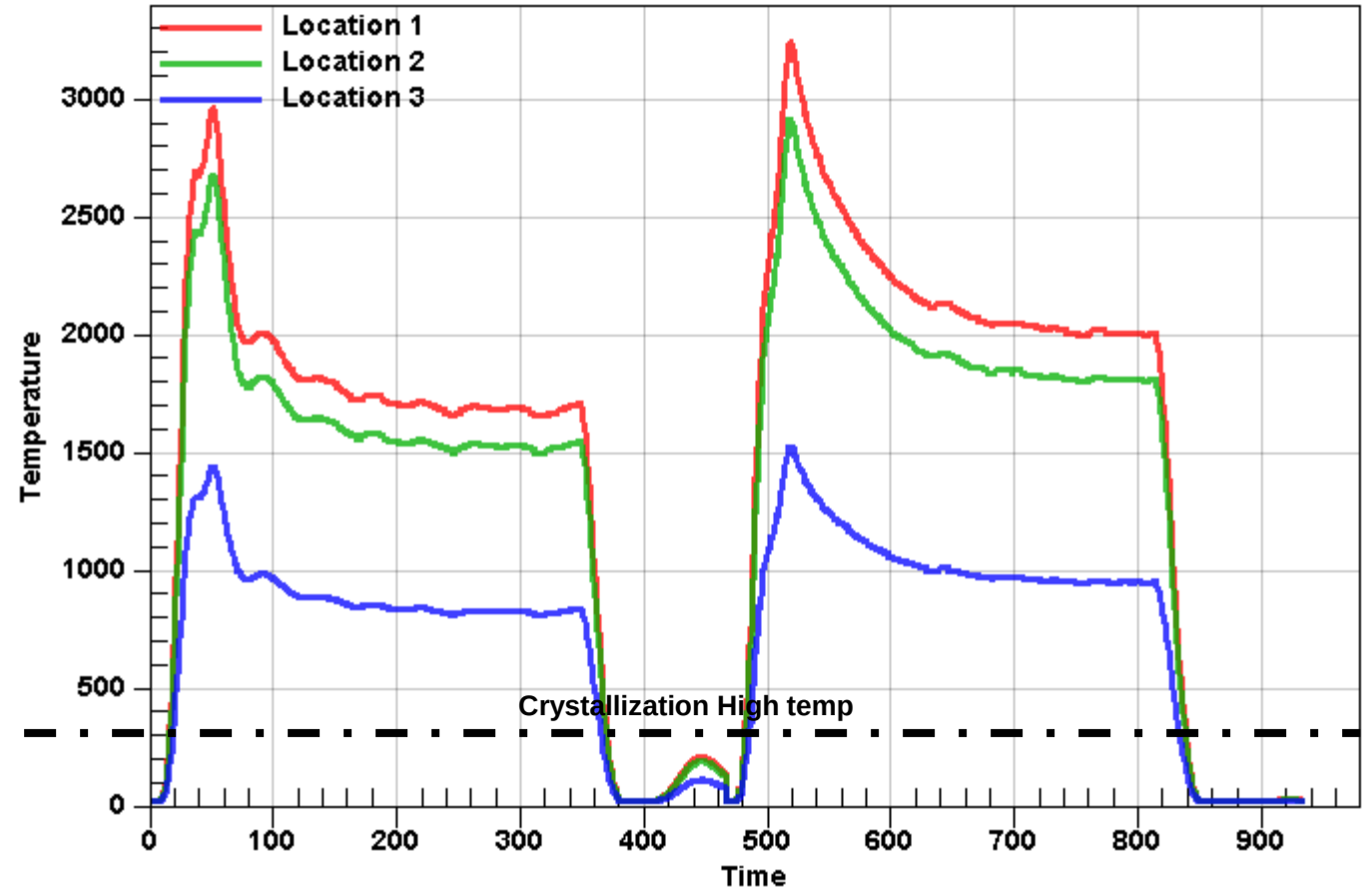
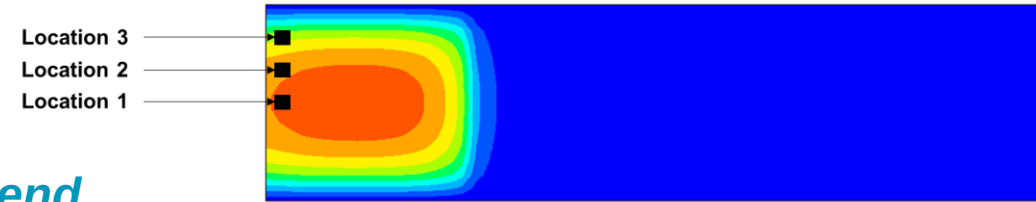
- Melt is total at all locations
- Re-crystallization happens early at location 3 after ~100 sec
- Due to faster cooling rates in the simulation, the re-crystallization is partial at location 1 and 2 – Similar results as observed in the single lap-shear test



# Double Lap-Shear Tests

## *Temperatures at the Different Locations in the Middle Adherend*

- Temperature in location 1 and 2 remain above crystallization for the entire duration of the welding process
- Temperatures in the middle adherend are way higher than in the upper or lower adherends
- Temperature at location 3 remains above crystallization for the entire duration of the heating element heat-up as opposed to the upper and lower adherends
- The cooling rates in the simulation are again higher than the cooling rate measured during the experiments



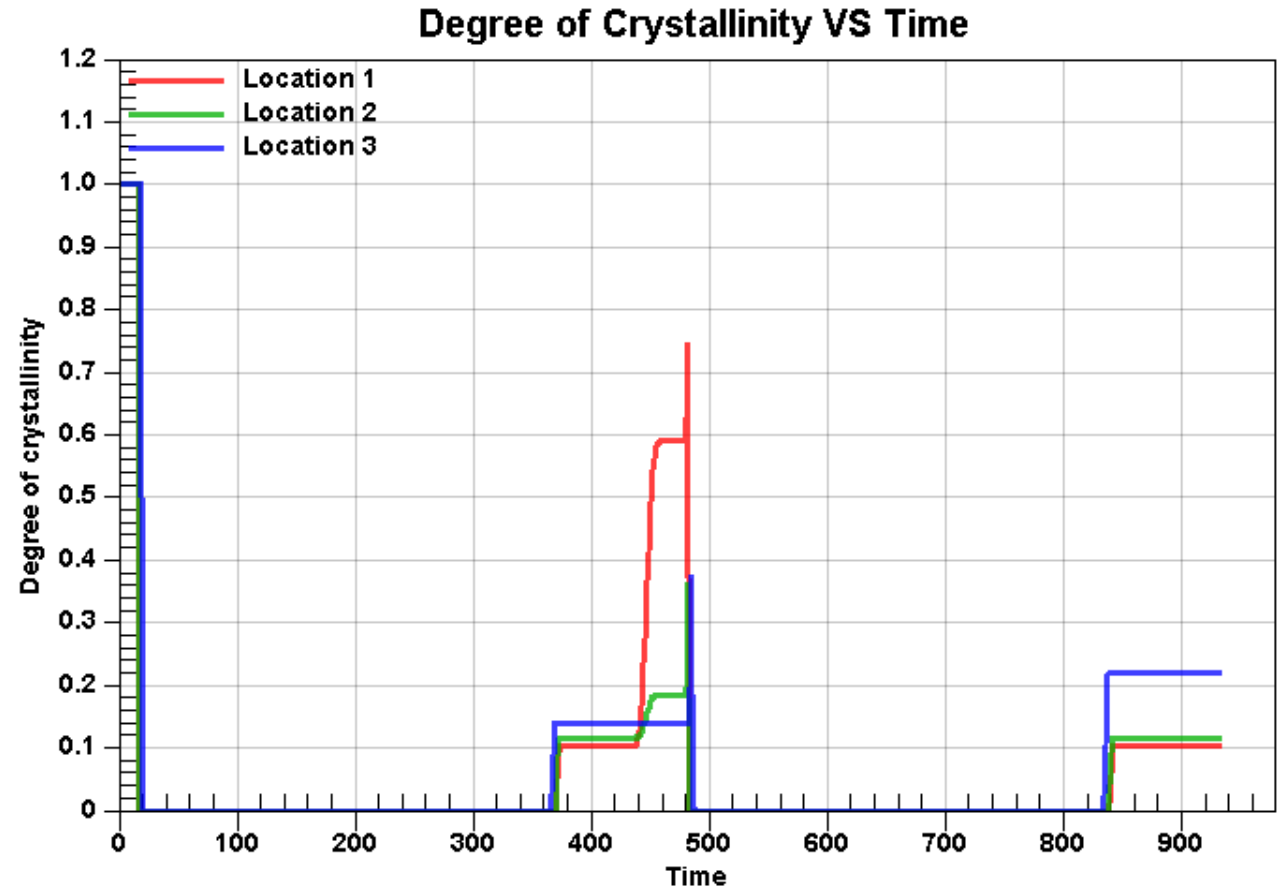
# Double Lap-Shear Tests

## *Degree of Crystallinity at the Different Locations in the both Adherends*

Location 3  
Location 2  
Location 1

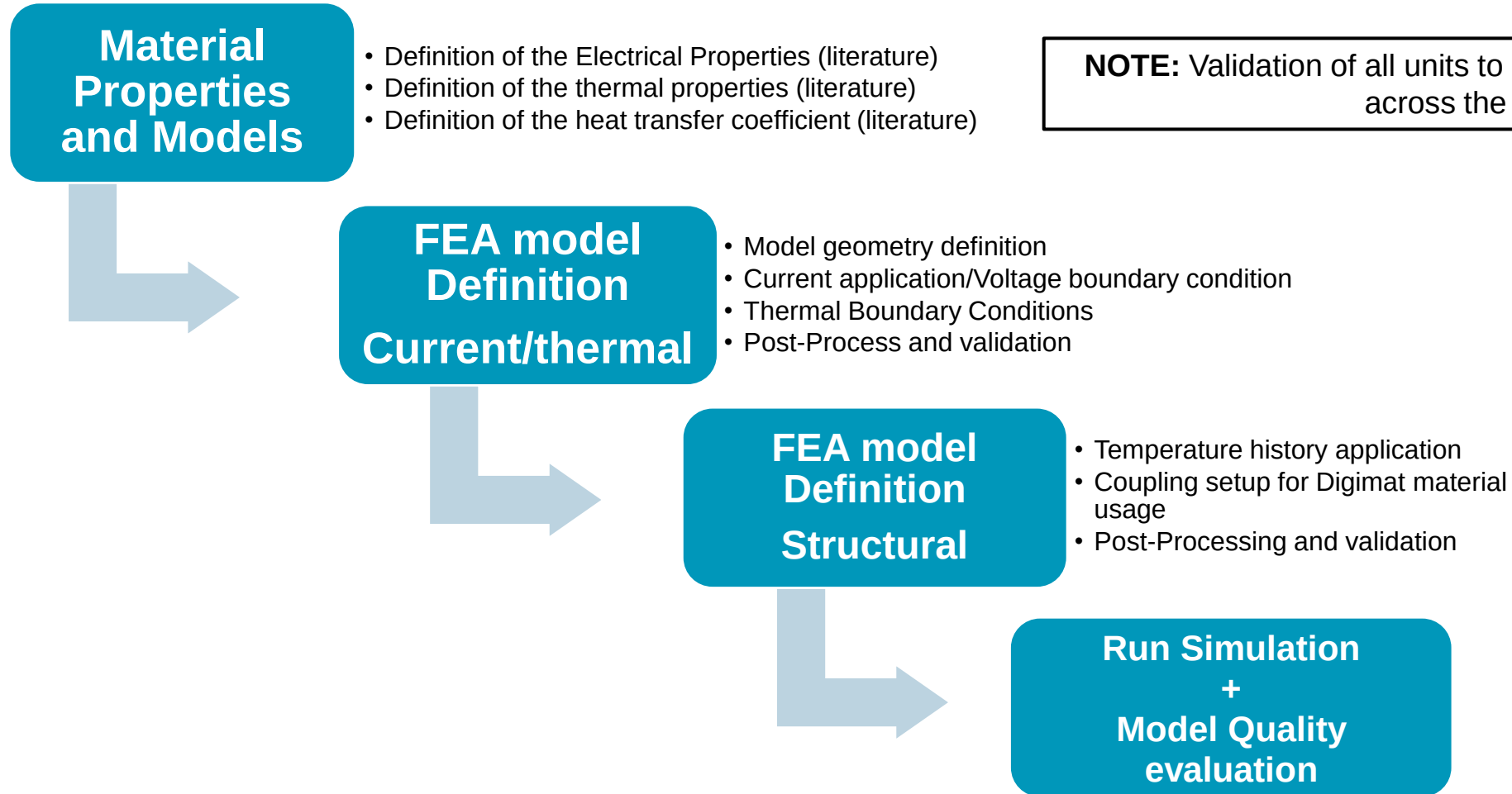


- Melt is total at all locations
- Re-crystallization happens only during cooling down in all locations
- Due to faster cooling rates in the simulation, the re-crystallization is partial at all locations



# Step 3

## Workflow



# Conclusion

# Crystallization Kinetic Models

## Calibration

### Two models have been calibrated:

- Double-Nakamura Weibull: *Capture cold and cooldown crystallization*
- Single-Nakamura Hoffman Lauritzen: *Capture cooldown crystallization only*

**Crystallization Kinetic Calibration:** The overall calibration was very good - method used led to a good fit.

- The model available in Digimat can only captures uniform trends (no asymmetric trends)
- The approach used for the calibration included 3 experimental curves followed by a validation over 2 other curves:
  - It might be better to include all experimental curves into the calibration process which may lead to a better overall fit

### Thermo-viscoelastic + Shift function

- A mix of experimental data from different origin was used which led to a reasonable calibration
- The approach confirms that the methodology works but requires some adjustments

# FEA Modeling

## *Current/Thermal Analysis & Structural Analysis (Usage of Thermal History)*

### **Current/Thermal Analysis:**

- Better identifications of the HTC between the different materials
- Experimental characterization of the different Electrical properties for the heating element would help improve the temperature estimation
- Accurate current/power application seems to have a non-negligeable impact on the temperature profile.

### **Structural Analysis:**

- The current TVE material model leads to high CPU times
- The crystallization results show that temperature measurement location identification is important as well as cooling methods

# General Conclusion

## *Structural Analysis (Usage of Thermal History)*

- The Crystallization kinetic characterization is simple and led to a good fit
- The TVE model calibration and experimental data acquisition can be a challenging process
- The current/Thermal analysis proved to be a relevant approach linking experimental inputs to simulation results.
- The structural analysis including crystallization shrinkage and thermal expansion is CPU intensive

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# Annex

# Test Data

## Summary

| Parameters                            | Test                                               | Data available                                                                 | Reference / Origin                                                                                                                                                                                                                                                                                                               |
|---------------------------------------|----------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Phase change properties               | DSC                                                | Dynamic (1,2,3,4,5,6,7,8,9,10 °C/min)<br>Isotherm                              | Test data provided by NASA                                                                                                                                                                                                                                                                                                       |
| Crystallization Kinetics              | DSC                                                | Dynamic (1,2,3,4,5,6,7,8,9,10 °C/min)<br>Isotherm                              | Test data provided by NASA                                                                                                                                                                                                                                                                                                       |
| Density                               |                                                    | <b>ρ as a function of Temperature</b><br>(0,50,100,150,200,250,300,350,400)°C  | <b>Data extracted from:</b><br>C. Ageorges, L. Ye, Y.-W. Mai, and M. Hou, “Characteristics of resistance welding of lap shear coupons. Part I: Heat transfer.”                                                                                                                                                                   |
| Specific Heat Capacity                | Specific Heat Capacity (Cp)                        | <b>Cp as a function of Temperature</b><br>(0,50,100,150,200,250,300,350,400)°C | <b>Data extracted from:</b><br>C. Ageorges, L. Ye, Y.-W. Mai, and M. Hou, “Characteristics of resistance welding of lap shear coupons. Part I: Heat transfer.”                                                                                                                                                                   |
| Thermal Conductivity<br>ASTM E1530-19 | Thermal conductivity (K)                           | <b>K as a function of temperature</b><br>(0,50,100,150,200,250,300,350,400)°C  | <b>Data extracted from:</b><br>C. Ageorges, L. Ye, Y.-W. Mai, and M. Hou, “Characteristics of resistance welding of lap shear coupons. Part I: Heat transfer.”                                                                                                                                                                   |
| Shear Modulus<br>(Prony Series)       | DMA<br>(Torsional)<br>(Tensile or 3-point bending) | <b>Tensile modulus</b><br>(0.1 Hz, 1Hz, 10Hz)<br><b>Shear modulus</b><br>(1Hz) | <b>Test data provided by NASA and Additional data extracted from:</b><br><br>R. Yaseen, H. Al-Mezrakchi, K. T. Hartwig, and S. Rathinam, “MANUFACTURING PROCESSING AND PROPERTIES MANIPULATIONS OF THICK ADVANCED PERFORMANCE PEEK POLYMER AND COMPOSITES FOR BIOMEDICAL AND EXTREMELY HARSH ENVIRONMENTS A Dissertation,” 2019. |
| Bulk Modulus<br>(Prony Series)        |                                                    | Calculation from Shear and Bulk Moduli                                         | Test data provided by NASA                                                                                                                                                                                                                                                                                                       |

# Test Data

## Summary

| Parameters                                  | Test                                               | Data available                                                                 | Reference / Origin                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|---------------------------------------------|----------------------------------------------------|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| C1 and C2                                   | DMA<br>(Torsional)<br>(Tensile or 3-point bending) | Tensile modulus (T dependent)<br>(0.1 Hz, 1Hz, 10Hz)<br>Shear modulus<br>(1Hz) | Test data provided by NASA and Additional data extracted from:<br><br>R. Yaseen, H. Al-Mezrakchi, K. T. Hartwig, and S. Rathinam, "MANUFACTURING PROCESSING AND PROPERTIES MANIPULATIONS OF THICK ADVANCED PERFORMANCE PEEK POLYMER AND COMPOSITES FOR BIOMEDICAL AND EXTREMELY HARSH ENVIRONMENTS A Dissertation," 2019.                                                                                                                                                                                                                                                                                                                                                                                                                                |
| C1 and C2<br>(Crystallization)              | DMA<br>(Torsional)<br>(Tensile or 3-point bending) | Tensile modulus (T dependent)<br>(0.1 Hz, 1Hz, 10Hz)<br>Shear modulus<br>(1Hz) | Test data provided and Additional data extracted from:<br><br>C. Bas, M. Fugier, and N. D. A. Rola, "Reinforcement Effect and Molecular Motions in Semicrystalline PEEK Films: Mechanical and Physical Modelings. I," John Wiley & Sons, Inc, 1997.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                      |
| Thermal Expansion Coefficient               | TMA                                                | Coefficient of Thermal Expansion<br>(CTE)                                      | Data extracted from:<br><a href="http://www.theplasticshop.co.uk/plastic_technical_data_sheets/peek_1000_technical_data_sheet.pdf">www.theplasticshop.co.uk/plastic_technical_data_sheets/peek_1000_technical_data_sheet.pdf</a><br><br>B. Ghosh, F. Xu, and X. Hou, "Thermally conductive poly(ether ether ketone)/boron nitride composites with low coefficient of thermal expansion," J Mater Sci, vol. 56, no. 17, pp. 10326–10337, Jun. 2021, doi: 10.1007/s10853-021-05923-0.<br><br>M. Nikonovich, J. F. S. Costa, A. C. Fonseca, A. Ramalho, and N. Emami, "Structural, thermal, and mechanical characterisation of PEEK-based composites in cryogenic temperature," Polym Test, vol. 125, Aug. 2023, doi: 10.1016/j.polymertesting.2023.108139. |
| Maximum volumetric crystal shrinkage strain | pVT (or TMA)                                       | Volumetric change                                                              | Data extracted from:<br>L. Benedetti, B. Brulé, N. Decreamer, K. E. Evans, and O. Ghita, "Shrinkage behaviour of semi-crystalline polymers in laser sintering: PEKK and PA12," Mater Des, vol. 181, Nov. 2019, doi: 10.1016/j.matdes.2019.107906.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                        |