



Thermoplastic Resistance Welding with a Carbon Fiber Heating Element Phase II



An assessment of the use of a Carbon Fiber Heating Element in Resistance Welding for PPS, PEI, LM-PAEK, and PEKK Thermoplastic Composite

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Scope

This document outlines an assessment of the quality and performance of thermoplastic composite welded single lap shear joints and mode one joints. The technique of resistance welding PPS, PEI, LM-PAEK, and PEKK thermoplastic composite with a carbon fiber heating element was used in this research.

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1.0 APPLICABLE DOCUMENTS

The latest issue of the publications shall apply. If a referenced document has been canceled and no superseding document has been specified, the last published issue of that document shall apply.

1.1 ASTM Publications

ASTM D3418-21	Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry
ASTM D5868-01	Standard Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding
ASTM D5528-01	Standard Test Method for Mode I Interlaminar Fracture Toughness of Unidirectional Fiber-Reinforced Polymer Matrix Composites

1.2 Abbreviations and Acronyms

ASTM	American Society for Testing and Materials
DCB	Double Cantilever Beam
DSC	Differential Scanning Calorimetry
FOD	Foreign Object Debris
G_{Ic}	Mode I Fracture Toughness
IM	Intermediate Modulus
IPA	Isopropyl Alcohol
LM-PAEK	Low-Melt Polyaryletherketone
NASA	The National Aeronautics and Space Administration
NDI	Non-Destructive Inspection
NIAR	National Institute for Aviation Research
PAEK	Polyaryletherketone
PEI	Polyetherimide
PEKK	Polyetherketoneketone
PPS	Polyphenylene Sulfide
RW	Resistance Weld
SLS	Single Lap Shear
SM	Standard Modulus
TPC	Thermoplastic Composite
ΔH_f°	Theoretical maximum heat of fusion for a fully crystalline sample

2.0 Requested Test Matrix

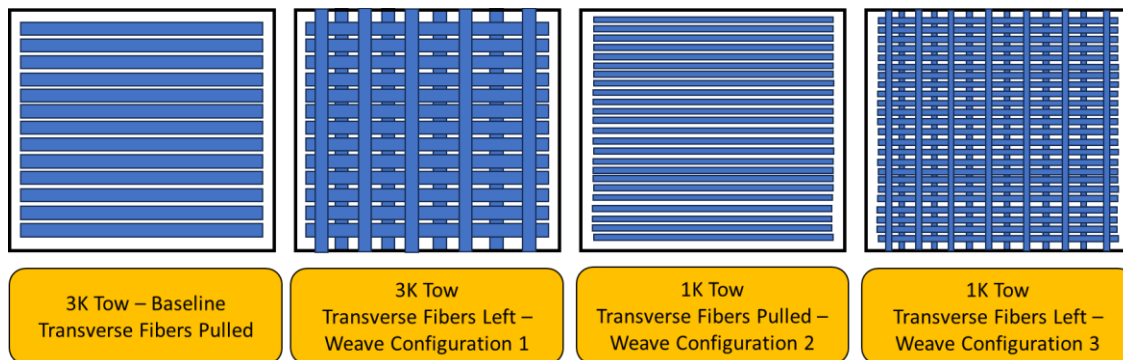
The requested test matrix from NASA is shown below in Table 1. Four material systems were compared in this research – TC1100 AS4/PPS, Solvay AS4/PEI, TC1225 T700/LM-PAEK, and M30S/PEKK. Two main test methods (SLS and DCB) were utilized in this study. DSC coupons and photomicrograph coupons were extracted from each type of joint for weld quality inspection. The modified fiber weave configurations are shown below in Table 2.

Table 1 – NASA Requested Test Matrix

Material system	Welding approach	Specimen count	
		SLS	DCB
AS4/PPS (TC1100)	Resistance	12	6
AS4/PEI (Solvay)	Resistance	12	6
T700/LM-PAEK (TC1225)- Baseline	Resistance	12	6
T700/LM-PAEK (TC1225) (modified fiber weave-1)	Resistance	5	0
T700/LM-PAEK (TC1225) (modified fiber weave-2)	Resistance	5	0
T700/LM-PAEK (TC1225) (modified fiber weave-3)	Resistance	5	0
M30S/PEKK (thin ply)	Resistance	12	0
Totals		63	18

Total welds = 81

Table 2 – Carbon Fiber Heating Element Weave Configurations



3.0 Definition of Welding Process

3.1 Single Lap Shear Baseline Manufacturing

Materials must be prepared for the welding process. For the single lap shear configuration two substrates, two resin films (compatible with substrate, 60 μ m), and one carbon fiber heating element (3K Tow - Thickness = 0.012") must be acquired as seen below in Figure 1.

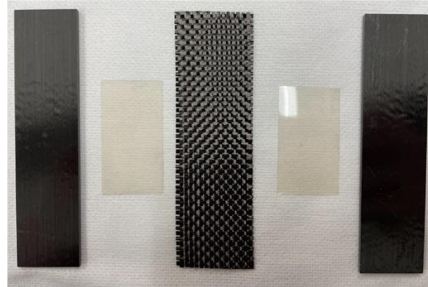


Figure 1 – SLS Material Example

After materials are prepped, the transverse fibers in the carbon fiber heating element must be removed as seen below in Figure 2. It's important to keep the same number of longitudinal fibers so that the resistance value stays consistent. Only remove the transverse fibers that will be in the weld area or in this case the middle inch of the heating element.

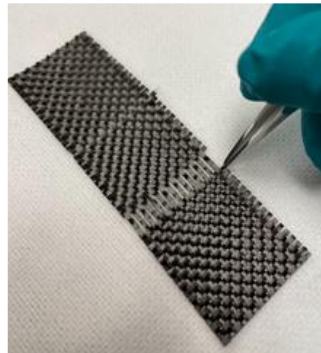


Figure 2 – Removing Transverse Fibers from CFHE

After the heating element is prepared, wipe down both substrates and resin films in order to reduce the risk of FOD at the weld line. Ensure the IPA has dried before placing any shims onto the substrate.



Figure 3 – Degreasing Substrate and Resin

After degreasing the welding materials with IPA, locate the appropriate metal shims for the weld joint. These shims are stainless steel wrapped in high-temperature Kapton tape. The overall thickness of each shim is around 0.02". Measure out 1" from the substrate edge as seen in Figure 4. Attach shims with high temperature Kapton tape.

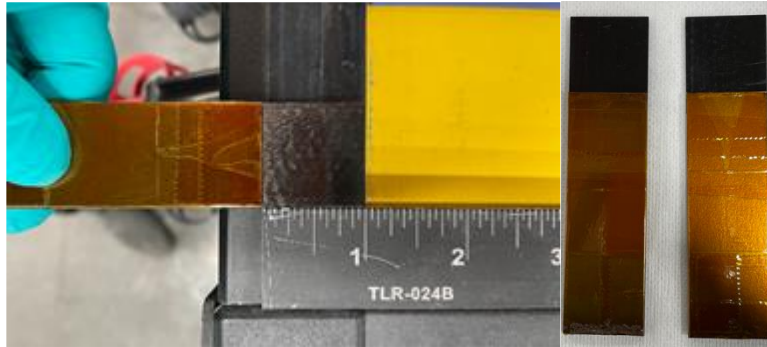


Figure 4 – Attaching Metal Shims

In the case of the PEKK material, process development welds were completed with the surface preparation of degrease only but the welded joints were unsatisfactory. For this reason the substrates were sanded with a P120 Grit sand paper to remove the resin layer and expose the bare fibers before welding took place. These process photos can be seen below in

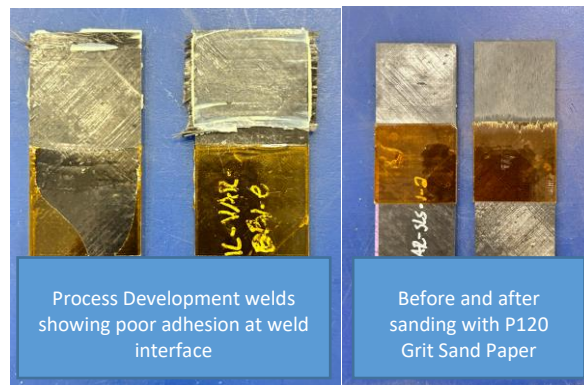


Figure 5 – PEKK Sanding Process Photos

After the shims have been attached to the substrates, place the first substrate into the welding fixture ensuring the edges are flush with the copper terminals as seen below in Figure 6. Use tension clamps to secure the first substrate into place.

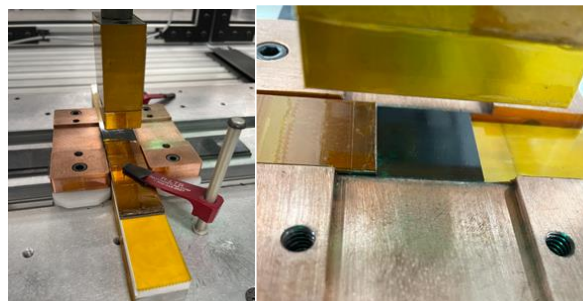


Figure 6 - First Substrate Placement

Place the resin films and carbon fiber heating element into the copper terminals as shown in Figure 7. Make sure the longitudinal fibers in the heating element are undisturbed as this can vary the resistance value.

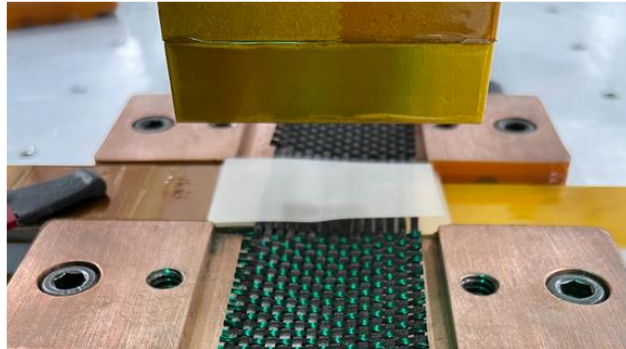


Figure 7 – Weld Stack

Tighten the copper terminals and place the second substrate on top of the weld stack and secure it with the secondary tension clamp as seen in Figure 8.

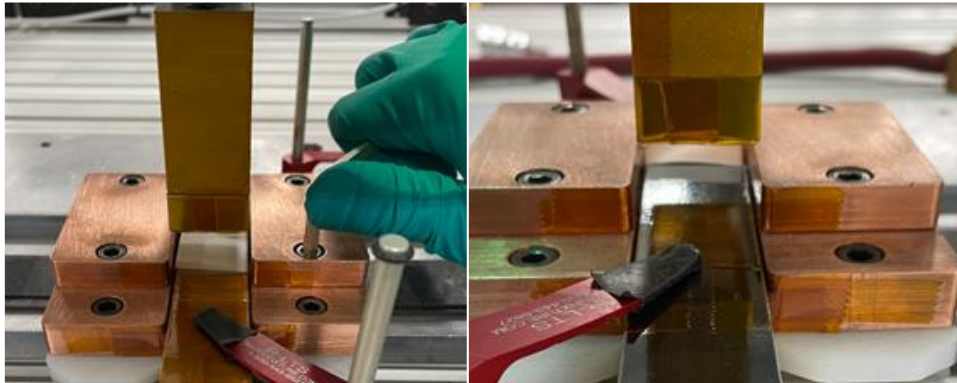


Figure 8 – Second Substrate Placement

Place the ceramic block and silicone block on top of the secondary substrate and attach the welding leads as seen in Figure 9.

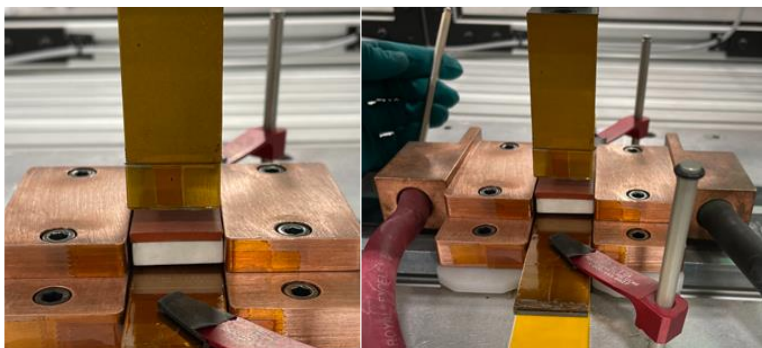


Figure 9. Pressure Block Placement and Welding Leads

Apply pressure with the appropriate actuator as seen in Figure 10. Select the proper weld cycle and run the weld program. Once the welding is complete, take the pressure off and take the specimen out of the weld fixturing.



Figure 10 – Pressure Application

3.2 Mode I Manufacturing

Materials must be prepared for the welding process. For the mode I configuration two substrates, two resin films (compatible with substrate), and one carbon fiber heating element must be acquired as seen below in Figure 11.

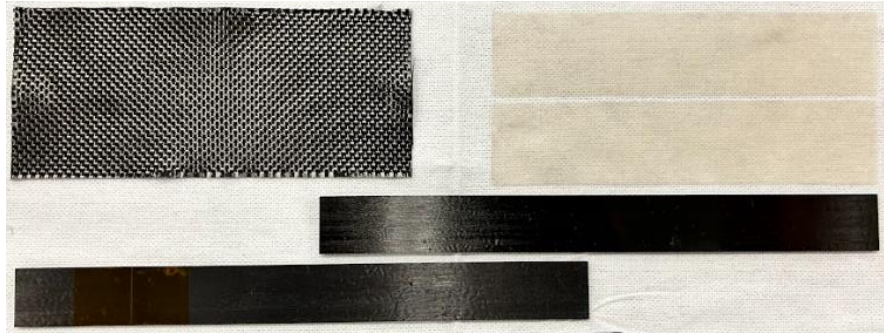


Figure 11 – Mode I Materials

After materials are prepped, the transverse fibers in the carbon fiber heating element must be removed as seen below in Figure 12. It's important to keep the same number of longitudinal fibers so that the resistance value stays consistent. Only remove the transverse fibers that will be in the weld area or in this case the middle inch of the heating element. After the heating element is prepared wipe down the substrates and resin films with IPA to mitigate any FOD at the weld line.



Figure 12 – Mode I / Mode II CFHE

For Mode I a thermoplastic composite base was used in order to place the materials more concisely. Two shims were used on either side of the coupon in order to create a zero-level entry for the heating element. Fiberglass insulation was attached on top of the shim in order for the heating element to not react with the shim as shown in Figure 13. The main difference in Phase II with the Mode I welding was that the heating element was separated into six 1” heating elements as opposed to one continuous heating element. This was done because the power supply that was used last time was under repair and the power supply that was working did not have the capacity to run the weld with a continuous heating element (more power is required in the continuous heating element setup than the discontinuous heating element setup). This also enabled the same process to be used for every weld section within a material system unlike in Phase I where a different process was used on the edge and middle sections.

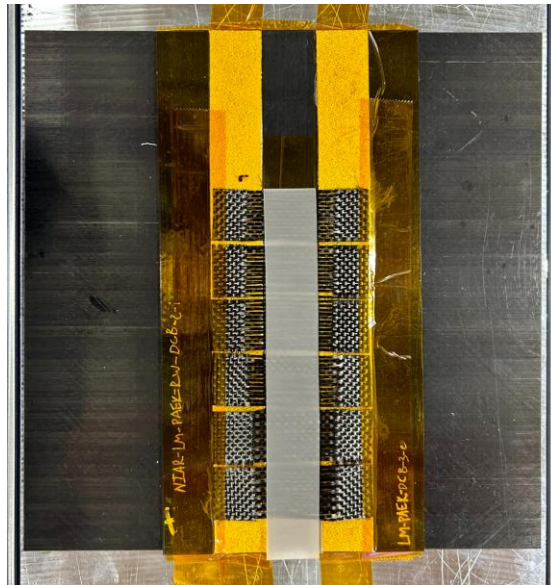


Figure 13 – Mode I Material Placement

After all of the materials are secured into place, the entire base is moved under the appropriate actuator and pressure is applied in the same way as the single lap shear setup as shown in Figure 14. The welding leads are then tied into each section and each weld section is completed until the whole specimen is welded together.



Figure 14 – DCB Manufacturing Setup

4.0 Weld Processing Data

4.1 Process Development Data

In the resistance welding process there are multiple data points recorded for every weld. These include pressure, resistance, voltage, current, and weld time. In process developments, K-Type micro-thermocouples are placed at the weld line and interface temperature is recorded. The utilized processing temperatures for these materials came from a recommendation from the material supplier. There were two main process developments for each material type. The primary weld in the single lap shear coupon, and each weld in the mode I coupons. The process development thermocouple locations for the different configurations are shown below in Figure 15.

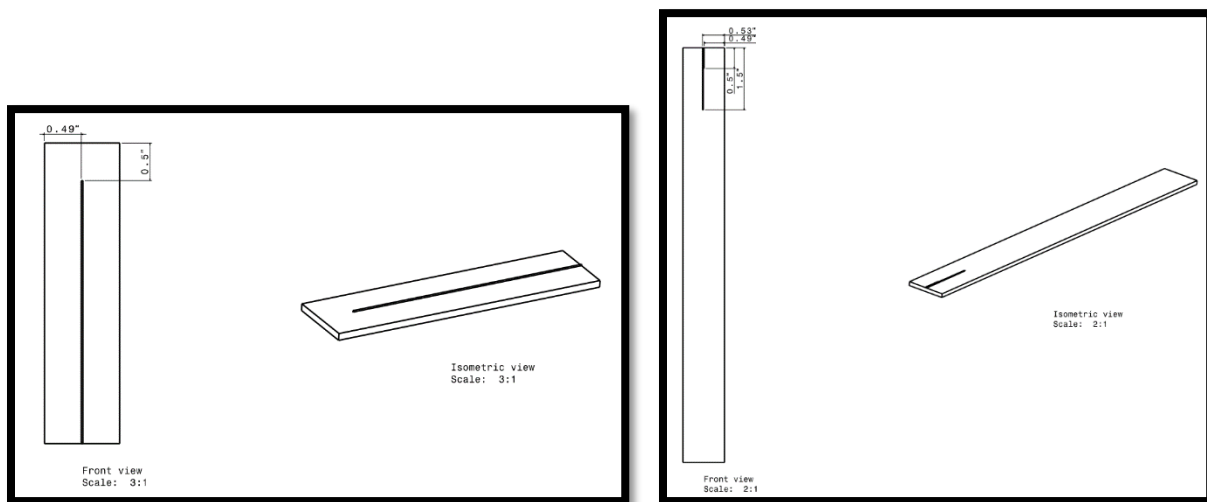


Figure 15 – SLS and Mode I Thermocouple Locations

The first chart shows the initial temperature control run. This data shows what power is needed in order to achieve the desired temperature. This is done by controlling a PID loop and automatically adjusting the power supply level.

Once this data is acquired, a power curve optimization or derivation is done to produce a power control curve in the welding software. The power curve is then ran while still monitoring the temperature at the interface. Multiple iterations may be needed in order to achieve the desired temperature response but once the temperature response is acceptable, the process development is now completed. The last check is making sure the temperature control resistance and power control resistance is similar just to ensure a defect was not developed in the heating element during process development. The process developments for processes A-K are shown below.

4.1.1 LM-PAEK Single Lap Shear Process Development

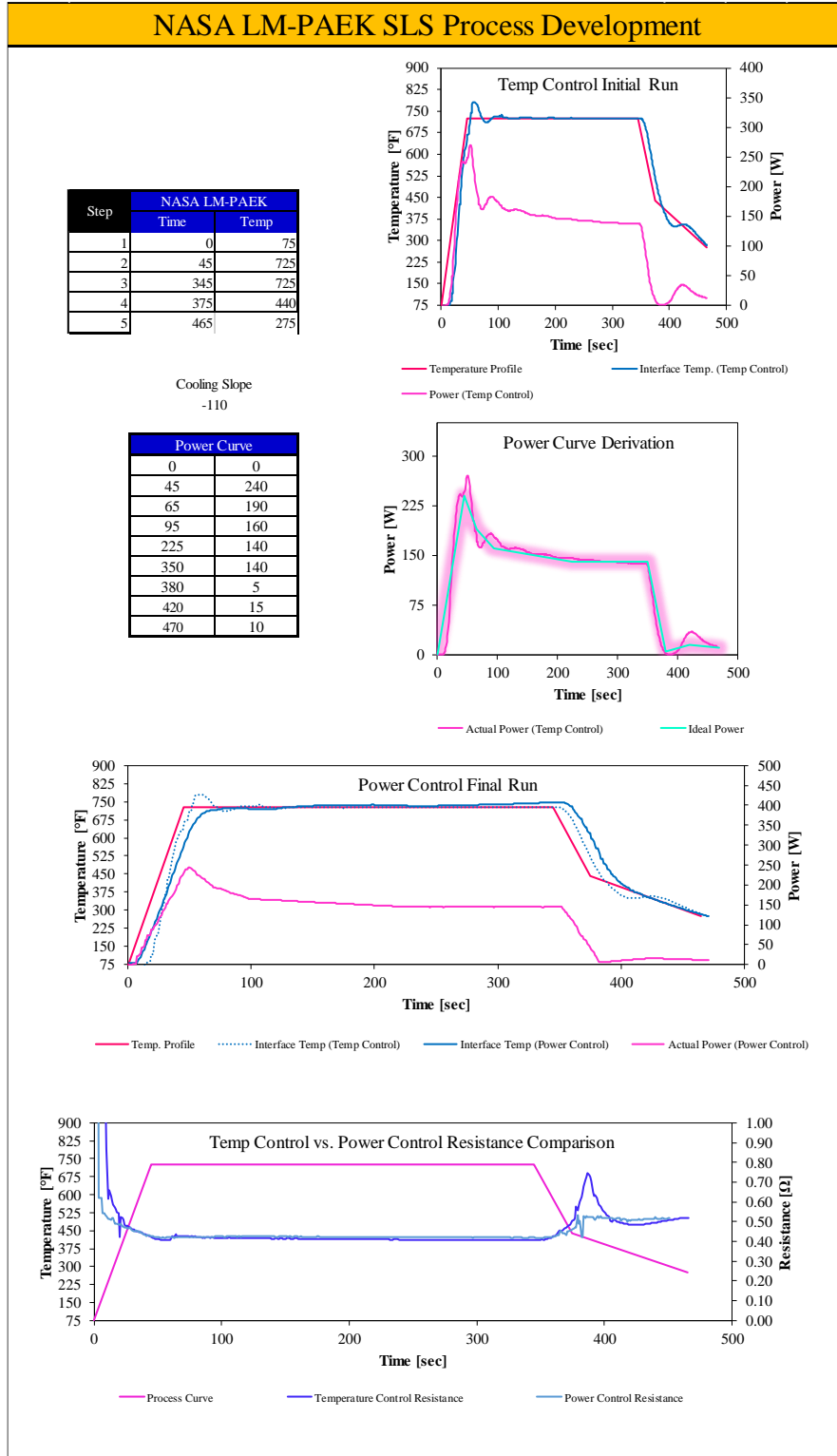


Figure 16 – LM-PAEK SLS Process Development

4.1.2 PEI Single Lap Shear Process Development

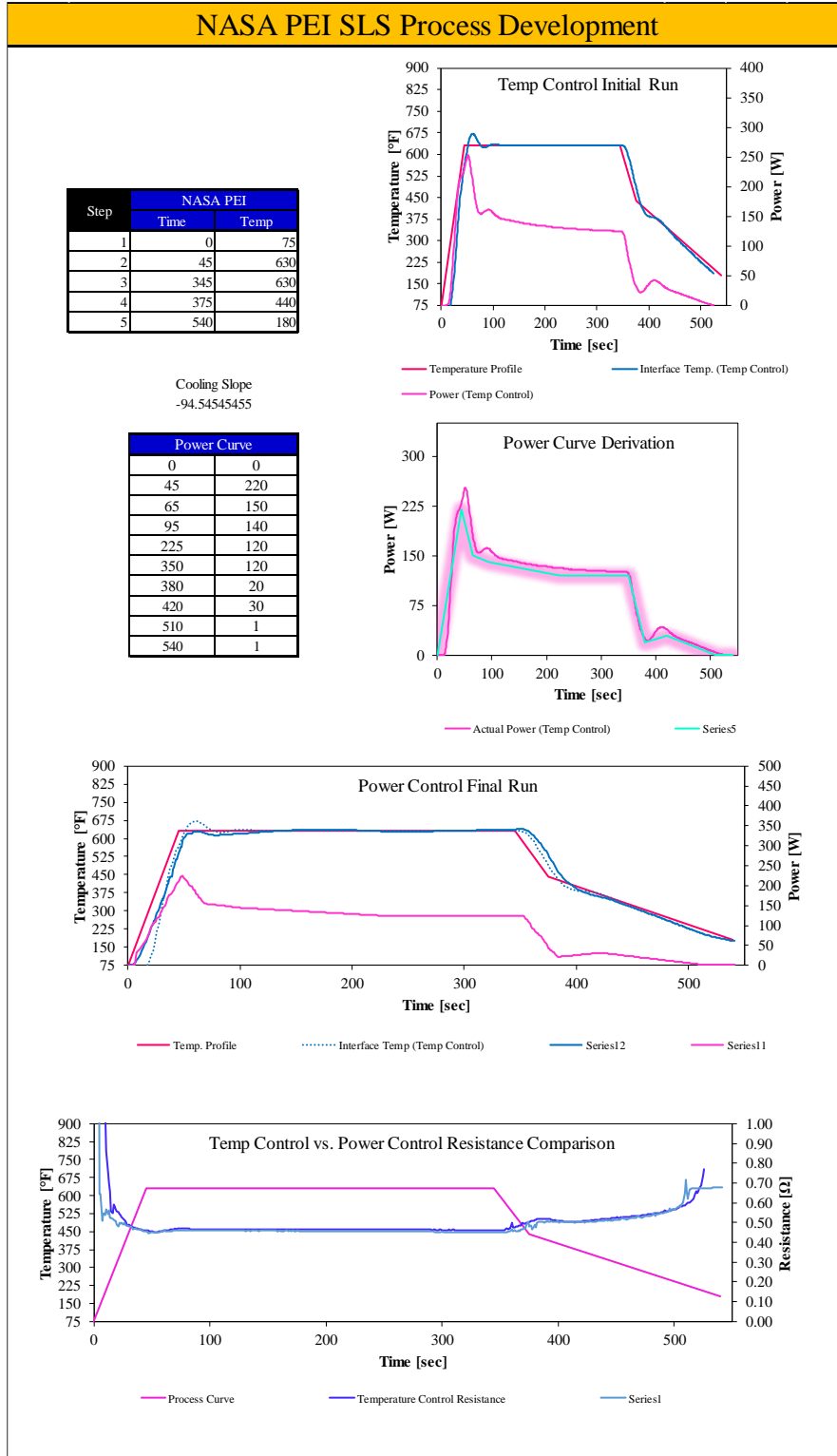


Figure 17 – PEI Single Lap Shear Process Development

4.1.3 PEKK Single Lap Shear Process Development

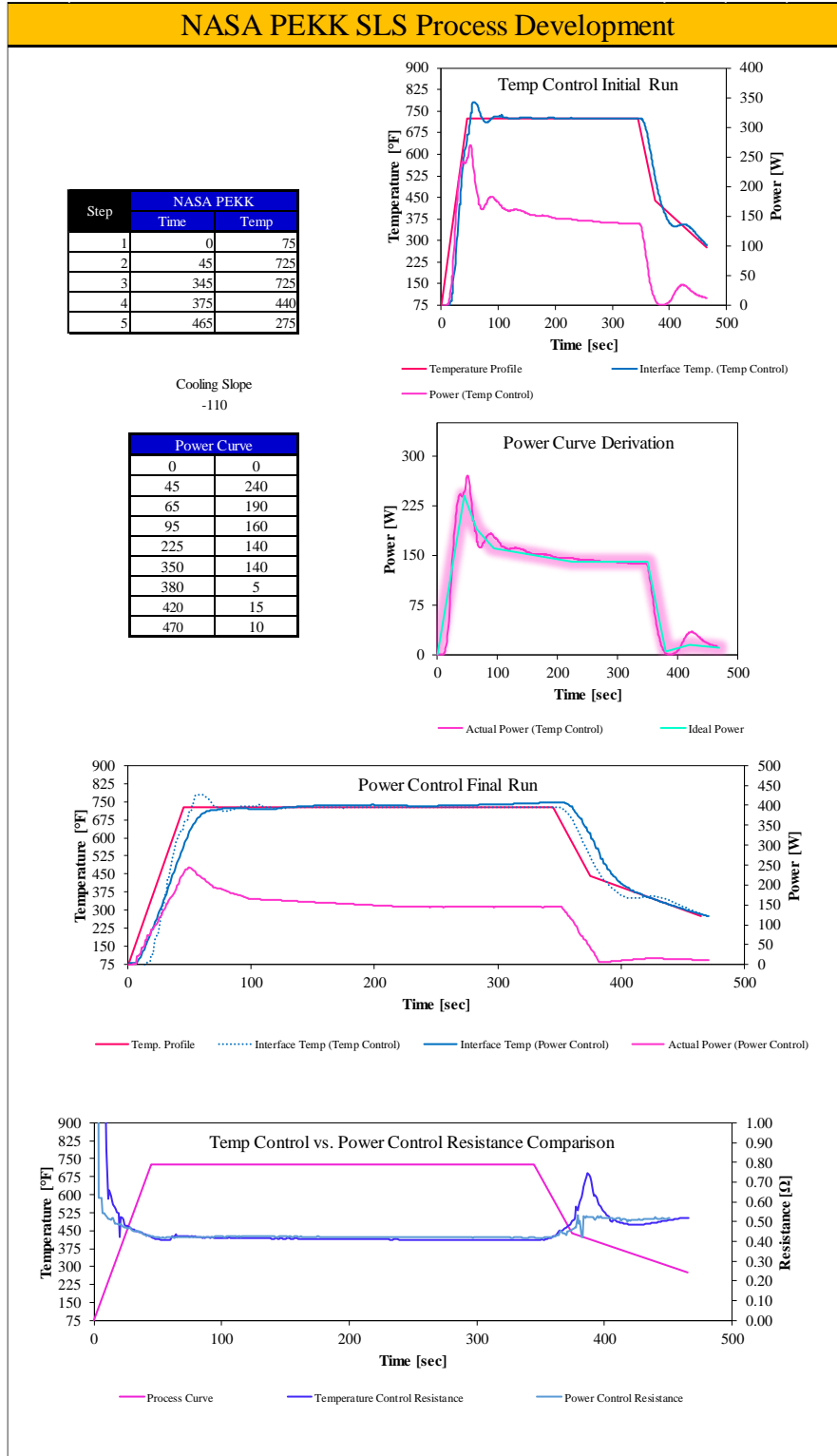


Figure 18 – PEKK Single Lap Shear Process Development

4.1.4 PPS Single Lap Shear Process Development

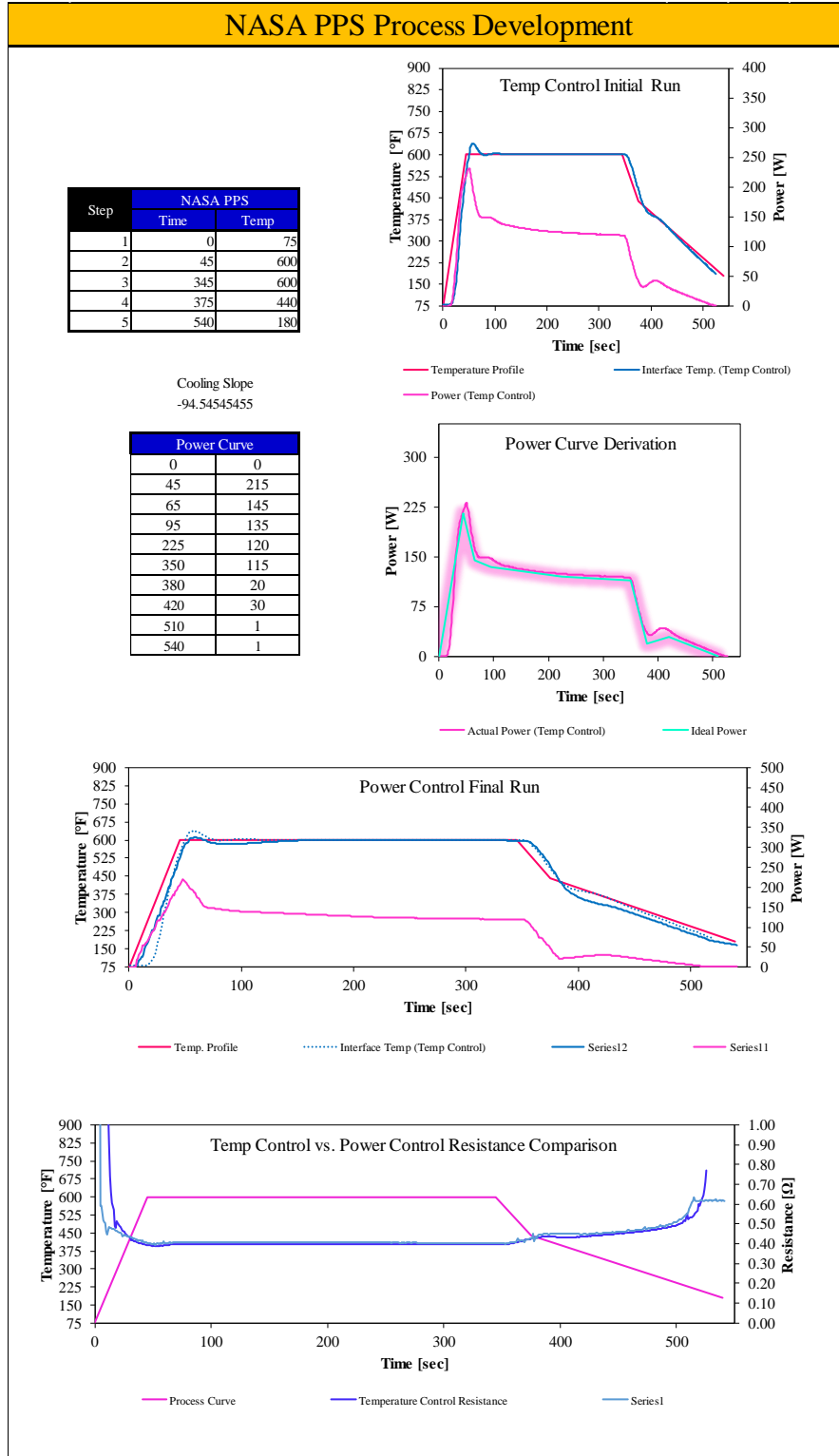


Figure 19 – PPS Single Lap Shear Process Development

4.1.5 LM-PAEK DCB Process Development

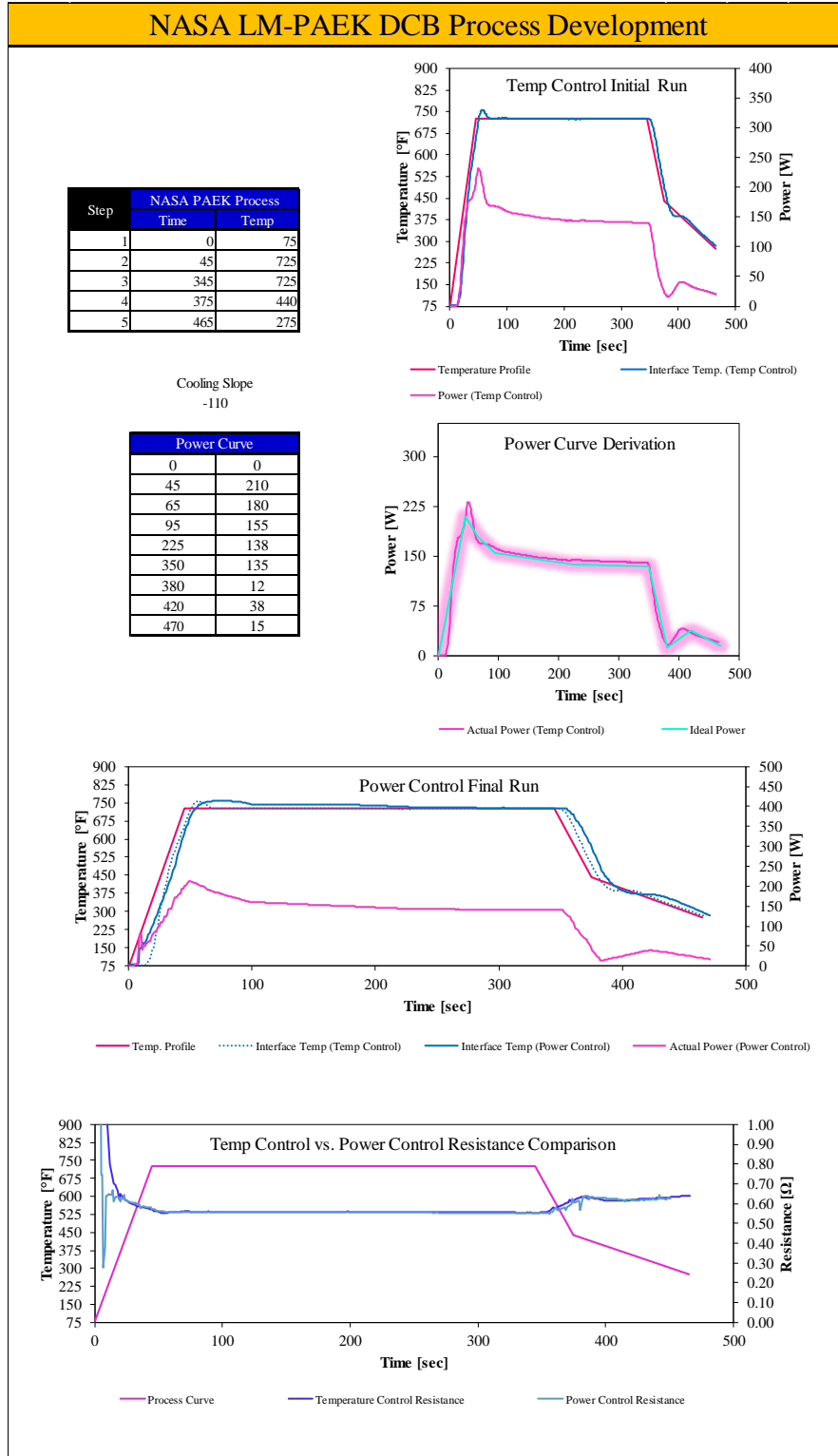


Figure 20 – LM-PAEK DCB Process Development

4.1.6 PEI DCB Process Development

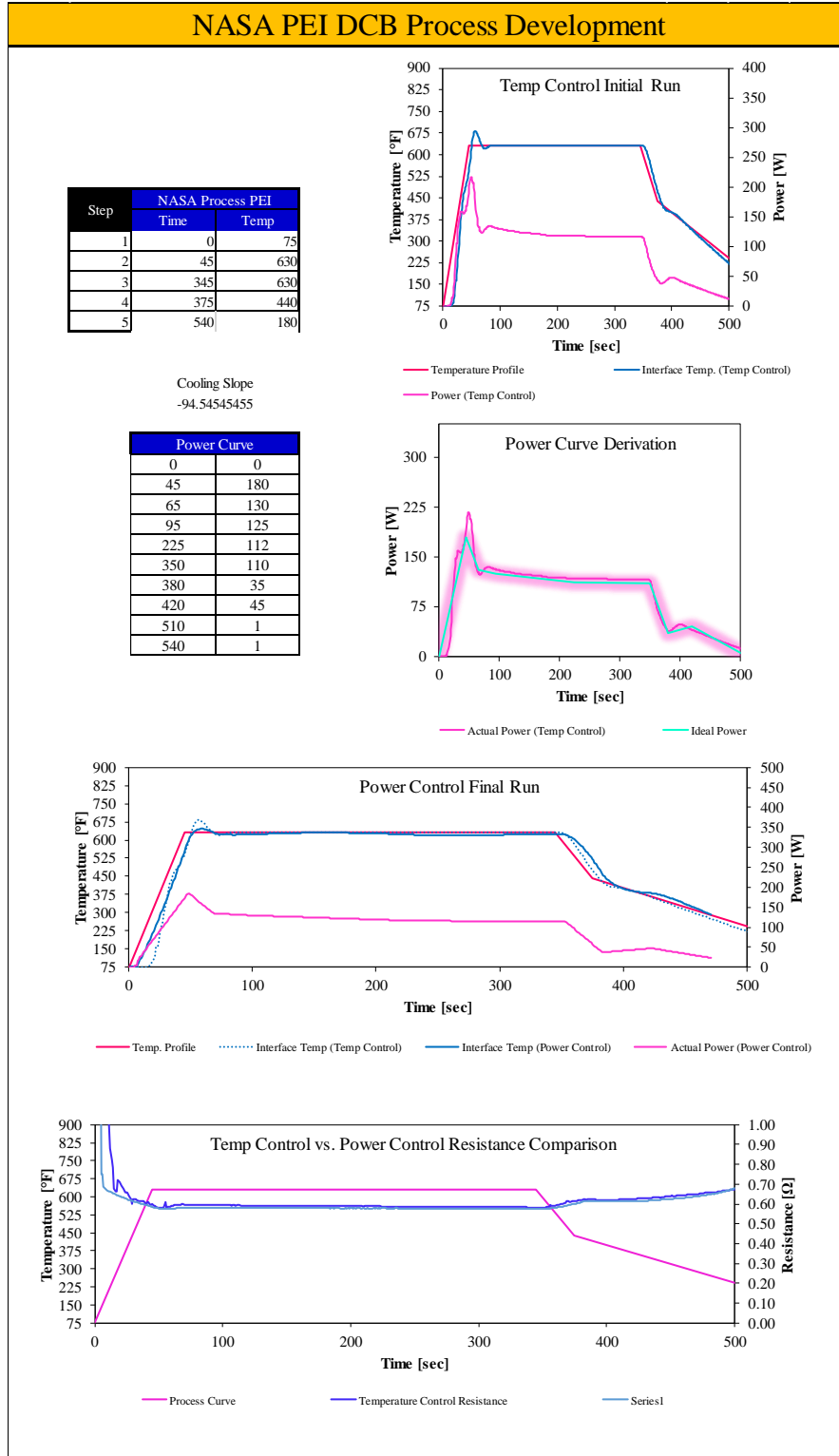


Figure 21 – PEI DCB Process Development

4.1.7 PPS DCB Process Development

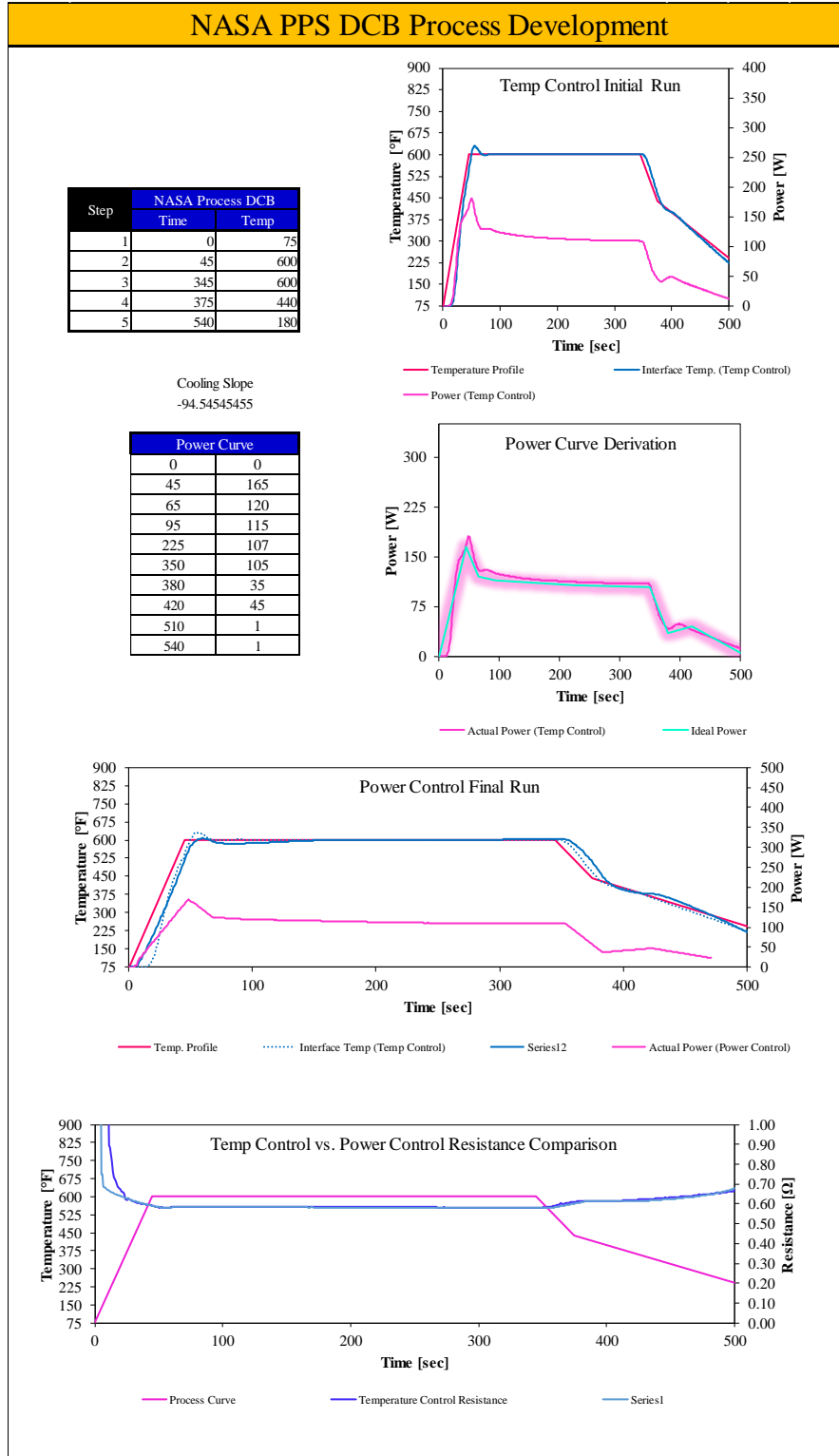


Figure 22 - PPS DCB Process Development

4.2 Welding Metrics

For each weld, resistance data and power data was captured. For single lap shear there was one weld per specimen and for Mode I there were six welds per specimen. The summaries for the welding metrics can be seen in this section.

4.2.1 LM-PAEK SLS Welding Metrics Summary

It can be seen in this summary that the power used was very consistent and the resistance had a range of +/- 0.2 ohms from the process development. Typically a resistance of +/- 0.1 ohms is desired but this range could also be due to changing the heating element configurations within the LM-PAEK material category.

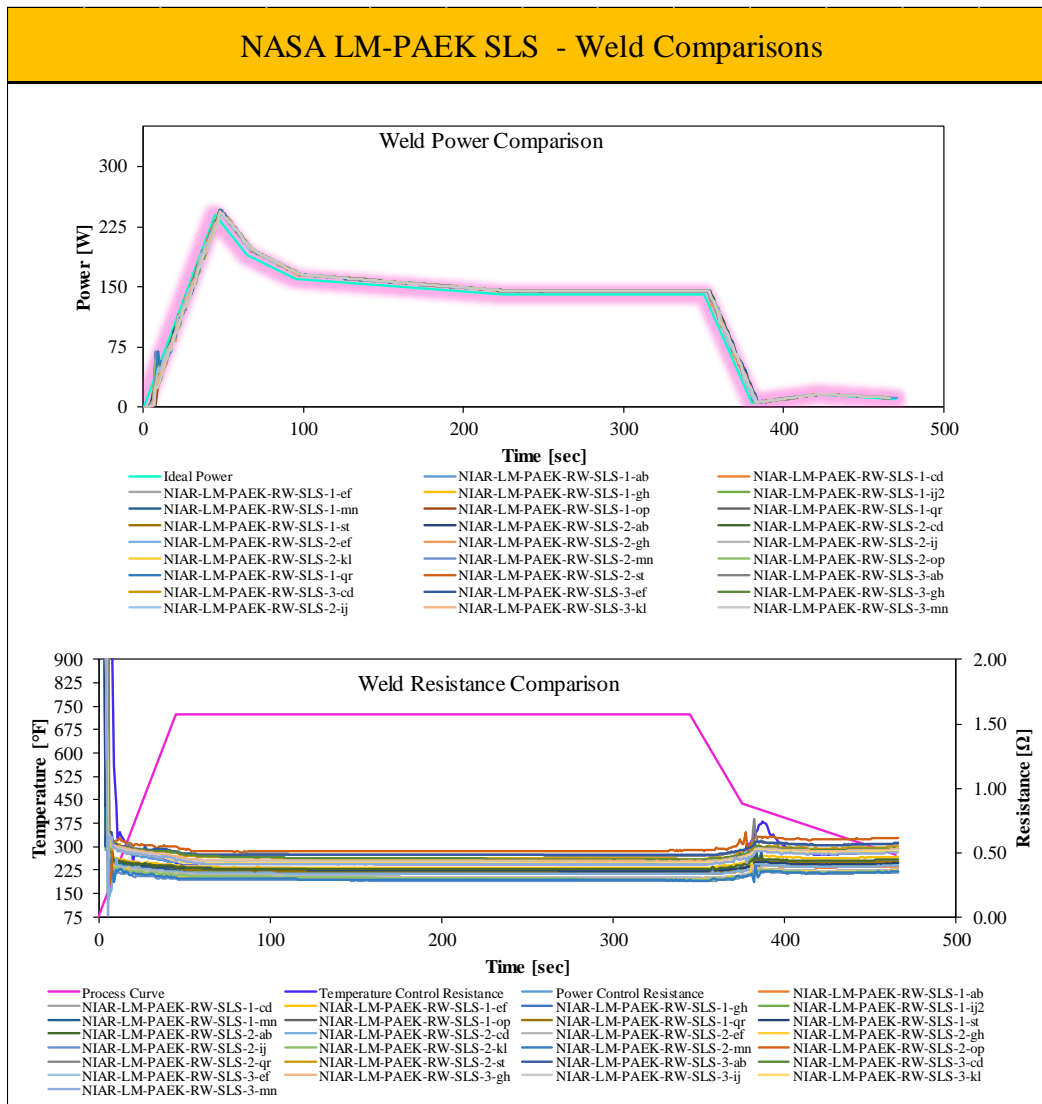


Figure 23 – LM-PAEK SLS Welding Metrics Summary

4.2.2 PEI SLS Welding Metrics Summary

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

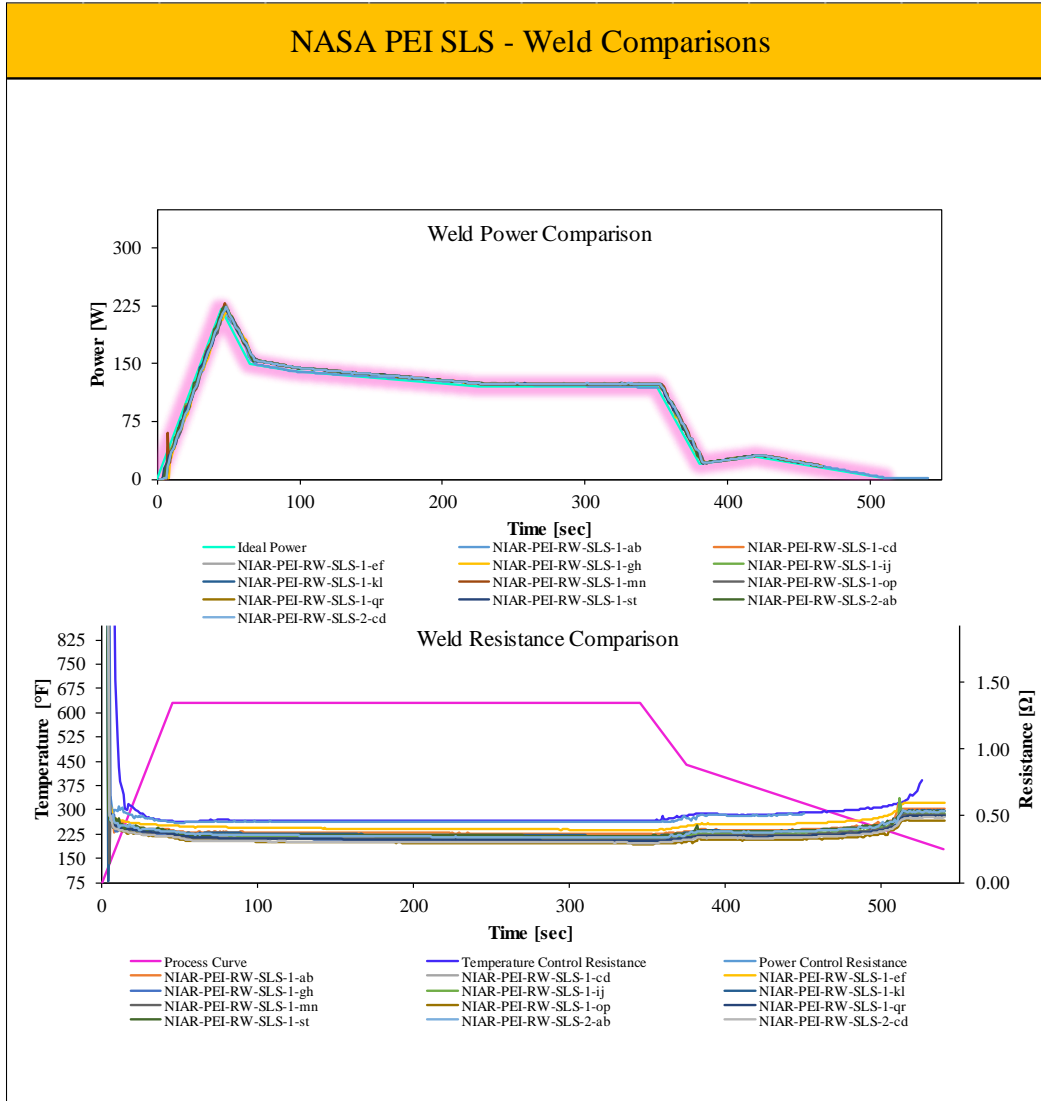


Figure 24 – PEI SLS Welding Metrics Summary

4.2.3 PEKK SLS Welding Metrics Summary

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

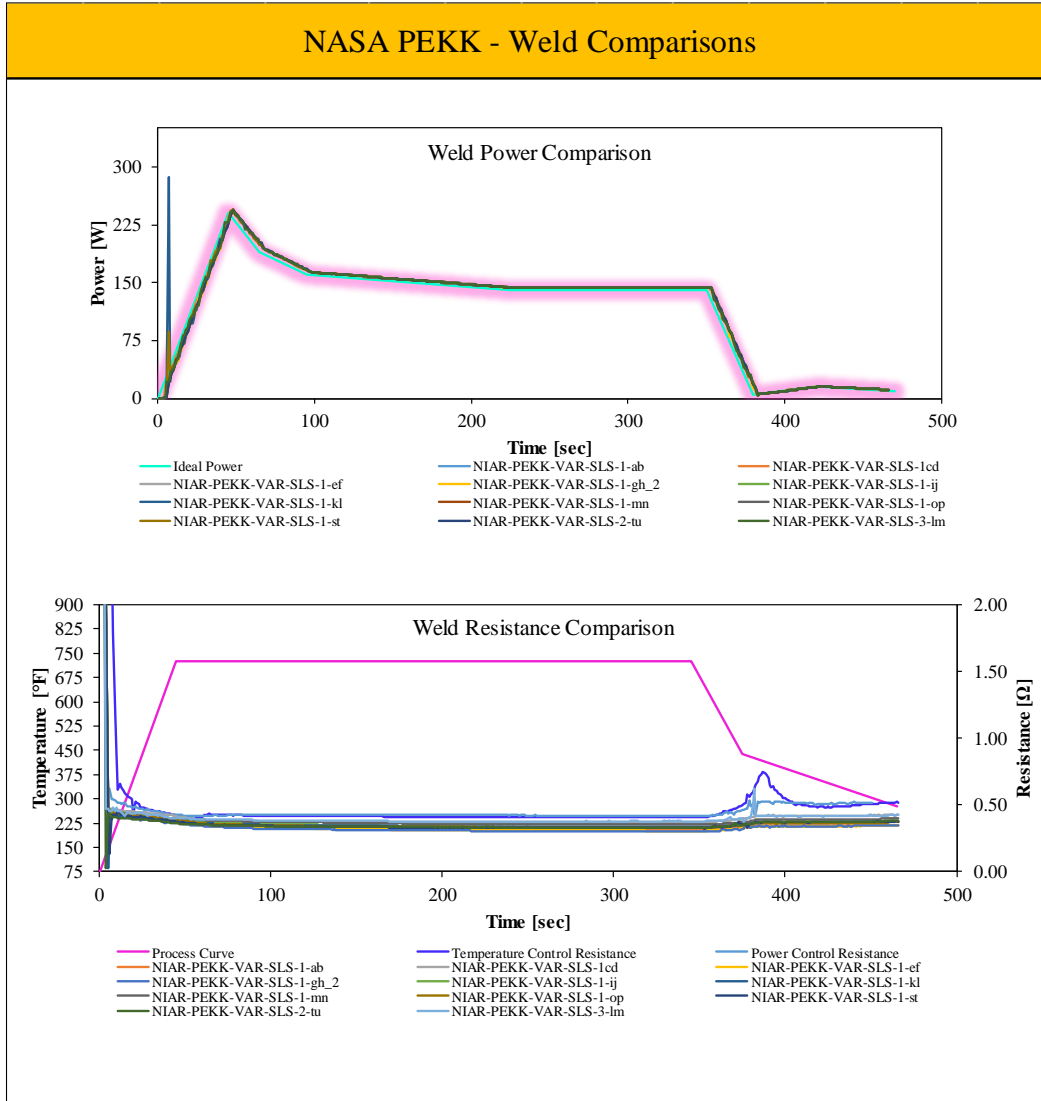


Figure 25 – PEKK SLS Welding Metrics Summary

4.2.4 PPS SLS Welding Metrics Summary

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

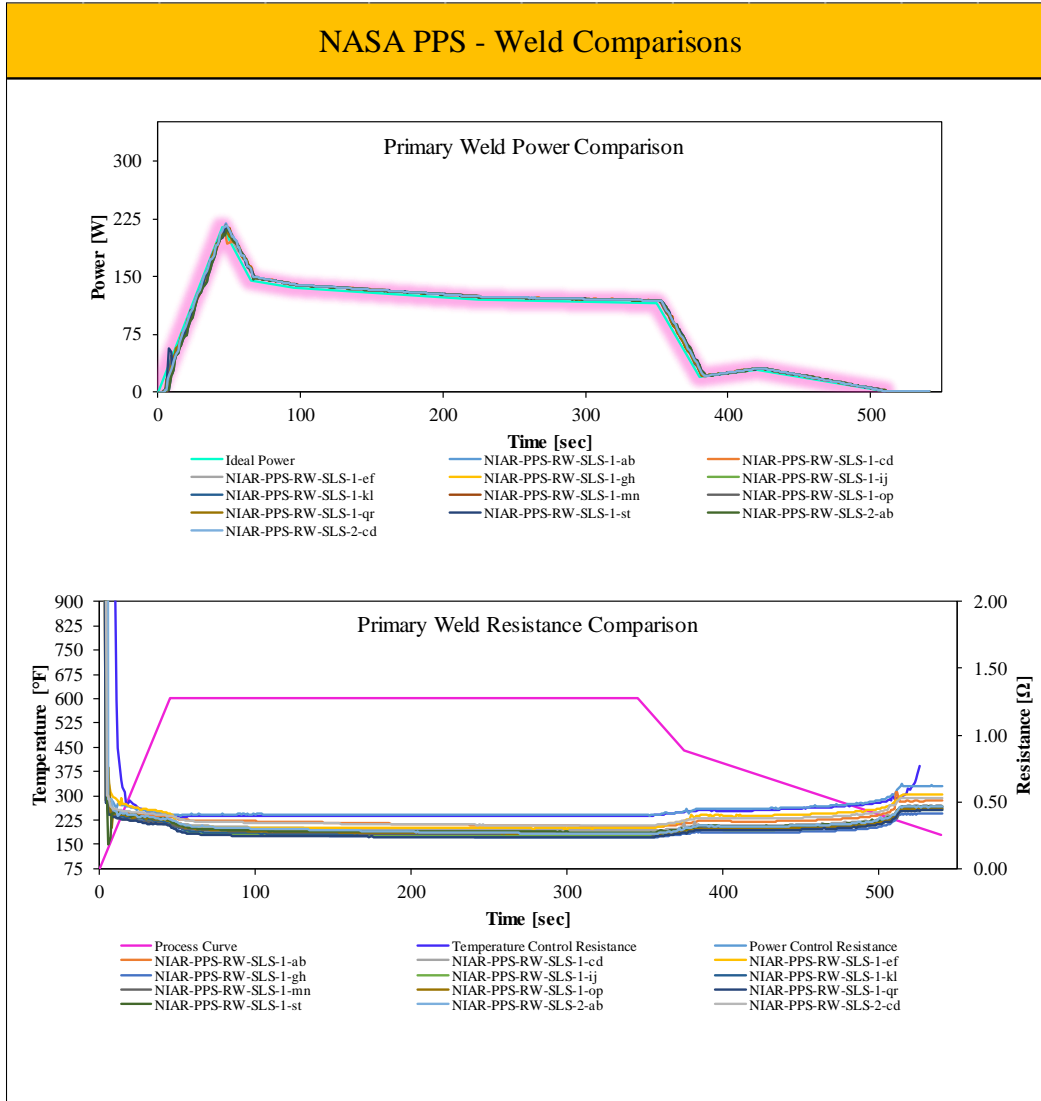


Figure 26 – PPS SLS Welding Metrics Summary

4.2.5 LM-PAEK DCB Welding Metrics Summary

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

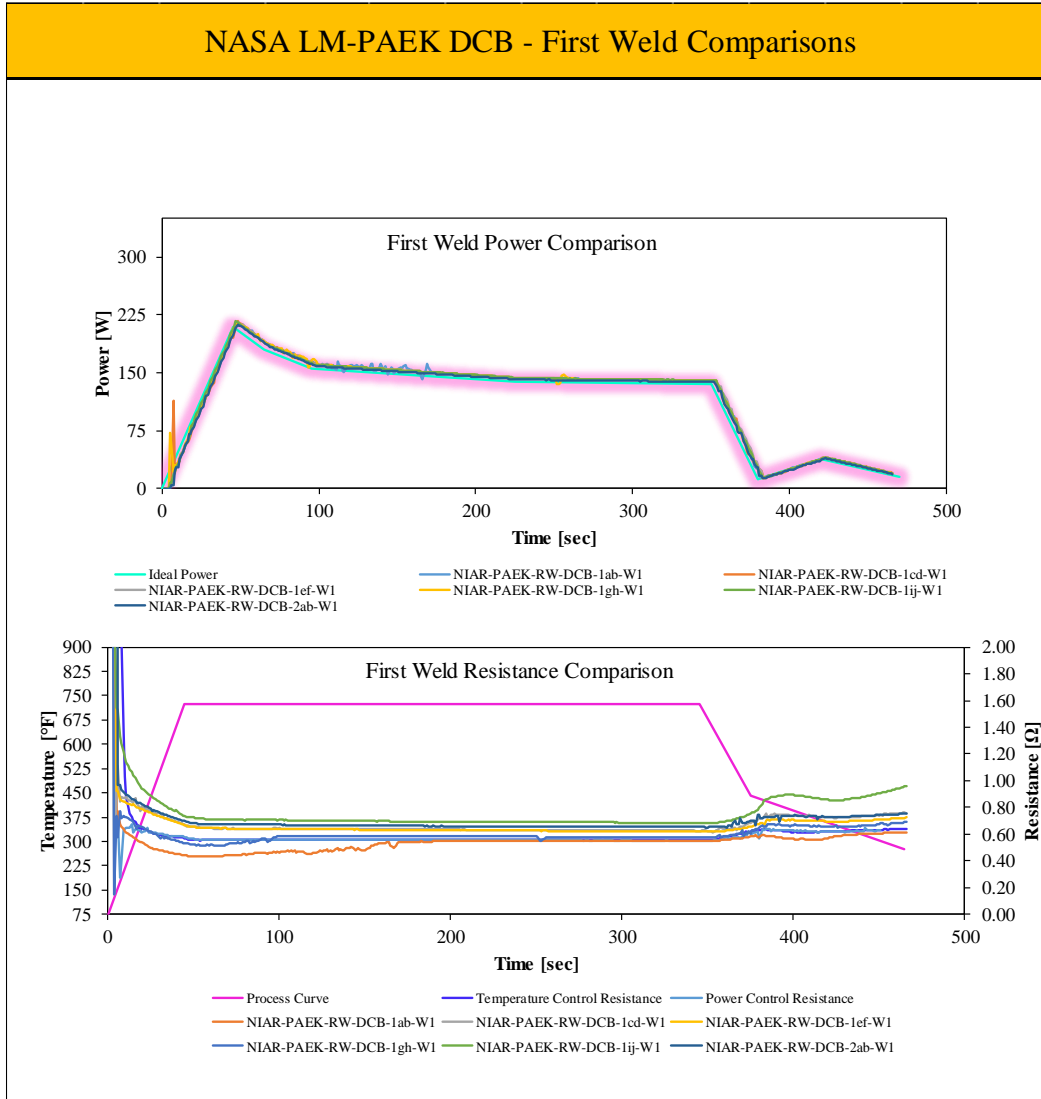


Figure 27 – LM-PAEK DCB Welding Metrics Summary Weld One

This data summary shows that NIAR-PAEK-RW-DCB-1ab-W2 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

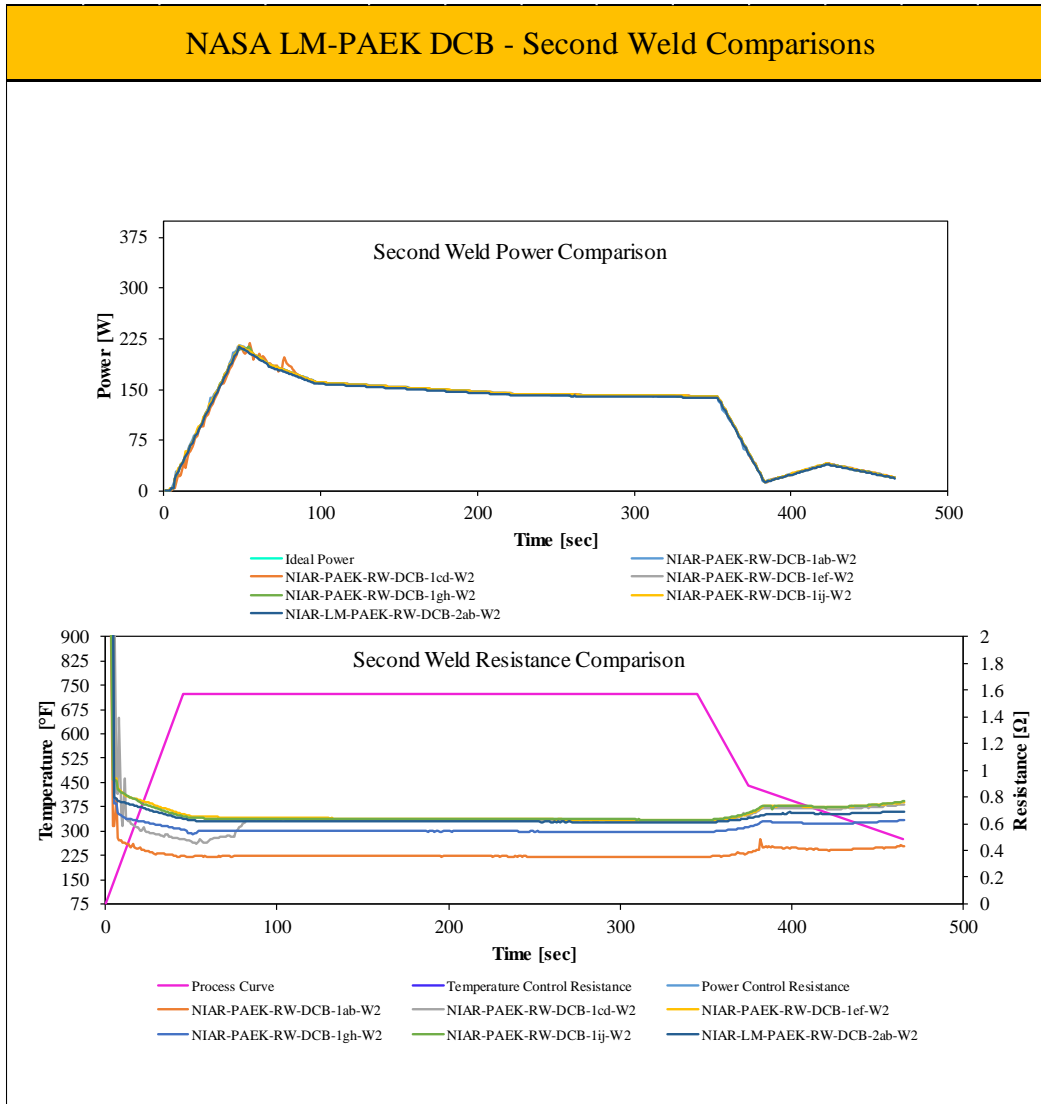


Figure 28 – LM-PAEK DCB Welding Metrics Summary Weld Two

This data summary shows that NIAR-PAEK-RW-DCB-1ab-W3 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

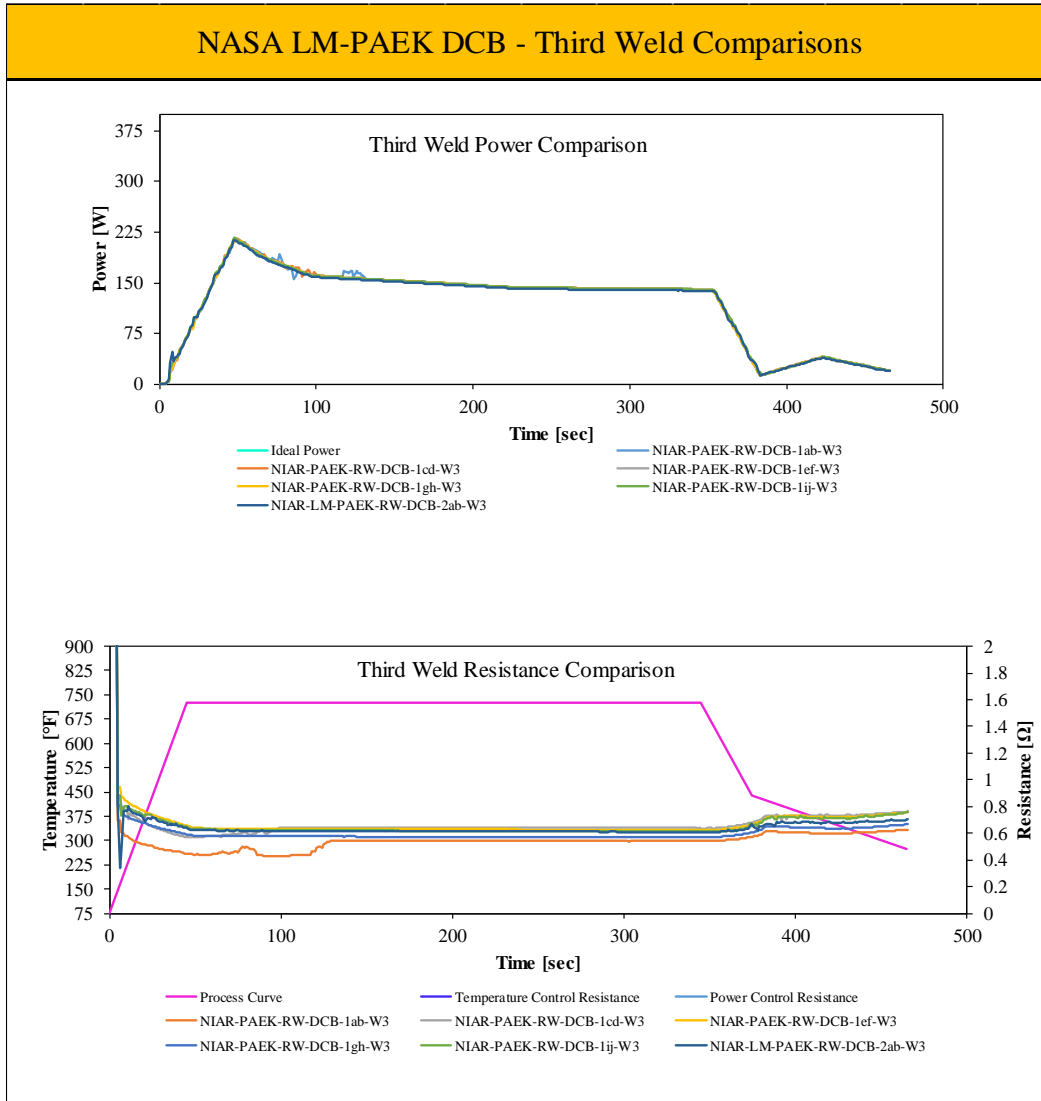


Figure 29 - LM-PAEK DCB Welding Metrics Summary Weld Three

This data summary shows that NIAR-PAEK-RW-DCB-1ab-W4 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

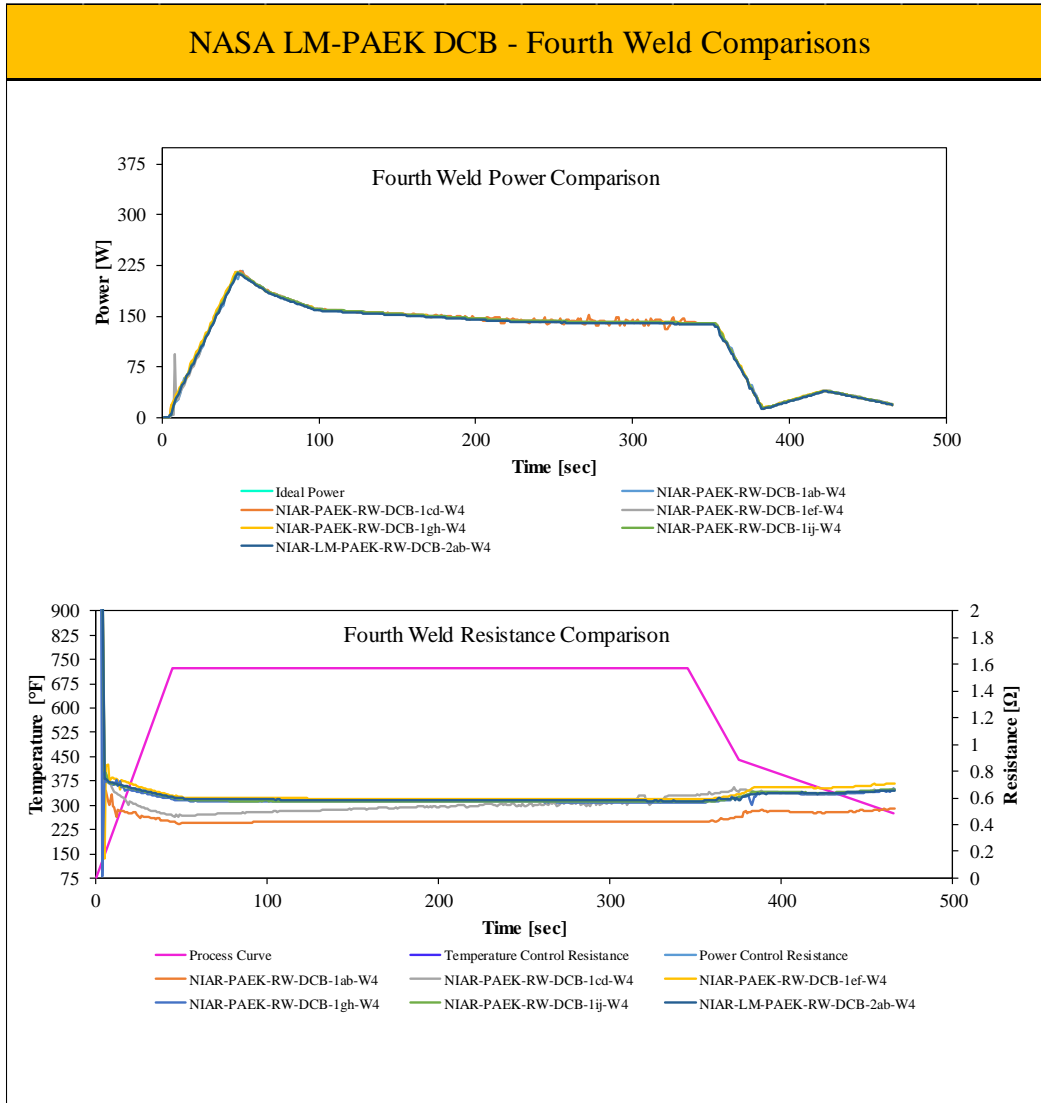


Figure 30 - LM-PAEK DCB Welding Metrics Summary Weld Four

This data summary shows that NIAR-PAEK-RW-DCB-1ab-W5 and NIAR-PAEK-RW-DCB-1cd-W5 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

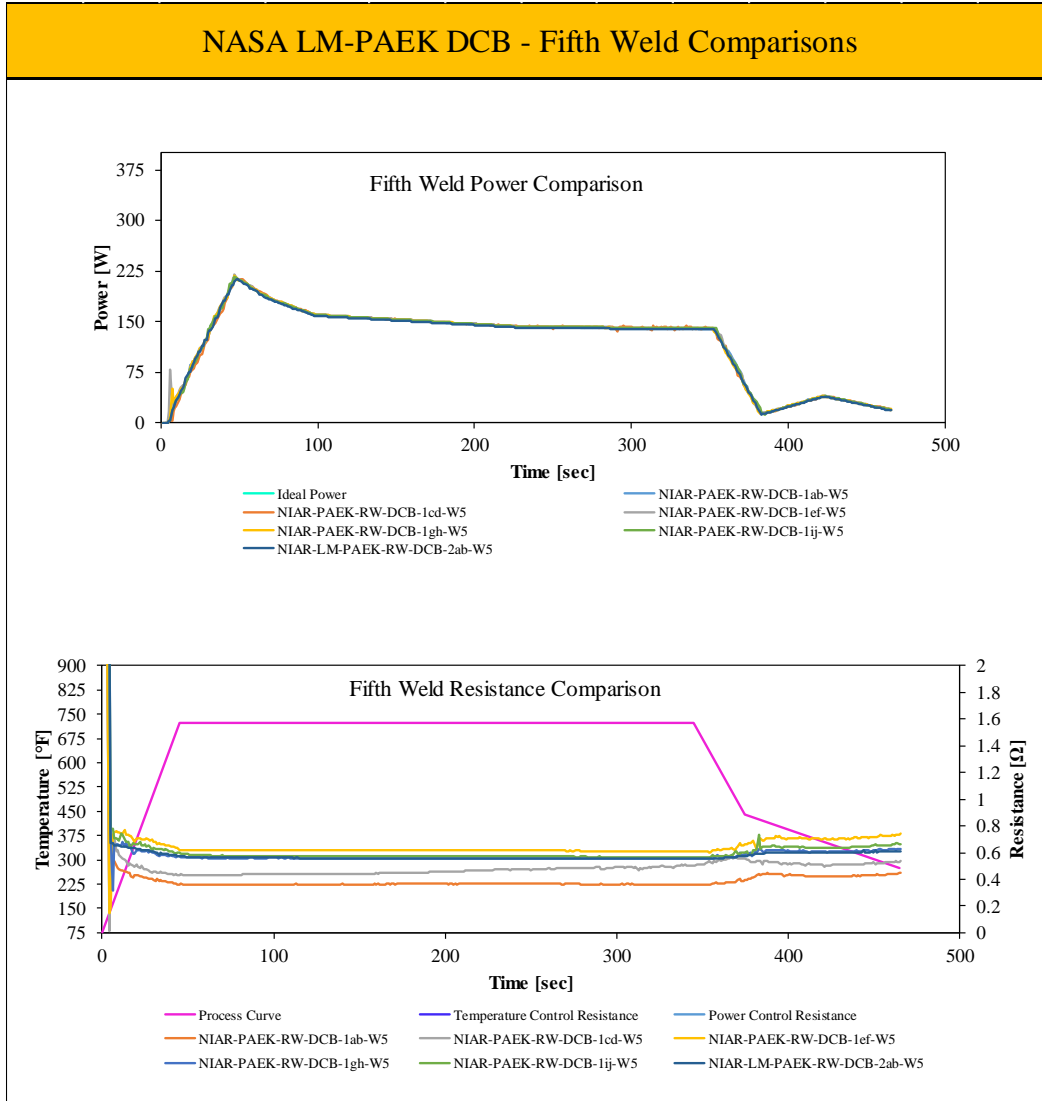


Figure 31 - LM-PAEK DCB Welding Metrics Summary Weld Five

This data summary shows that NIAR-PAEK-RW-DCB-1ab-W6 and had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

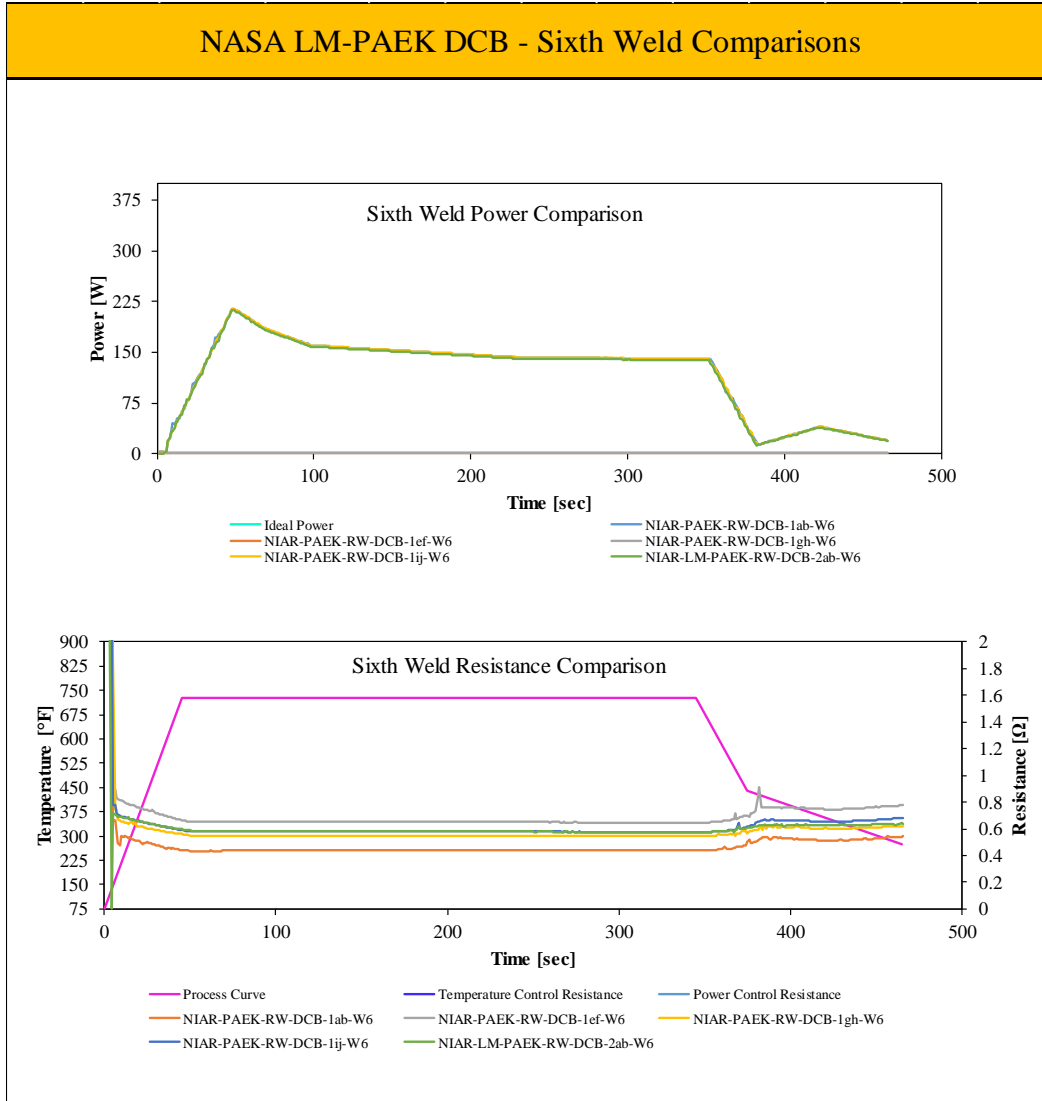


Figure 32 - LM-PAEK DCB Welding Metrics Summary Weld Six

4.2.6 PEI DCB Welding Metrics Summary

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

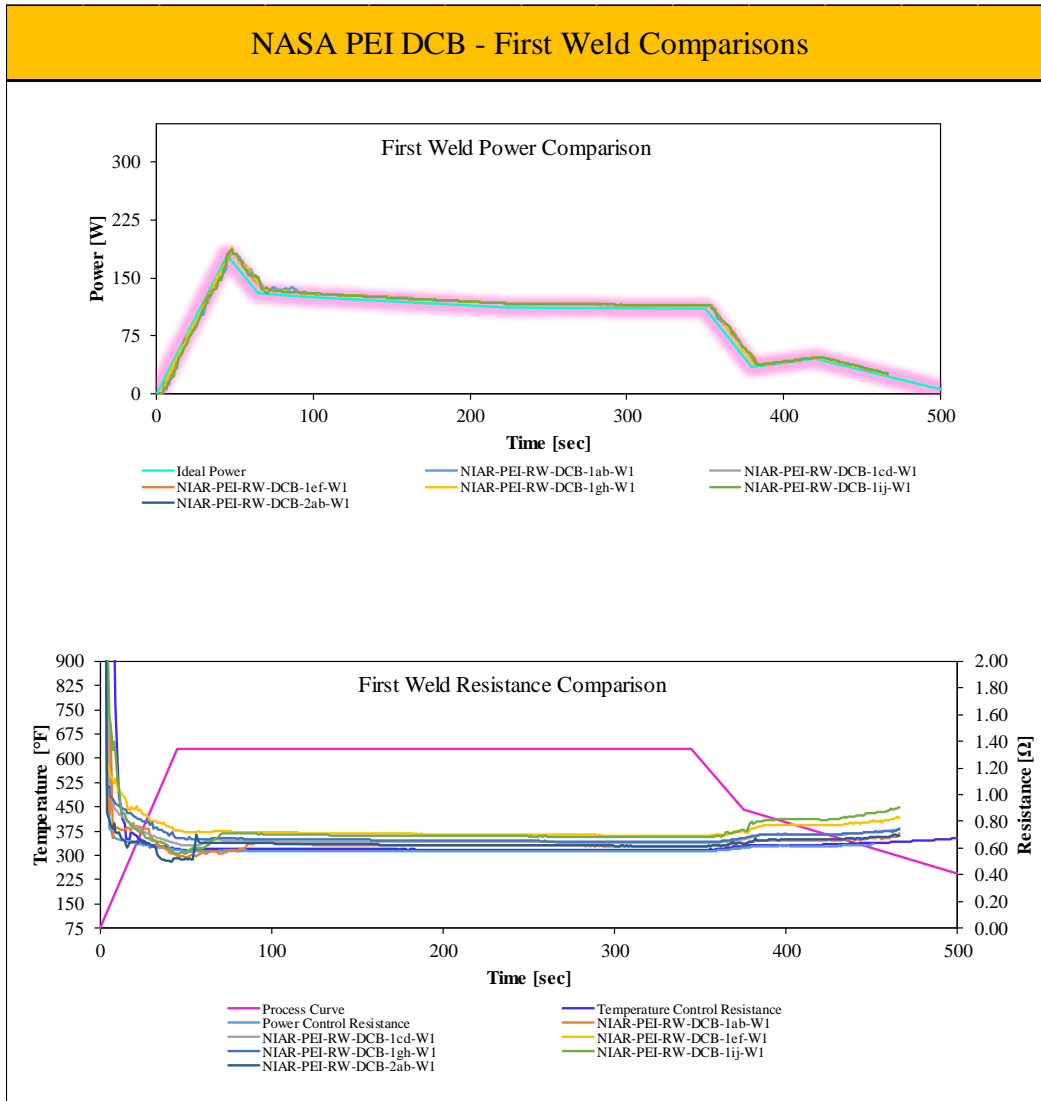


Figure 33 – PEI DCB Welding Metrics Summary Weld One

This data summary shows that NIAR-PEI-RW-DCB-2ab-W2 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

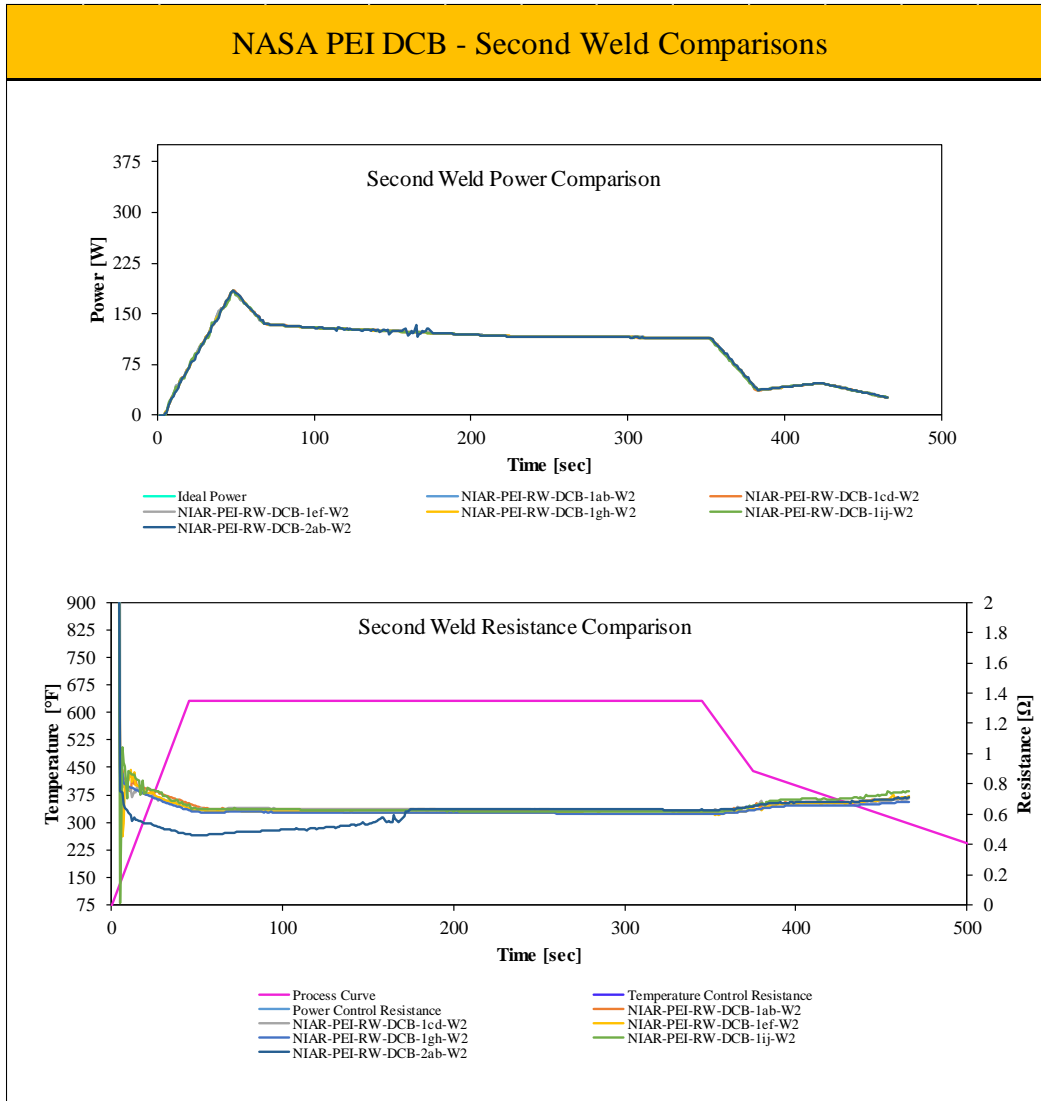


Figure 34 – PEI DCB Welding Metrics Summary Weld Two

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

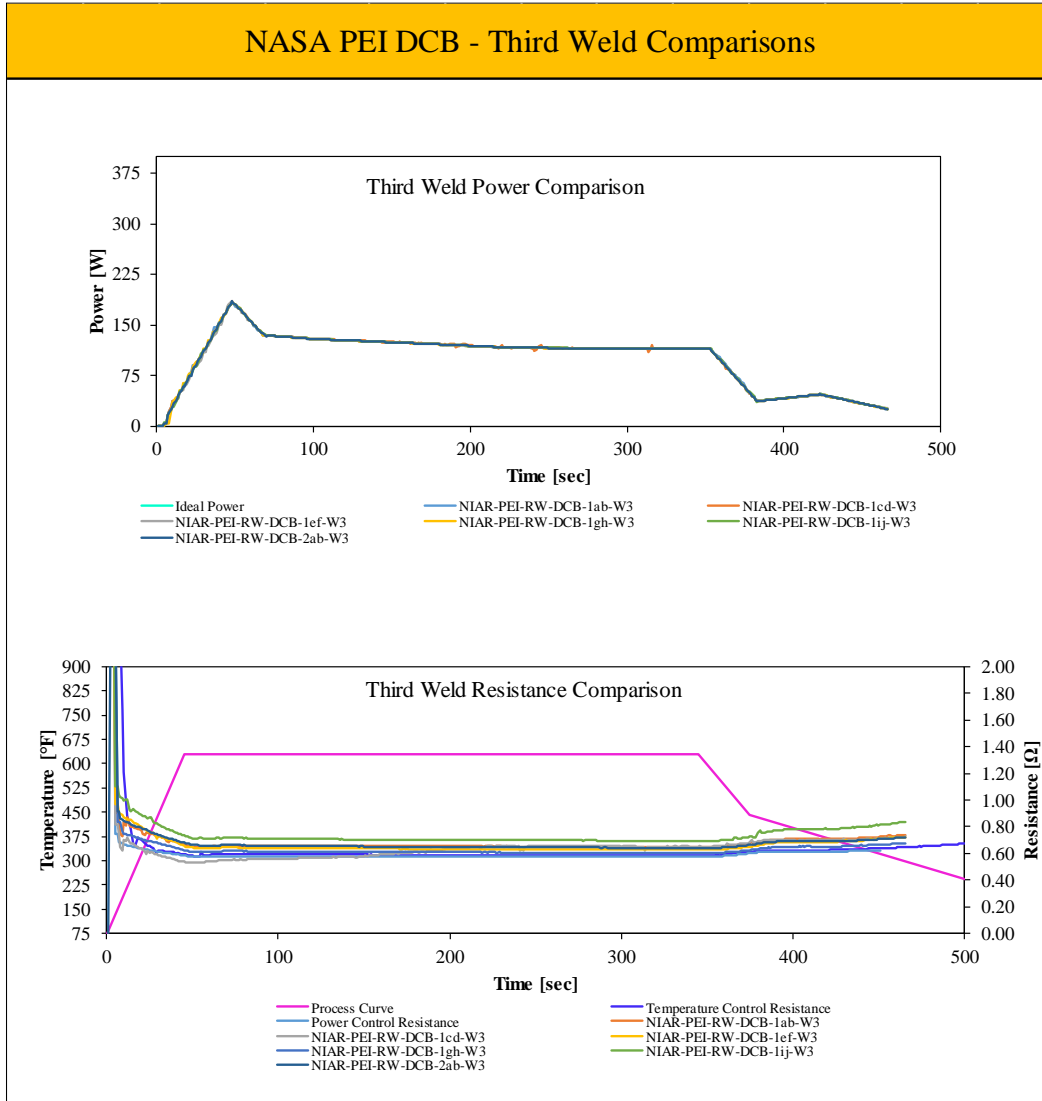


Figure 35 - PEI DCB Welding Metrics Summary Weld Three

This data summary shows that NIAR-PEI-RW-DCB-2ab-W4 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

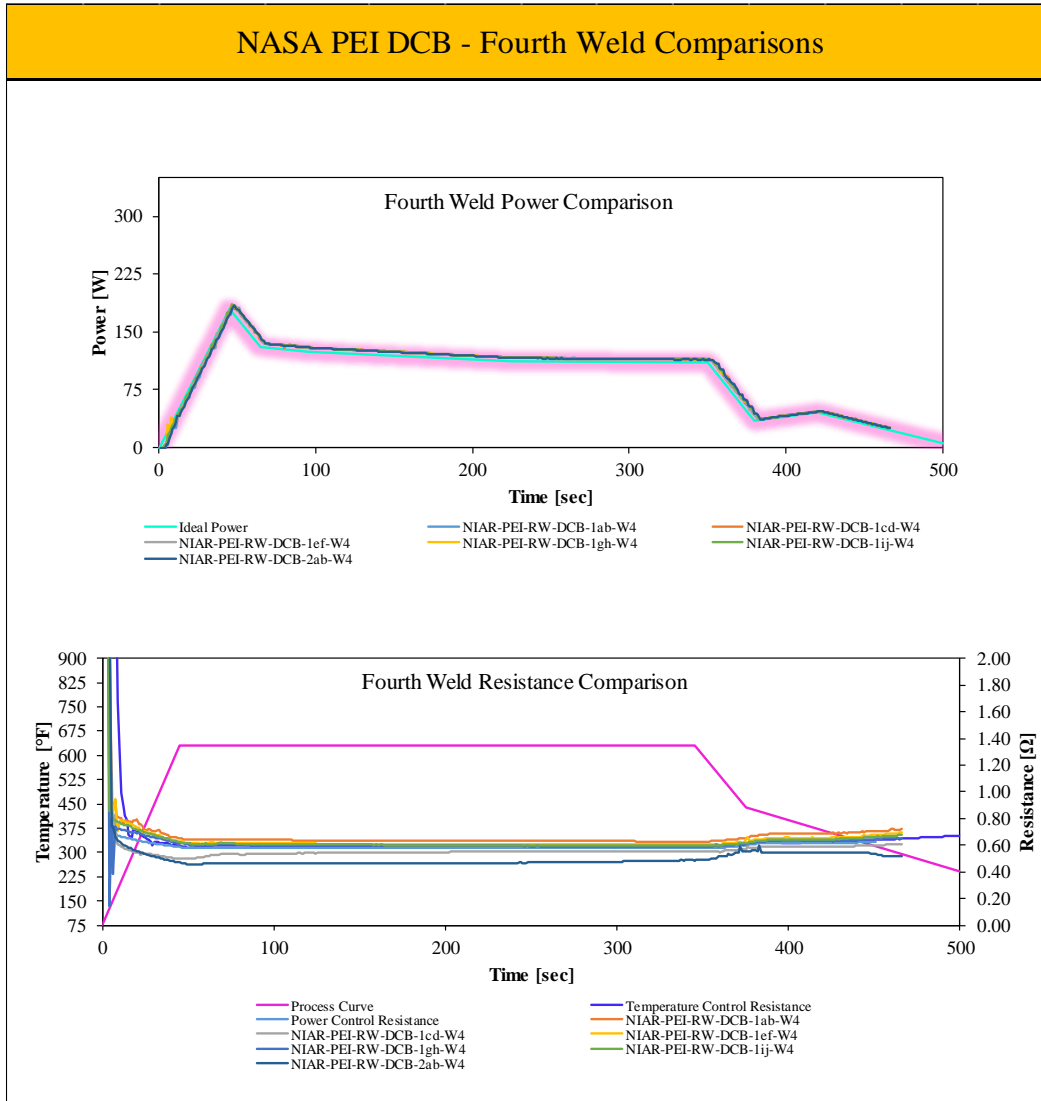


Figure 36 - PEI DCB Welding Metrics Summary Weld Four

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

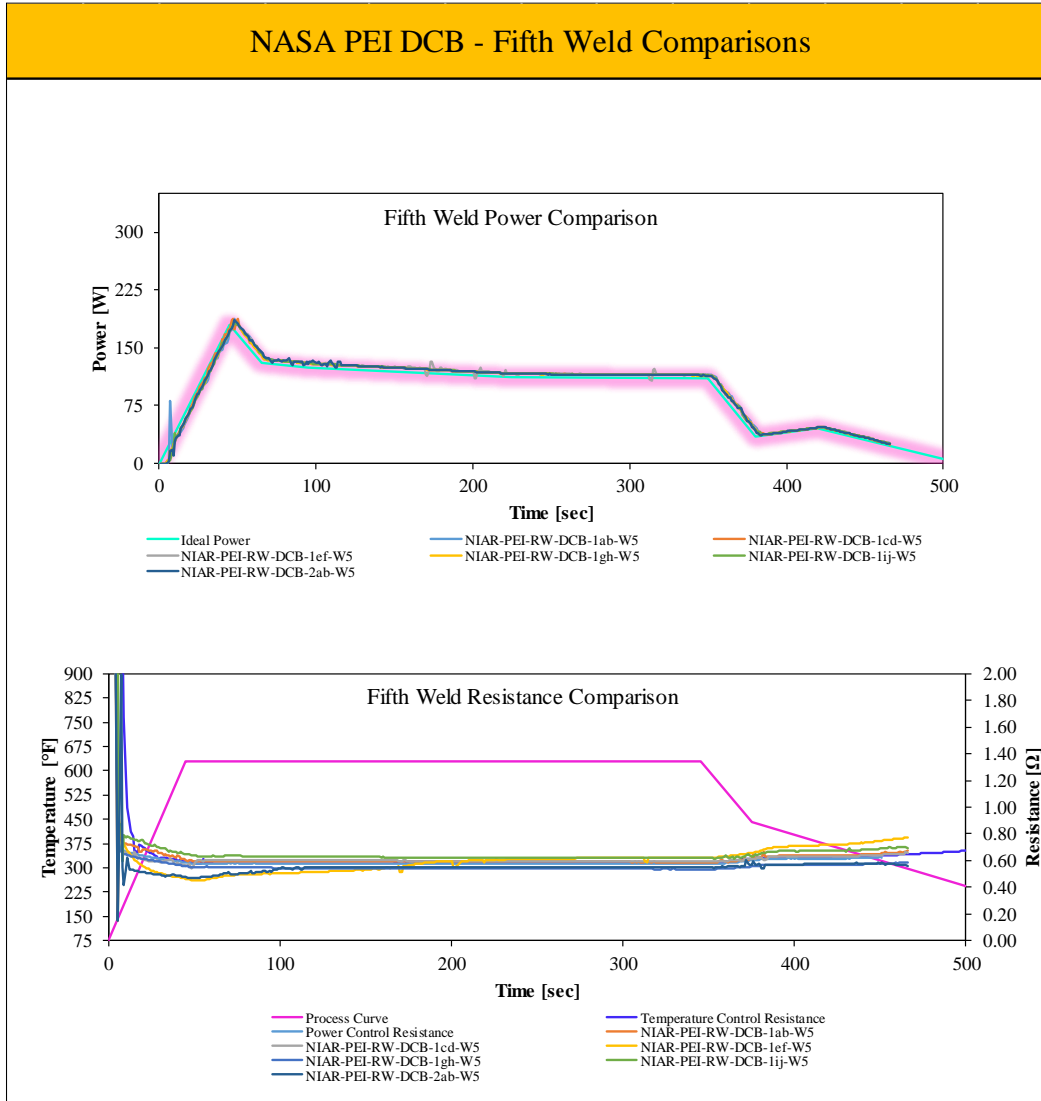


Figure 37 - PEI DCB Welding Metrics Summary Weld Five

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

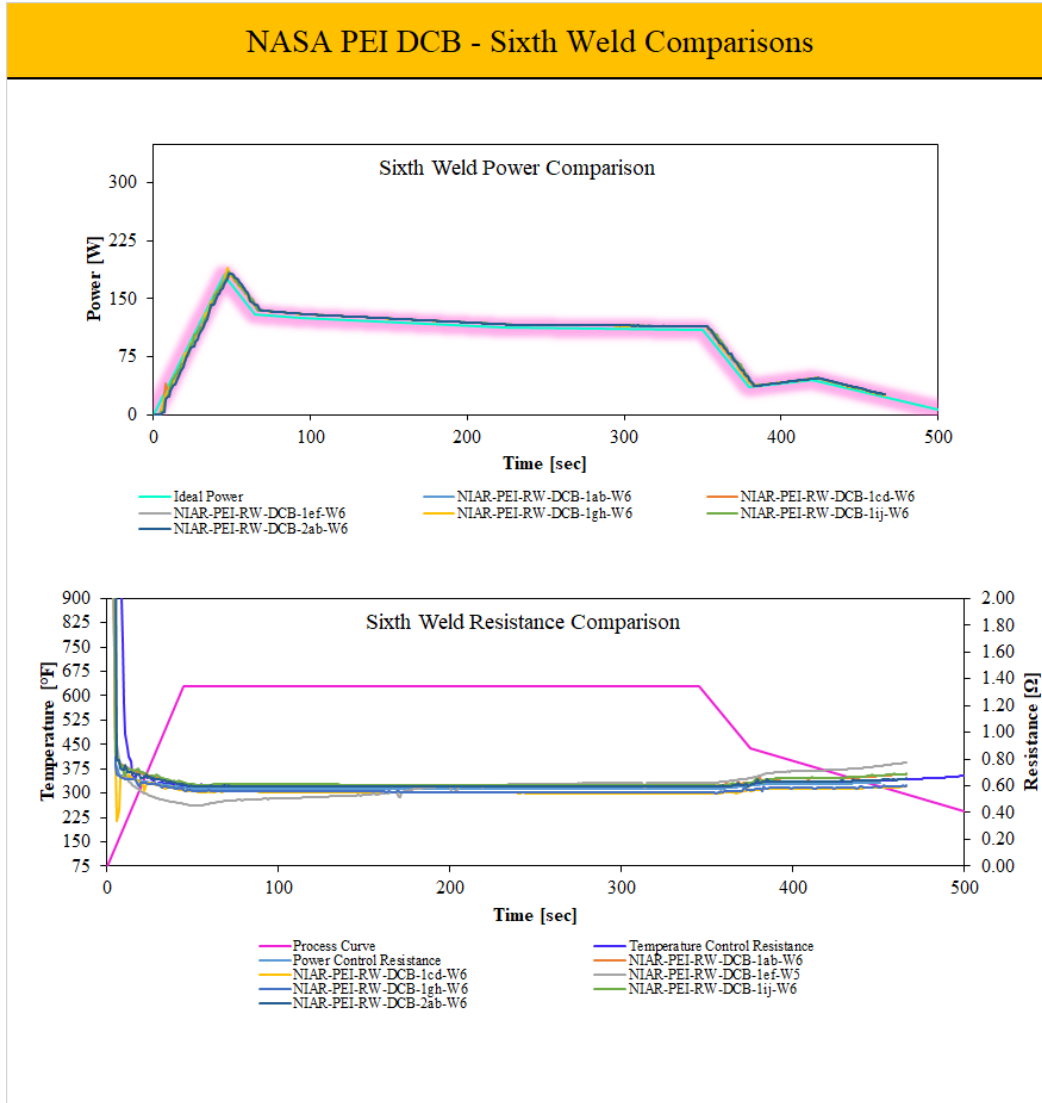


Figure 38 - PEI DCB Welding Metrics Summary Weld Six

4.2.7 PPS DCB Welding Metrics Summary

This data summary shows that NIAR-PPS-RW-DCB-1ef-W1_2 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

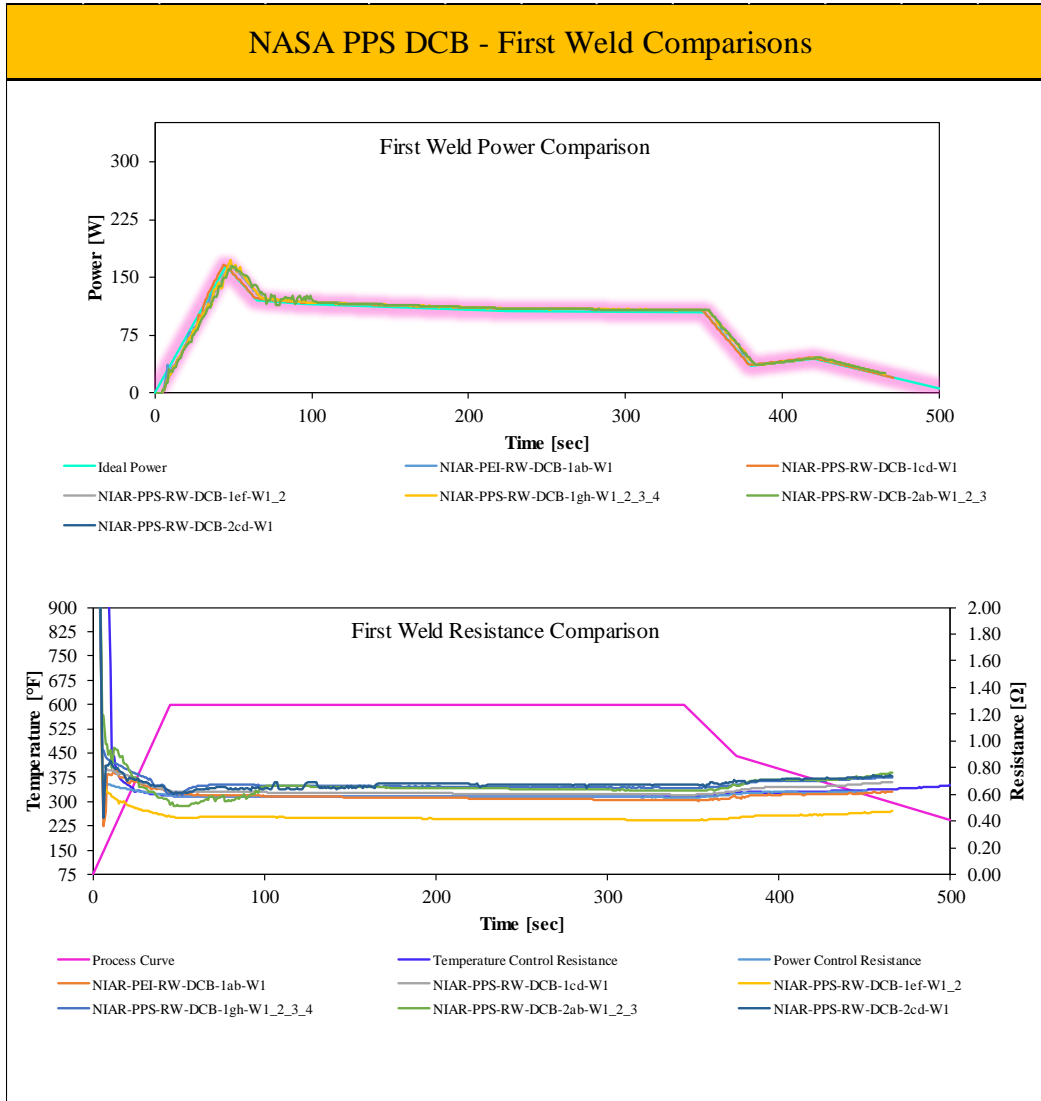


Figure 39 – PPS DCB Welding Metrics Summary Weld One

This data summary shows that NIAR-PPS-RW-DCB-1ef-W2-2 and NIAR-PPS-RW-DCB-2ab-W2-3 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

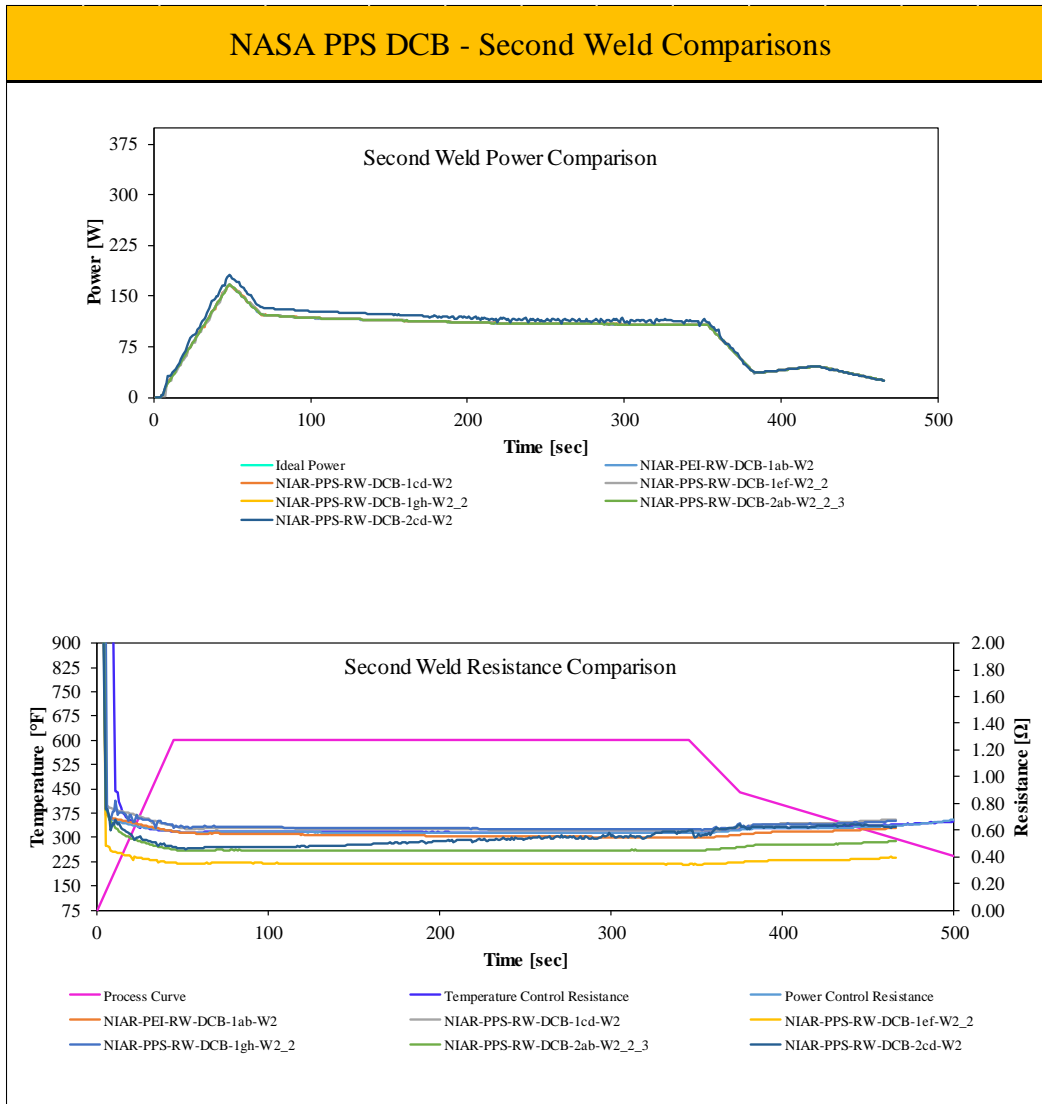


Figure 40 – PPS DCB Welding Metrics Summary Weld Two

This data summary shows that NIAR-PPS-RW-DCB-1ef-W3-2 and NIAR-PPS-RW-DCB-2ab-W3-2-3 had a significantly lower resistance than the other welds. This is most likely due to a defect in the heating element which will change the heating profile and cause the welding area to not be fully welded. This will lead to a lower mechanical strength performance in that area of the weld.

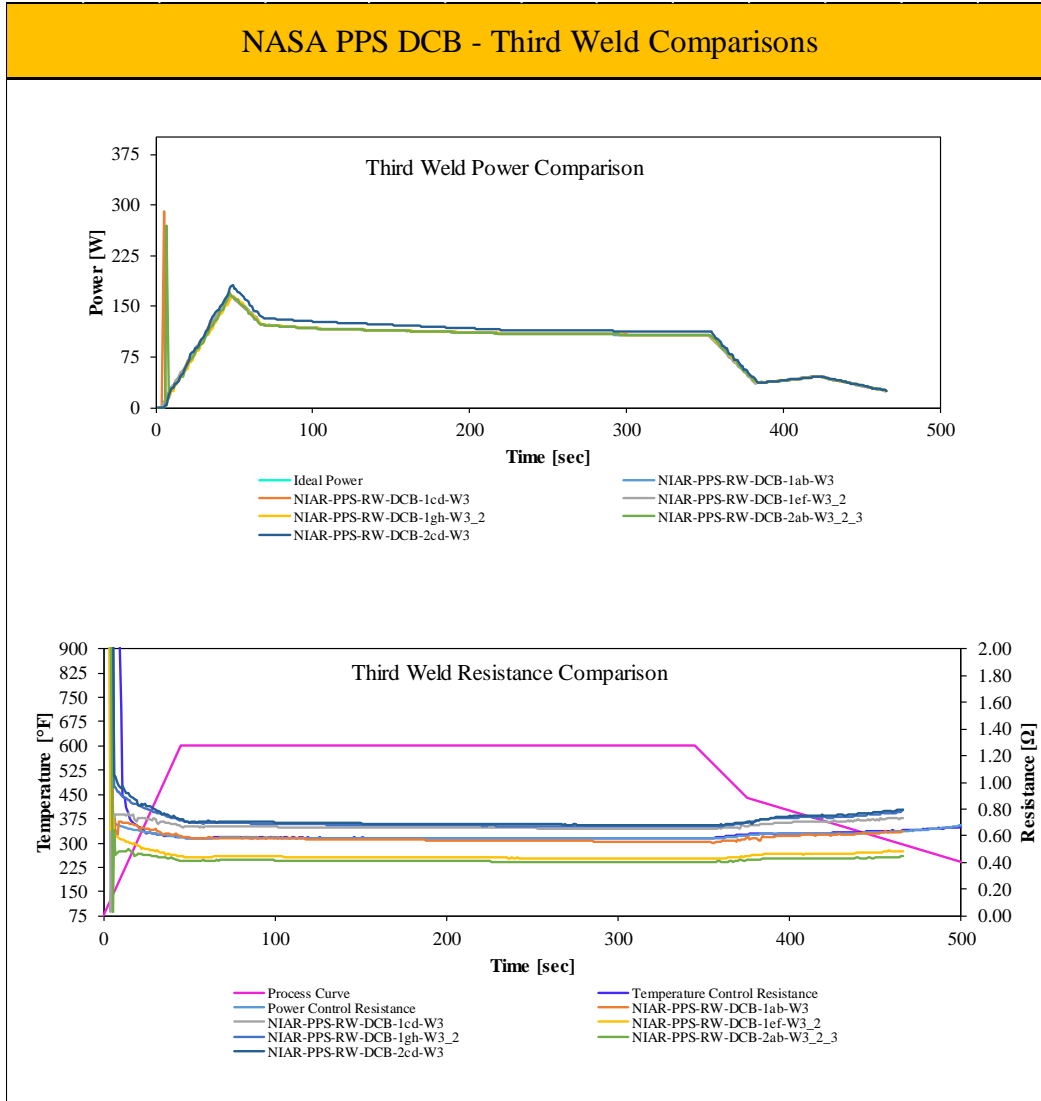


Figure 41 - PPS DCB Welding Metrics Summary Weld Three

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

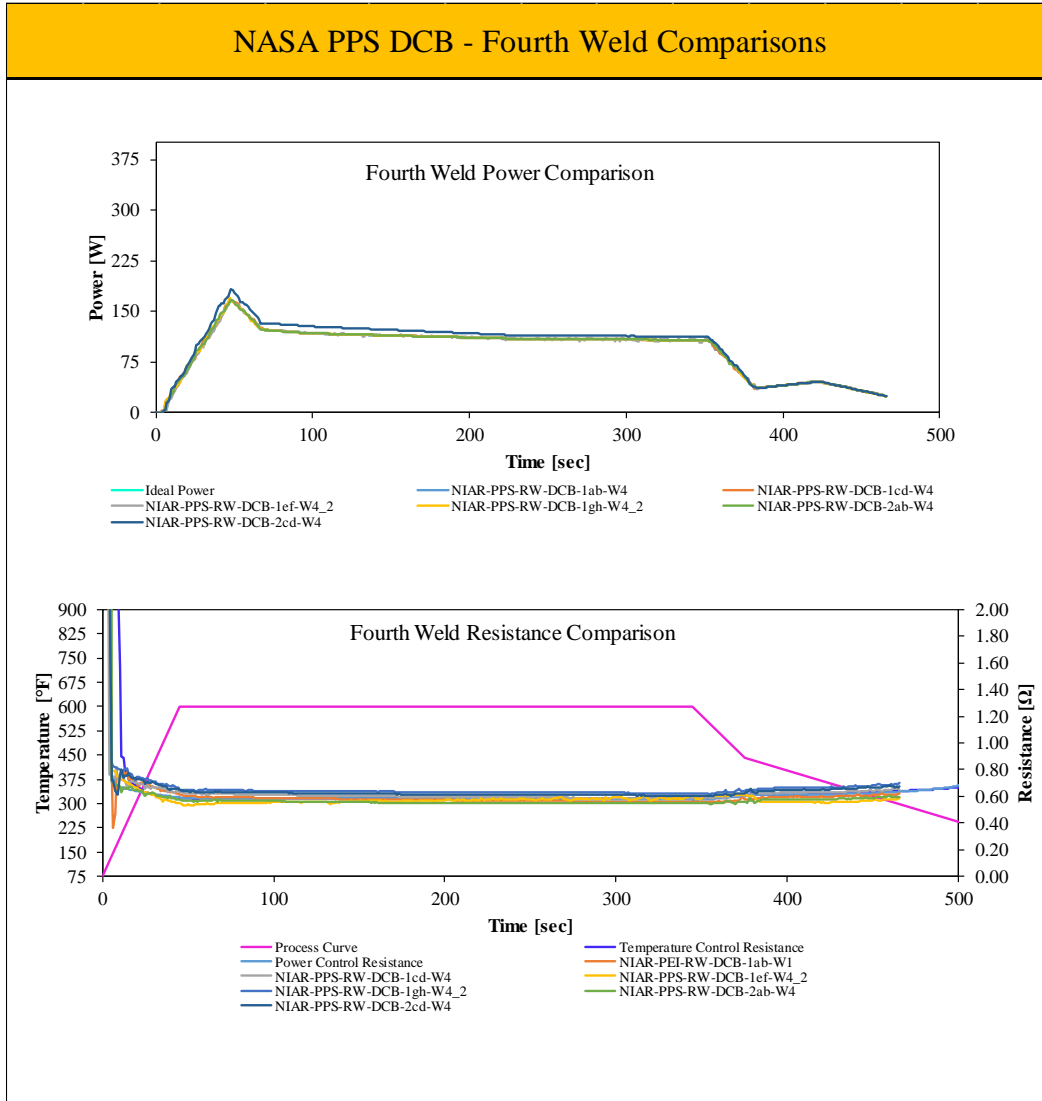


Figure 42 - PPS DCB Welding Metrics Summary Weld Four

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

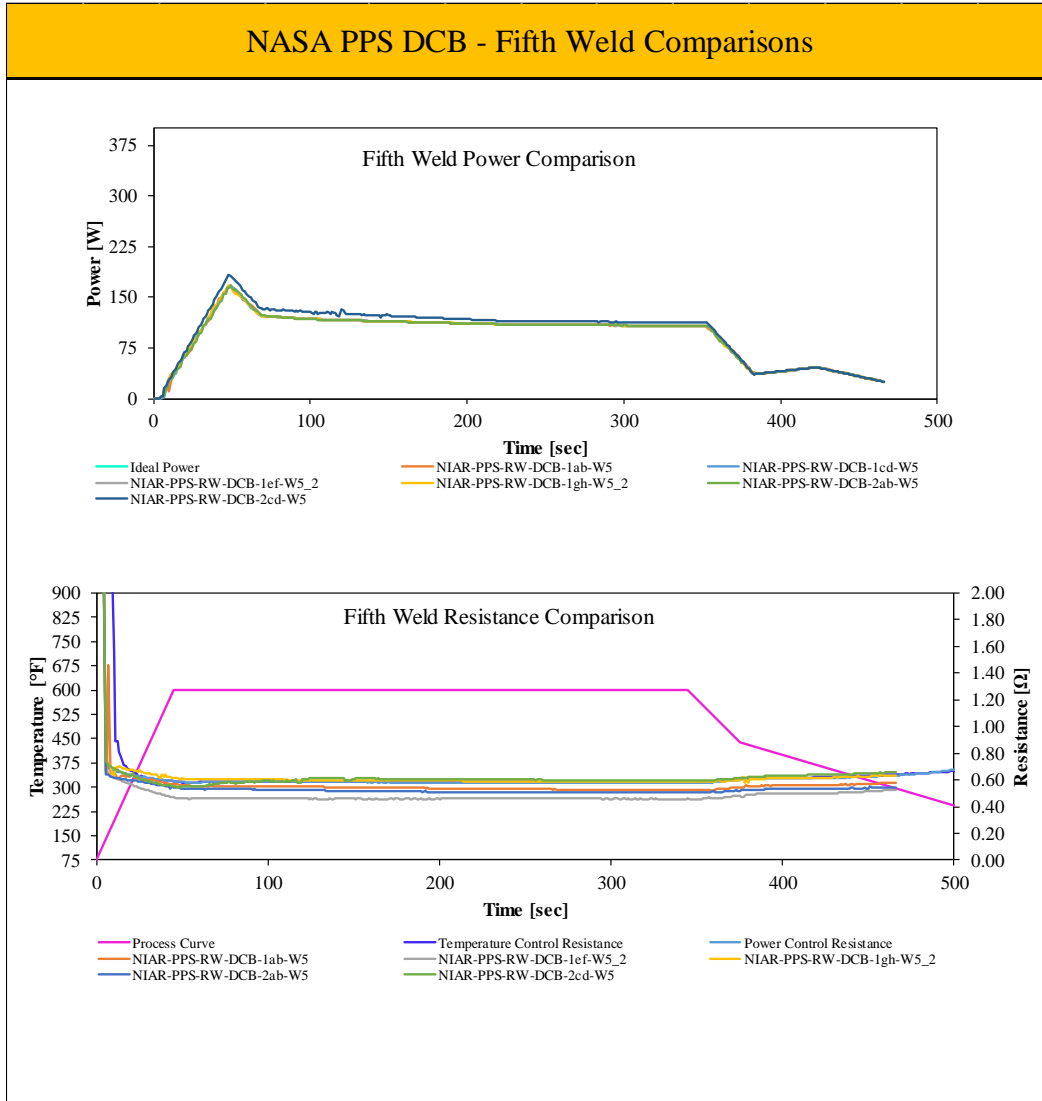


Figure 43 - PPS DCB Welding Metrics Summary Weld Five

This data summary shows uniform power and resistance across all welded specimens which then should result in a low COV when it comes to strength testing, assuming all other metrics are as expected (uniform pressure, no defects in substrate or FOD).

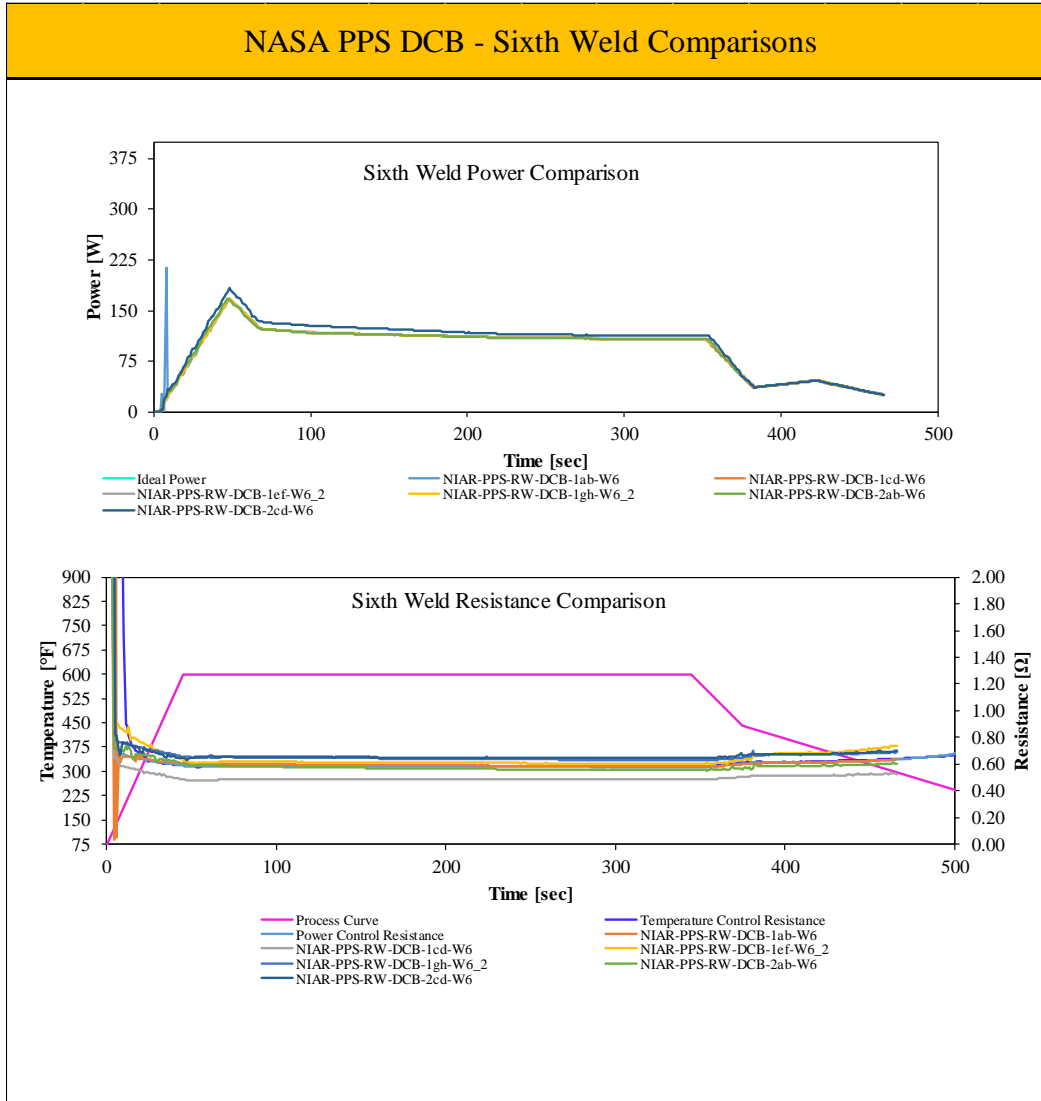
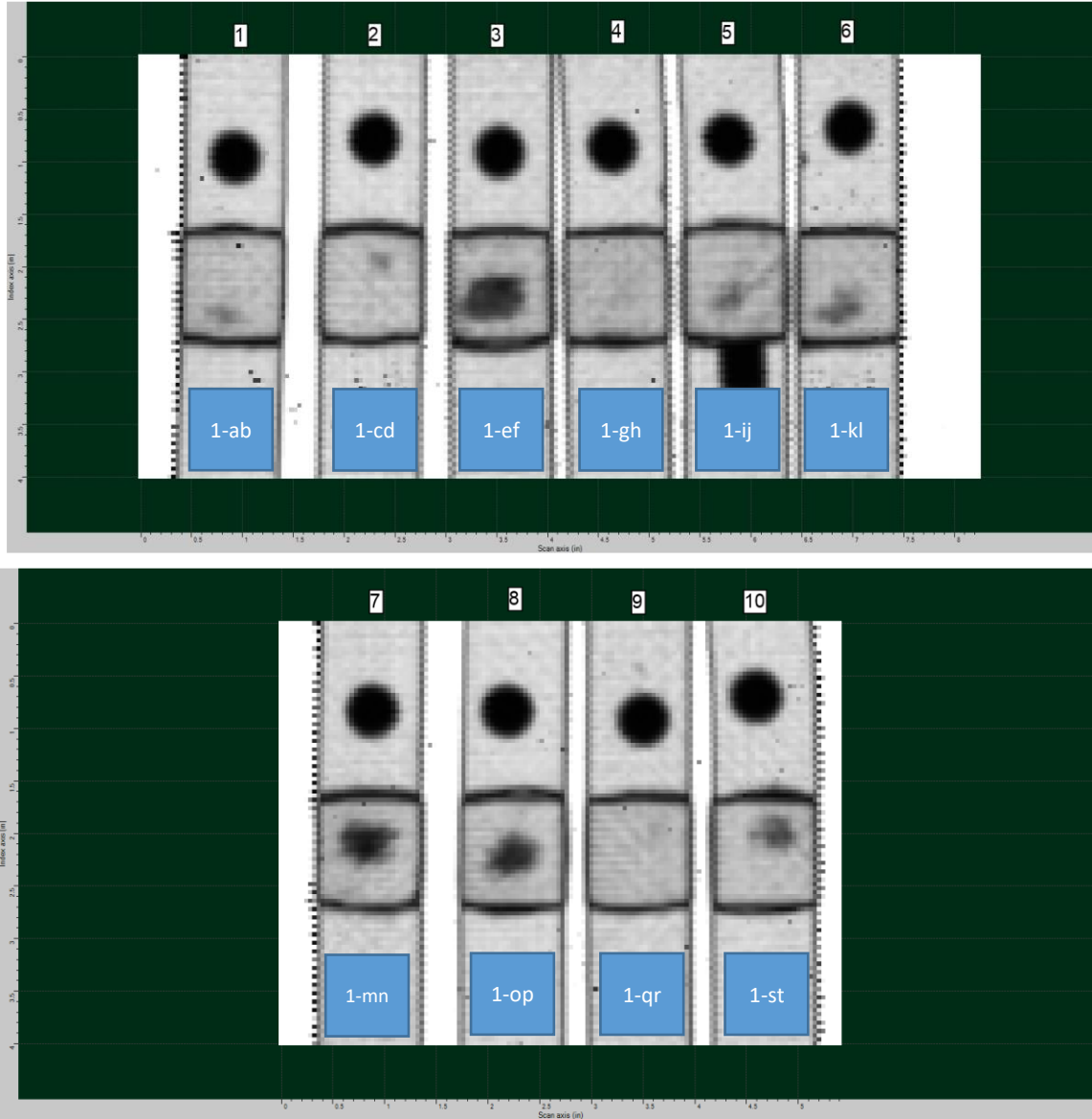


Figure 44 - LM-PAEK DCB Welding Metrics Summary Weld Six

5.0 Non-Destructive Inspection: C-Scan Imaging

5.1 LM-PAEK SLS NDI Results



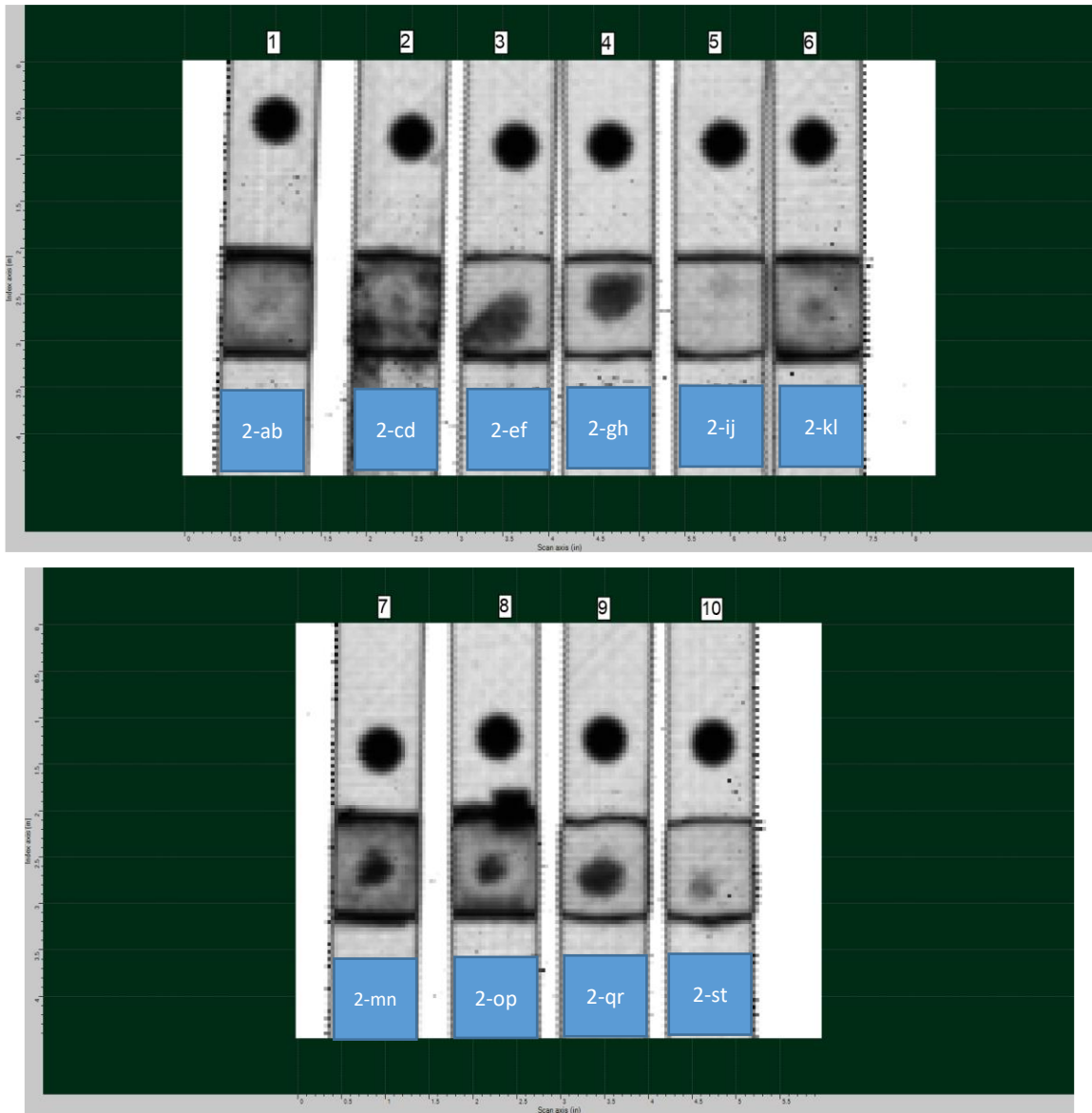
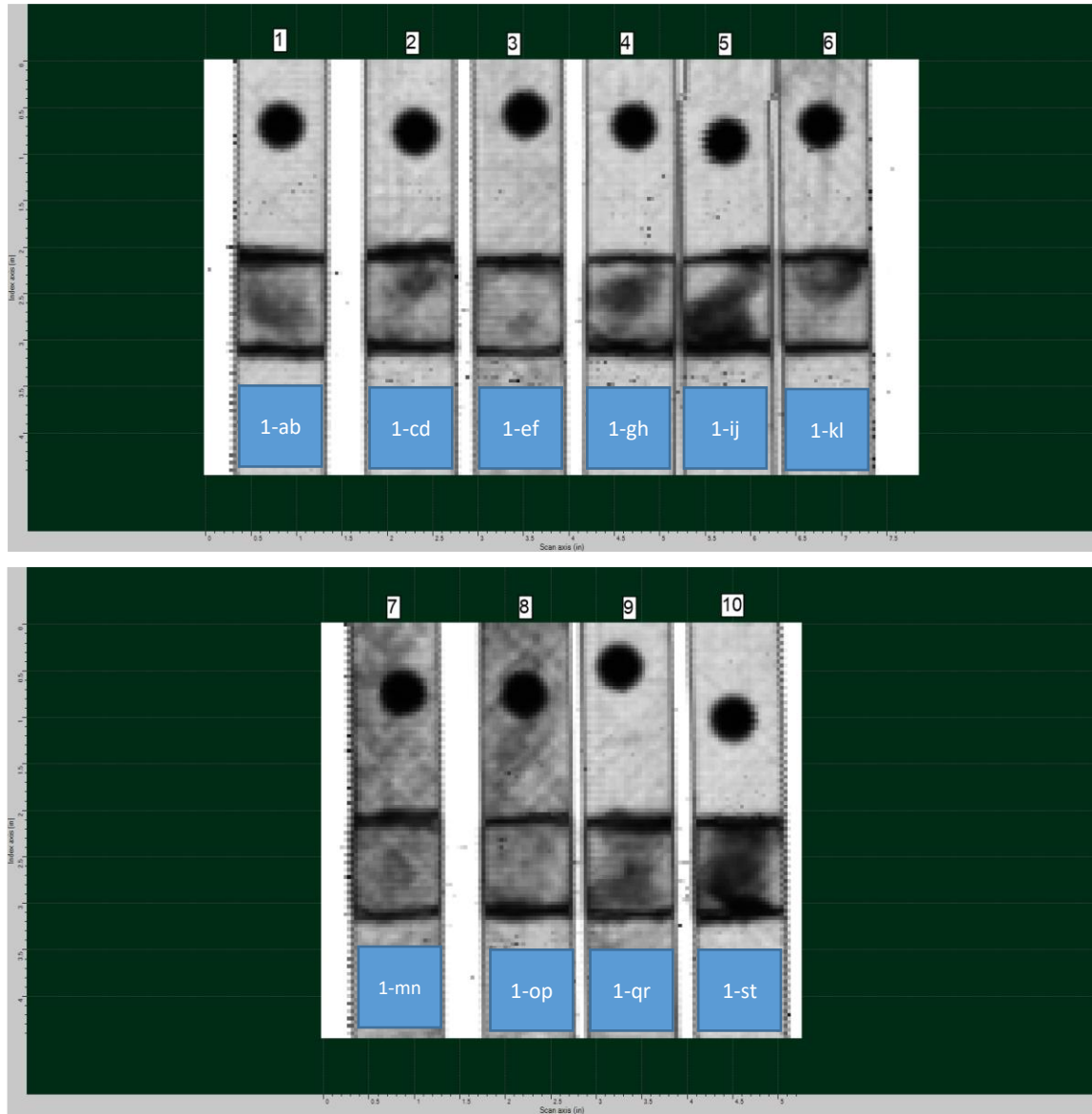


Figure 45 – LM-PAEK SLS NDI Results

5.2 PEI SLS NDI Results



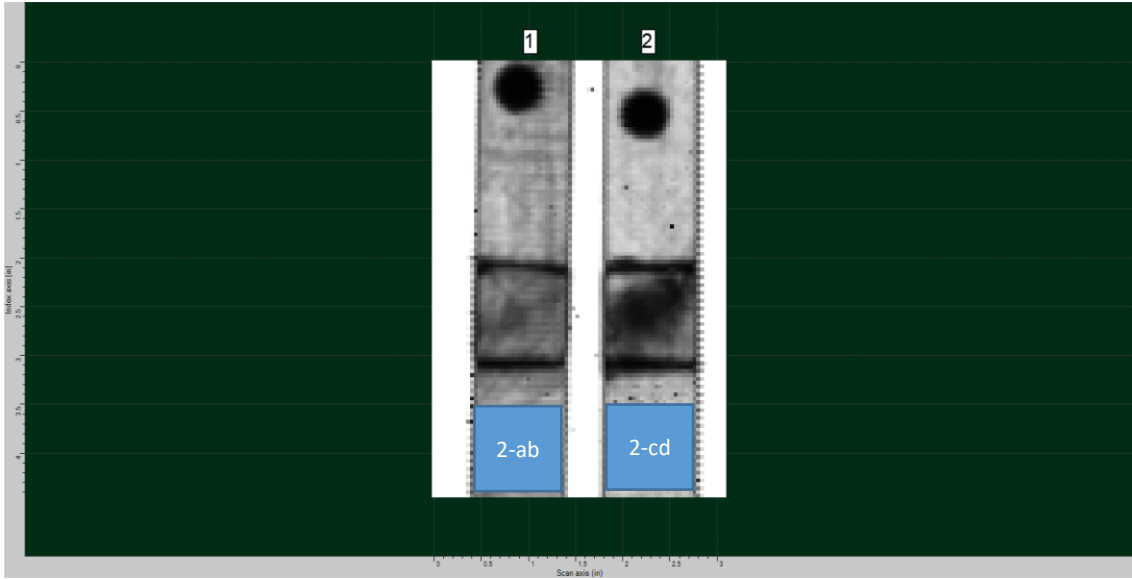
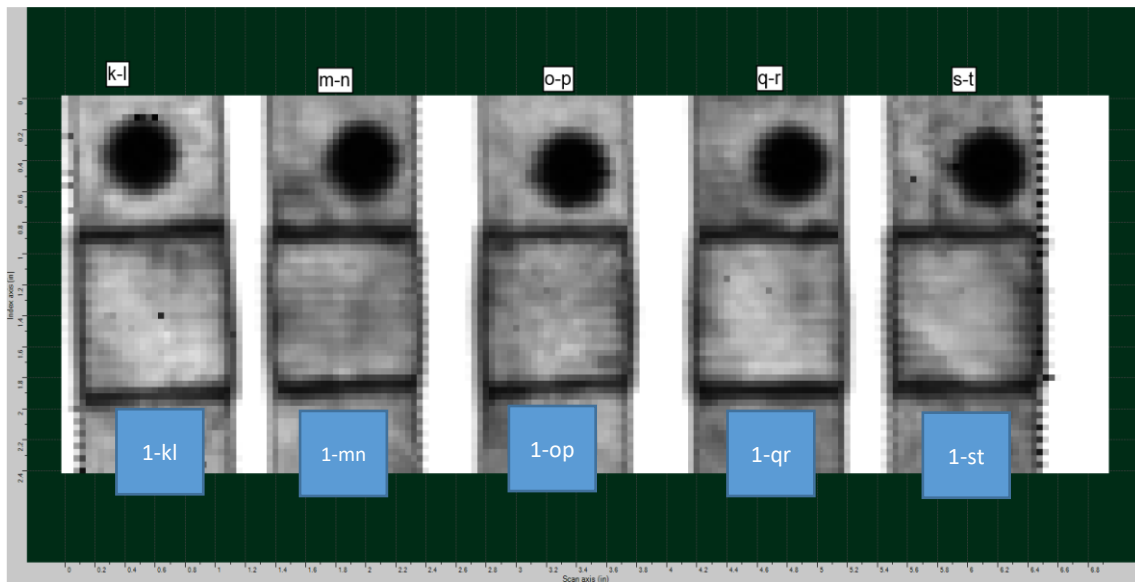
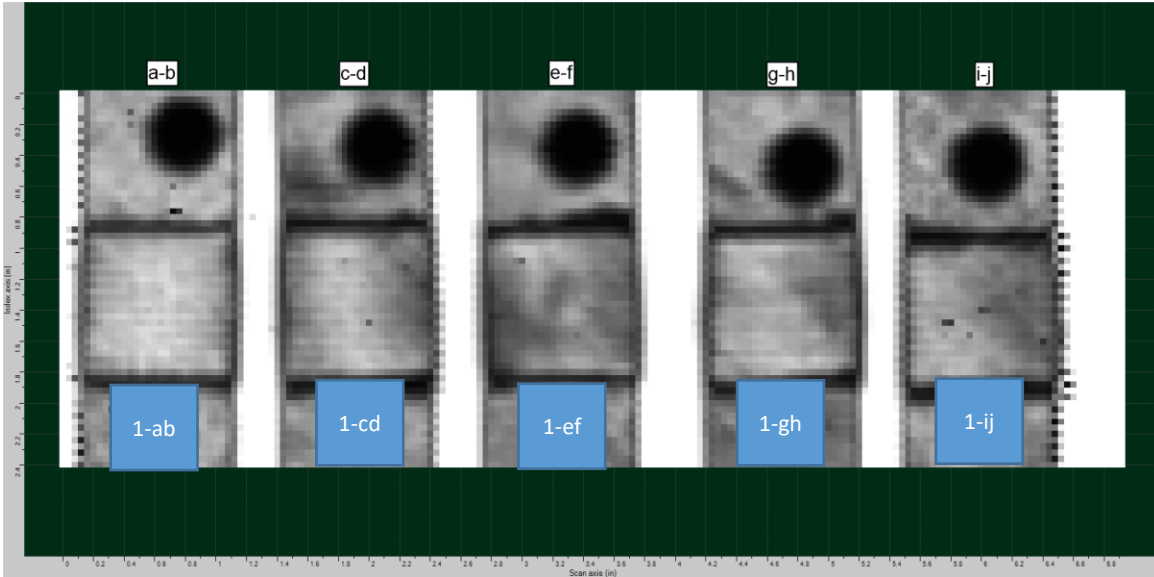


Figure 46 – PEI SLS NDI Results

5.3 PEKK SLS NDI Results



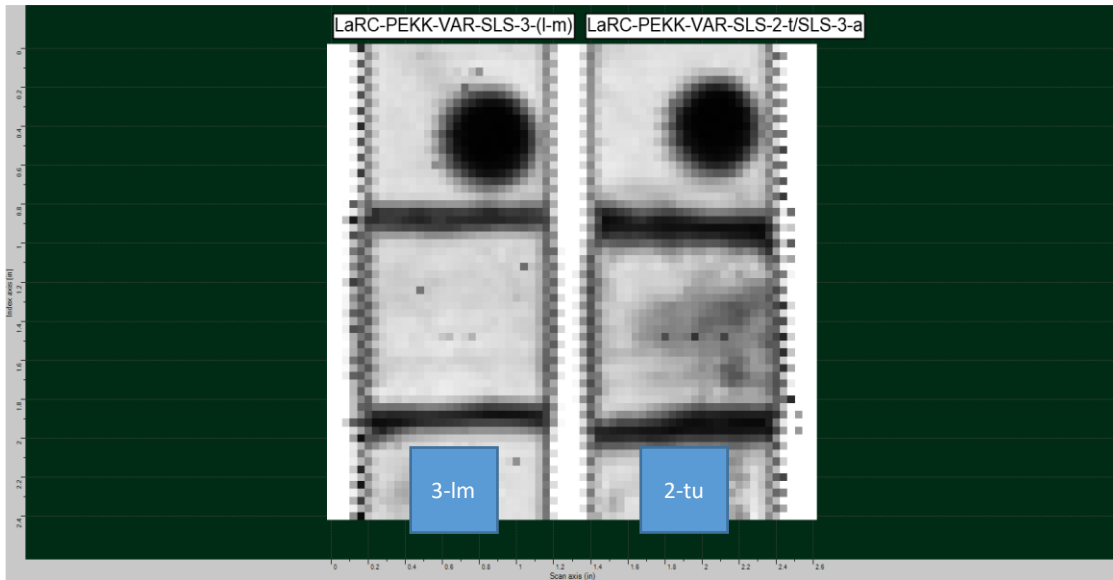
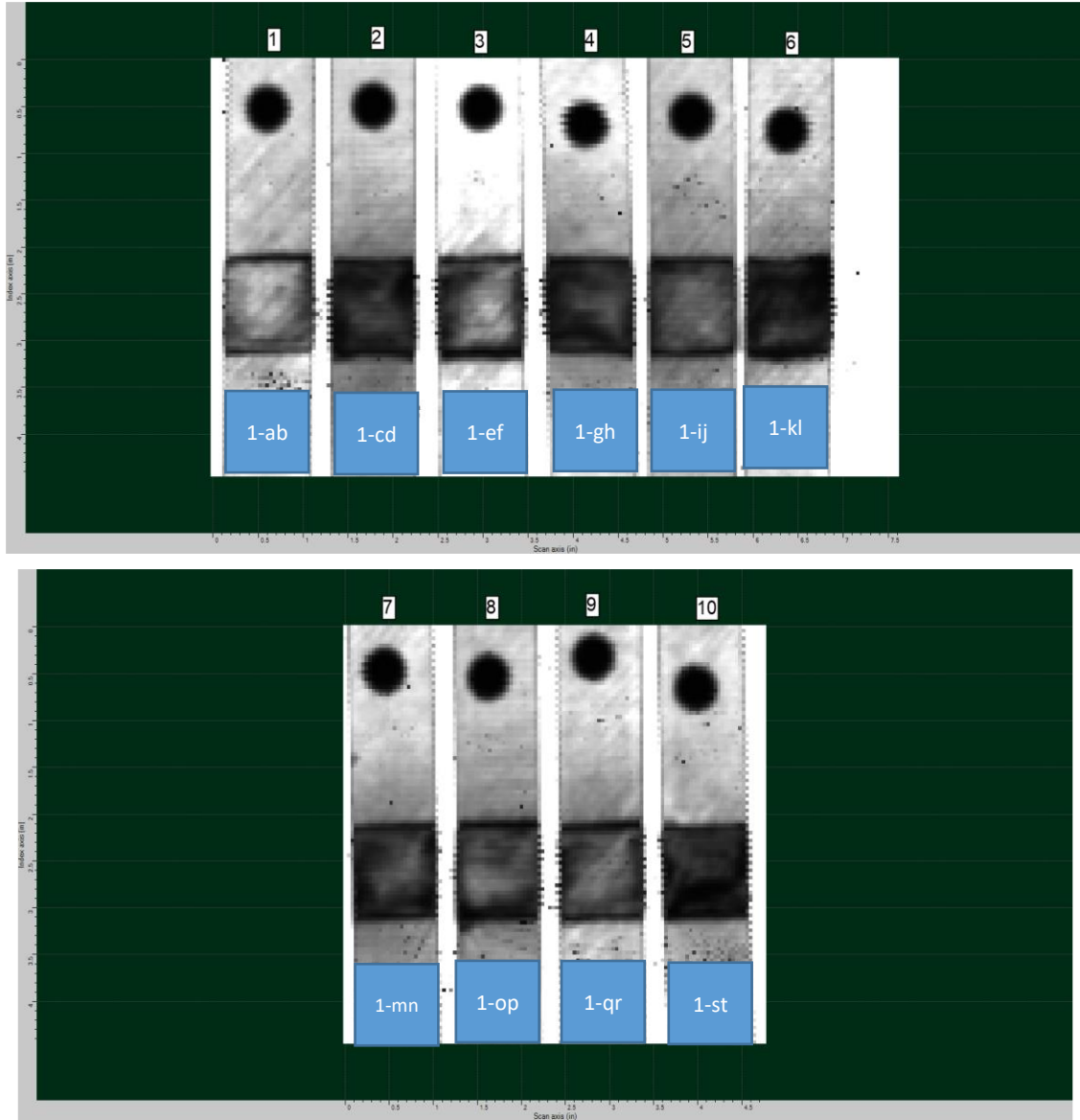


Figure 47 – PEKK SLS NDI Results

5.4 PPS SLS NDI Results



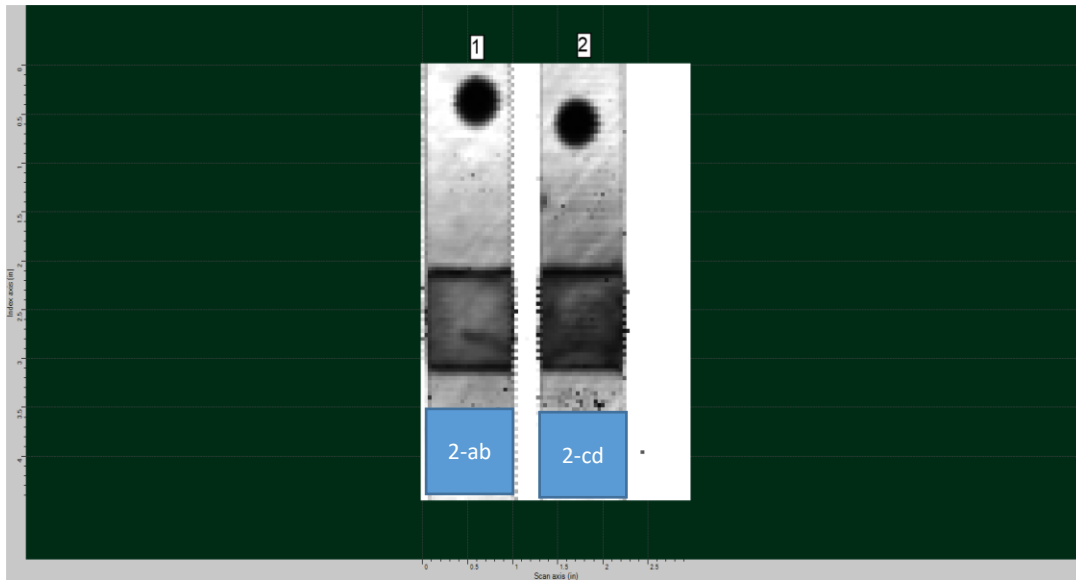


Figure 48 – PPS SLS NDI Results

5.5 LM-PAEK DCB NDI Results

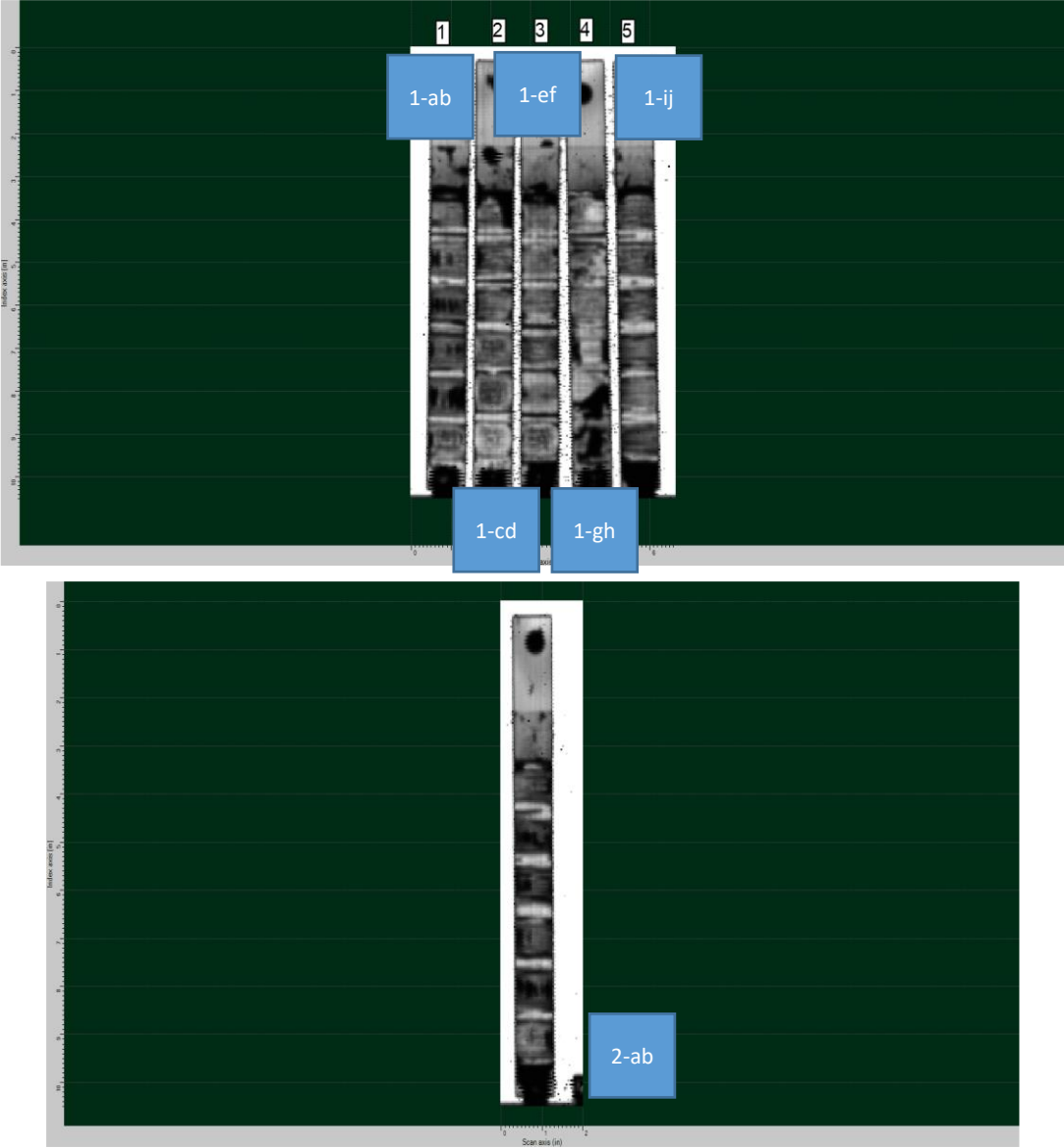


Figure 49 – LM-PAEK DCB NDI Results

5.6 PEI DCB NDI Results

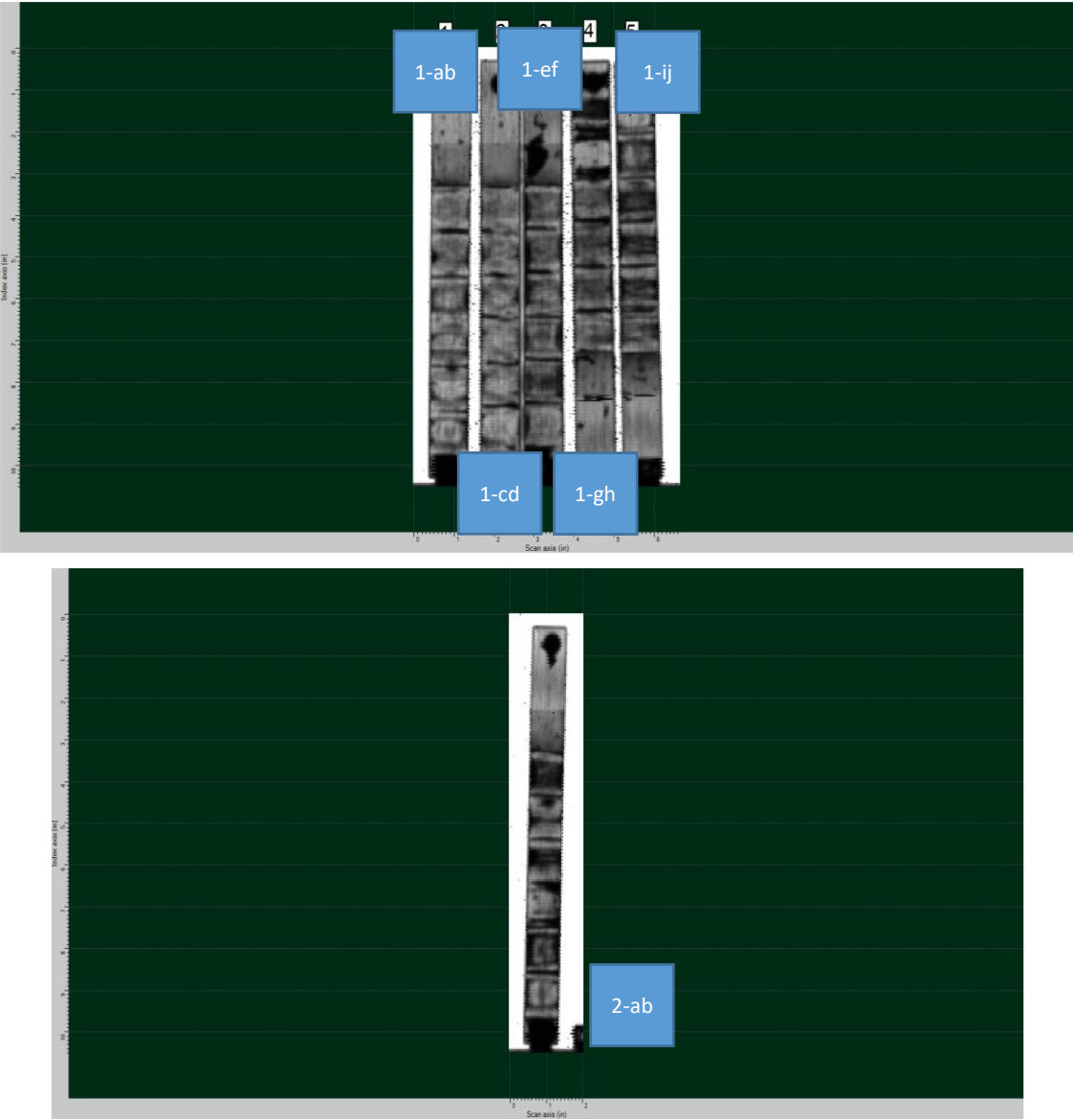


Figure 50 – PEI DCB NDI Results

5.7 PPS NDI Results

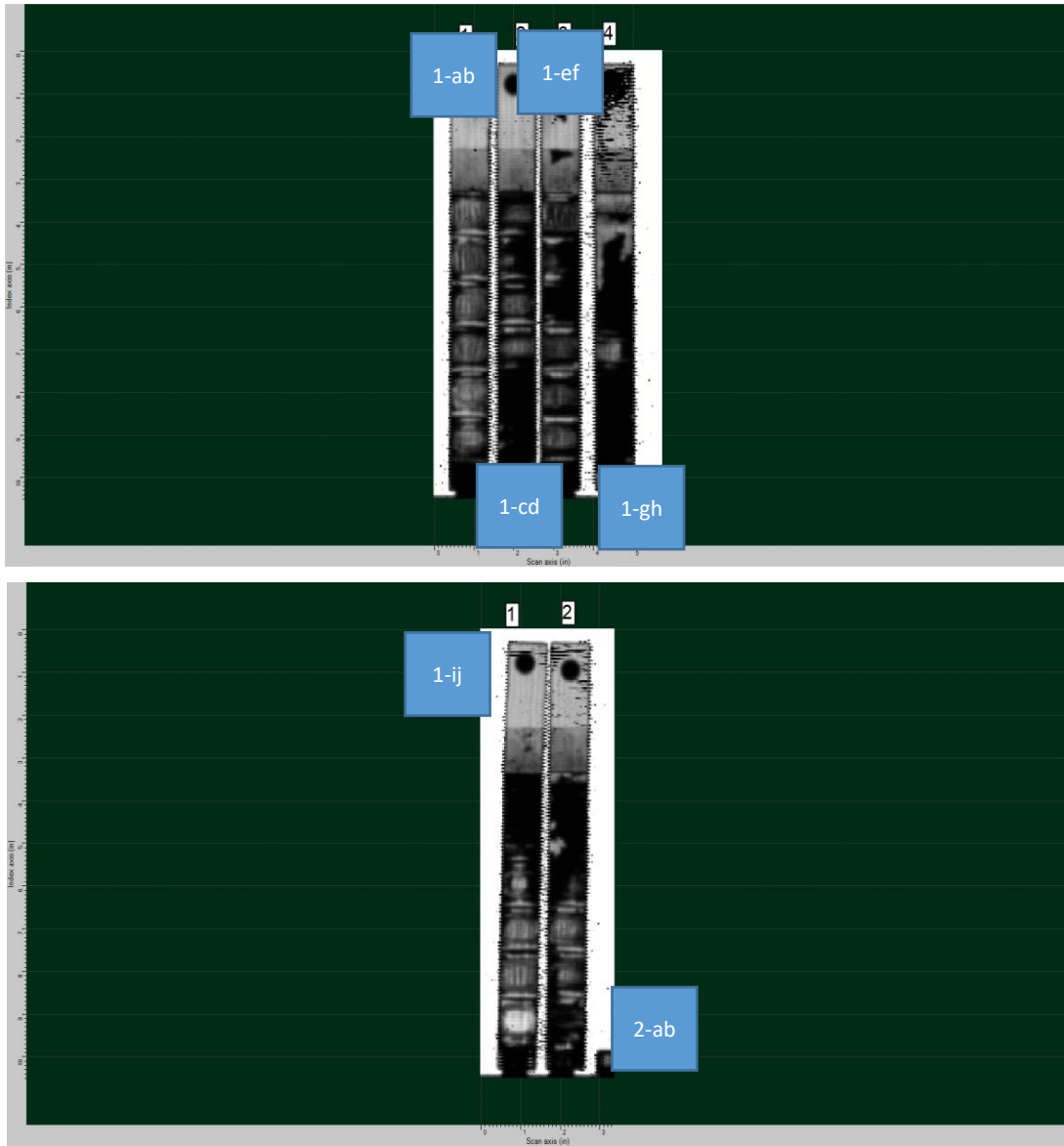


Figure 51 – PPS DCB NDI Results

6.0 Photomicrographs

Photomicrographs are essential in thermoplastic welding as they enable visual inspection, defect analysis and process optimization. One photomicrograph specimen was manufactured from each process. These results can be seen below.

6.1 LM-PAEK SLS Photomicrograph Results

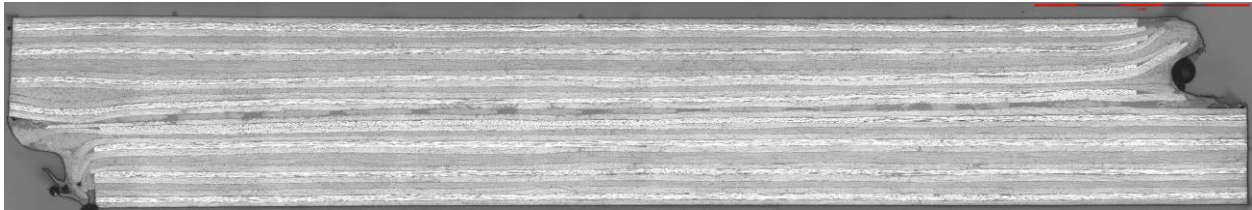


Figure 52 – LM-PAEK 3K EOFPO Photomicrograph

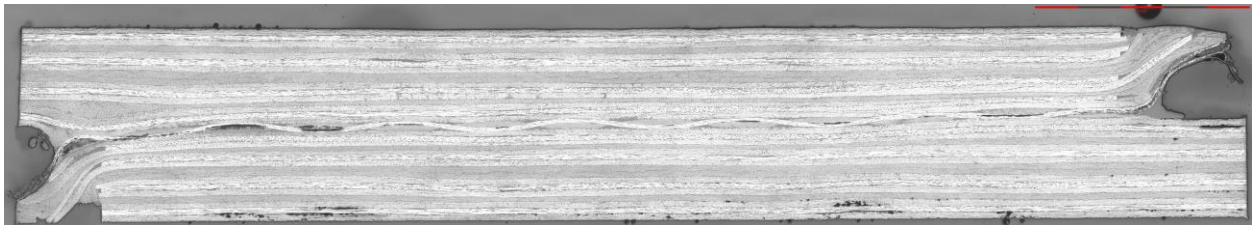


Figure 53 - LM-PAEK 3K NFPO Photomicrograph

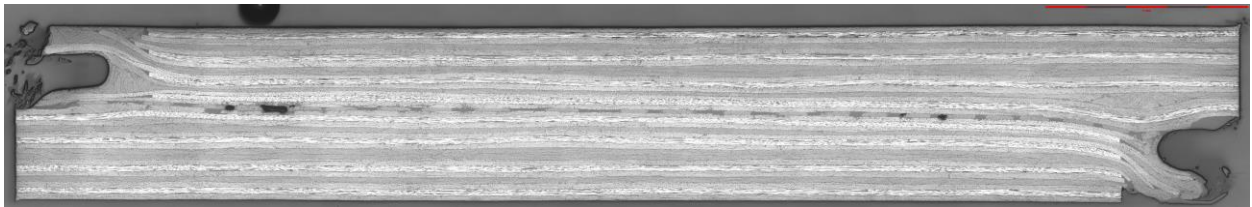


Figure 54 - LM-PAEK 1K EOFPO Photomicrograph

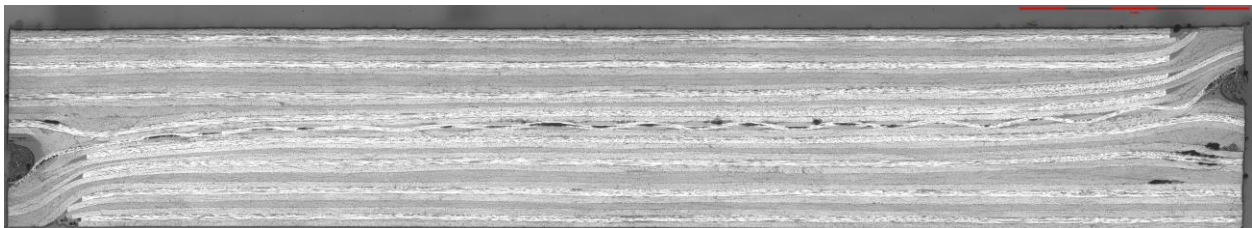


Figure 55 - LM-PAEK 1K NFPO Photomicrograph

6.2 PEI SLS Photomicrograph Results

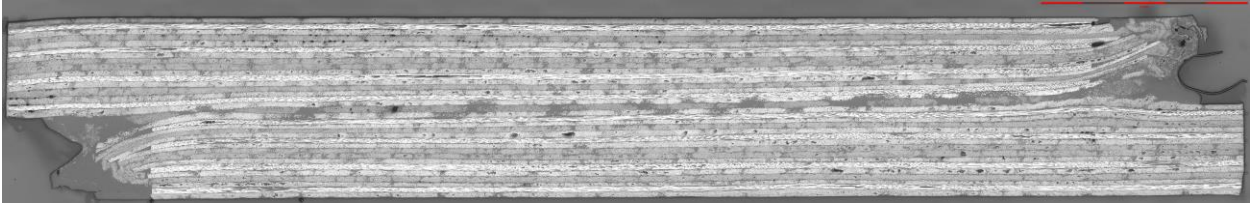


Figure 56 – PEI SLS Photomicrograph

6.3 PEKK SLS Photomicrograph Results

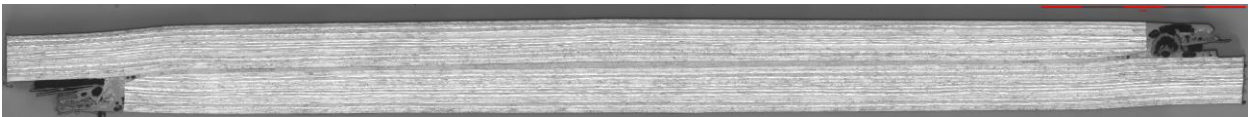


Figure 57 – PEKK SLS Photomicrograph

6.4 PPS SLS Photomicrograph Results

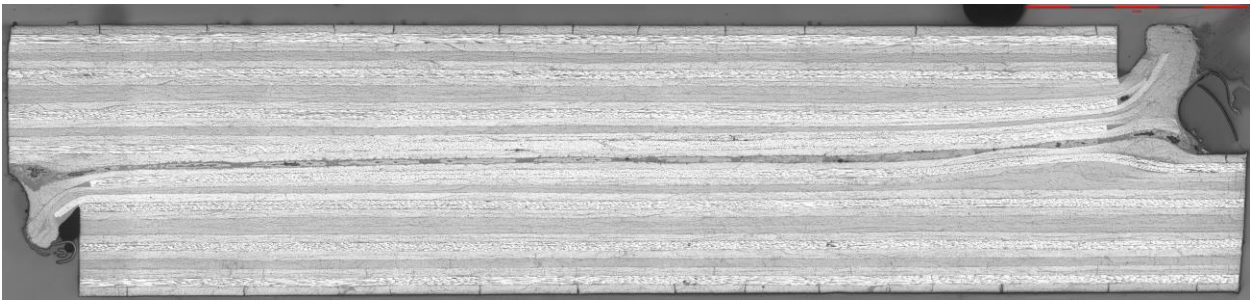


Figure 58 – PPS SLS Photomicrograph

6.5 LM-PAEK DCB Photomicrograph Results

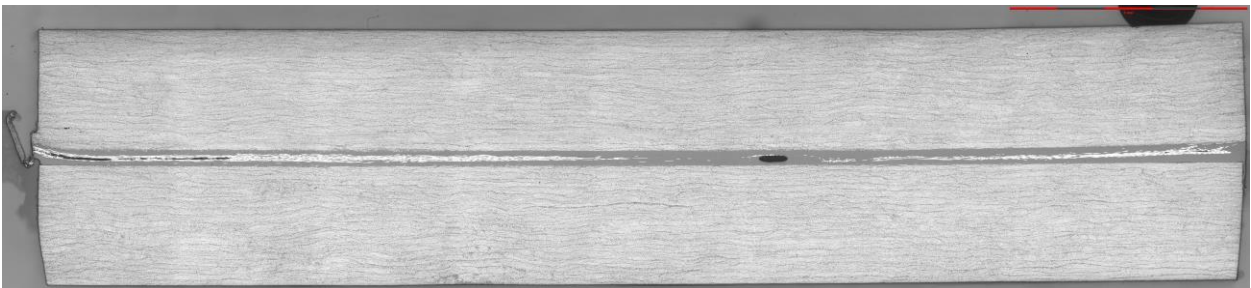


Figure 59 – LM-PAEK DCB Photomicrograph

6.6 PEI DCB Photomicrograph Results

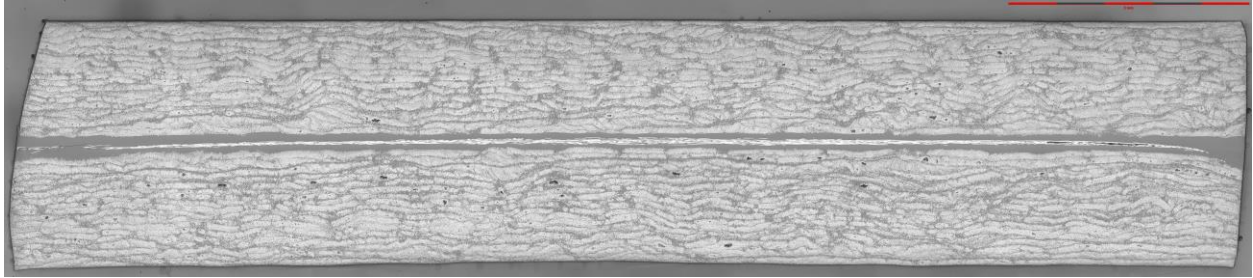


Figure 60 – PEI DCB Photomicrograph Results

6.7 PPS DCB Photomicrograph Results

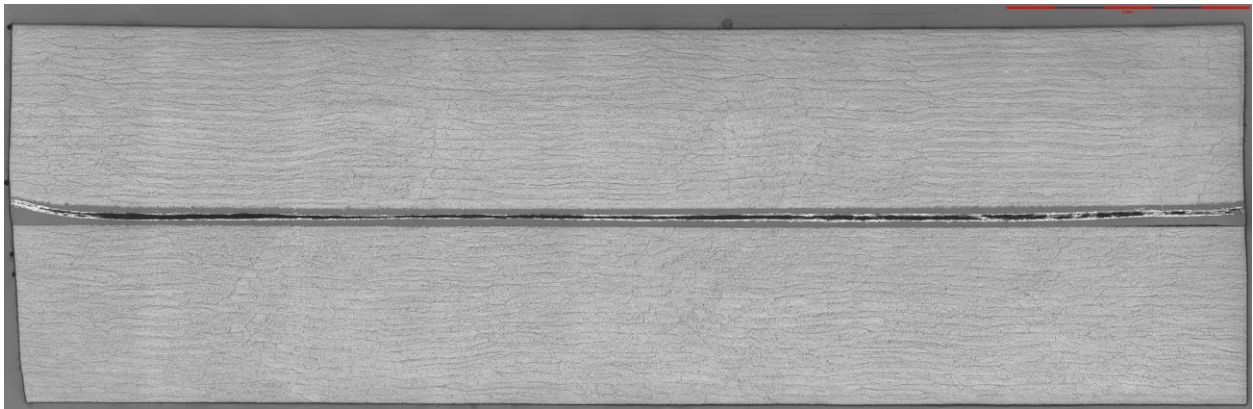


Figure 61 – PPS DCB Photomicrograph Results

7.0 Differential Scanning Calorimetry

DSC data is important in thermoplastic welding as it provides valuable insights into the thermal behavior and properties of the materials involved. This information aids in optimizing welding parameters, selecting compatible materials, and assessing the quality of weld joints, ultimately leading to improved welding processes and reliable final products.

7.1 Test Specimen Extraction Plan

DSC Specimens extracted from resistance welds were taken from the center of the 1" weld overlap. These DSC specimens were then ground down on either side to 0.04" (≈ 8 Plies) according to Figure 62.

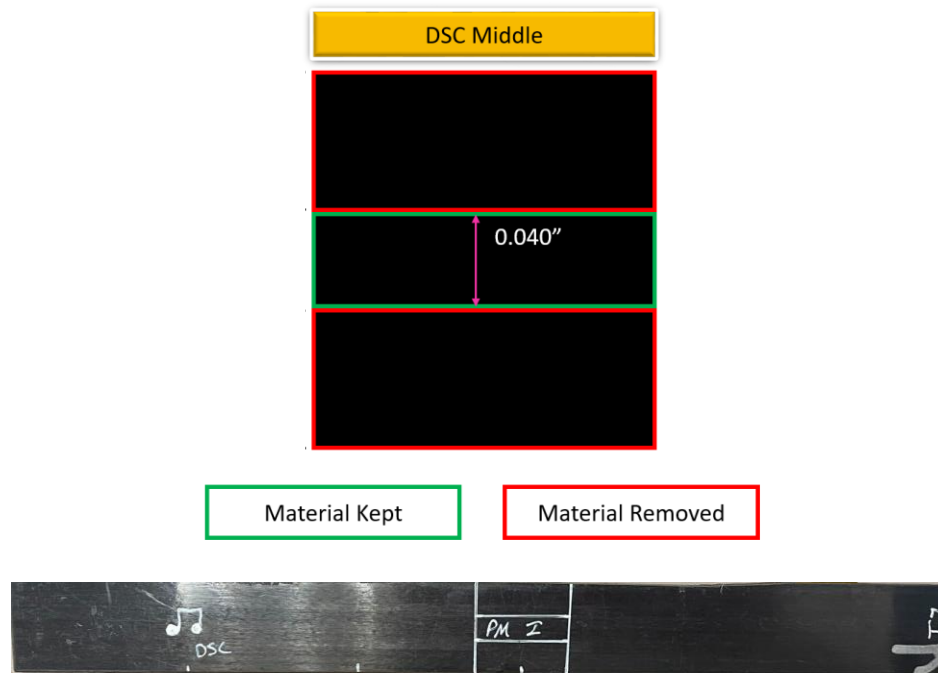


Figure 62 - DSC Specimen Extraction Plan

7.2 LM-PAEK 3K EOFPO SLS DSC Data Summary

Sample: NIAR-LM-PAEK-RW-SLS-3K-EOFPO-DSC

Method: Heat & Cool @ 10C/min

Operator: Ping

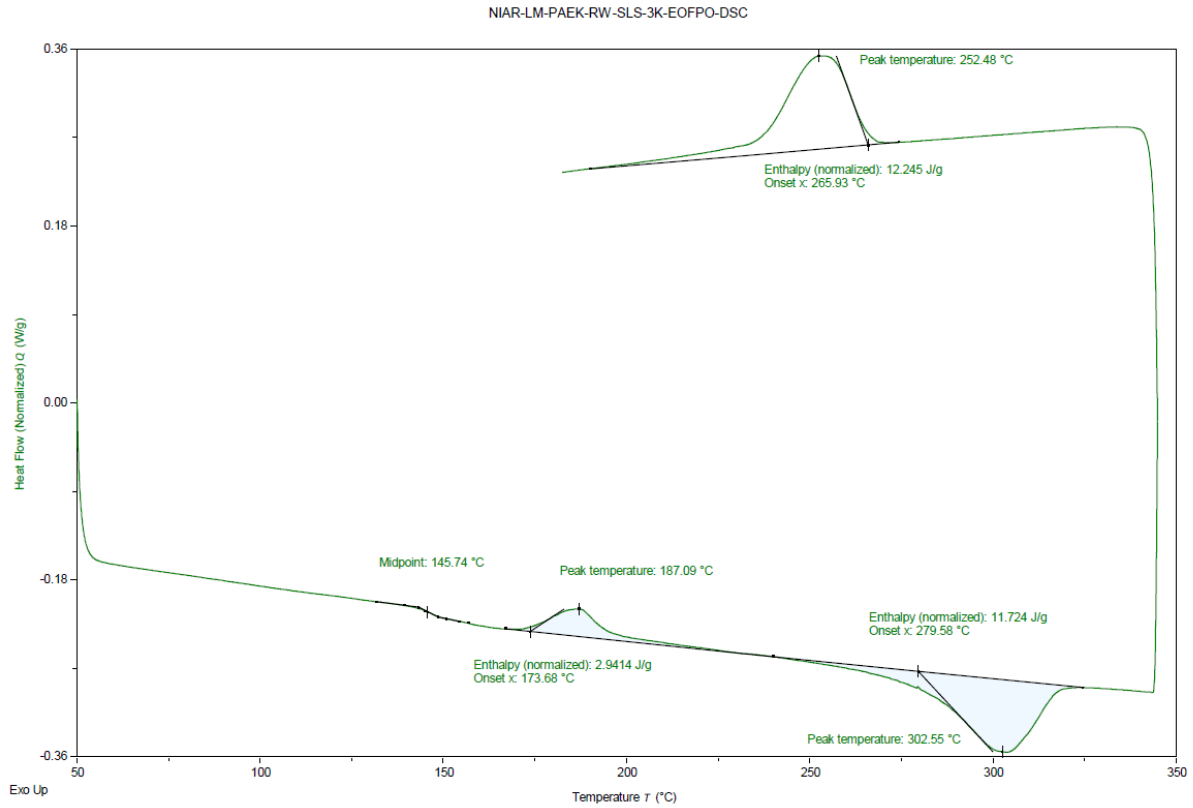
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-LM-PAEK-RW-SLS-3K-EOFPO-DSC.tri

Instrument/Date: DSC2500,4/30/2024 7:28:10 PM

Sample Mass: 28.47 mg

Pan type: Tzero Aluminum

Project: NASA CFHE Resistance Welding Phase II DSC



TA Instruments Trios V5.6.0.87

7.3 LM-PAEK 3K NFPO SLS DSC Data Summary

Sample: NIAR-LM-PAEK-RW-SLS-3K-NFPO-DSC

Method: Heat & Cool @ 10C/min

Operator: Ping

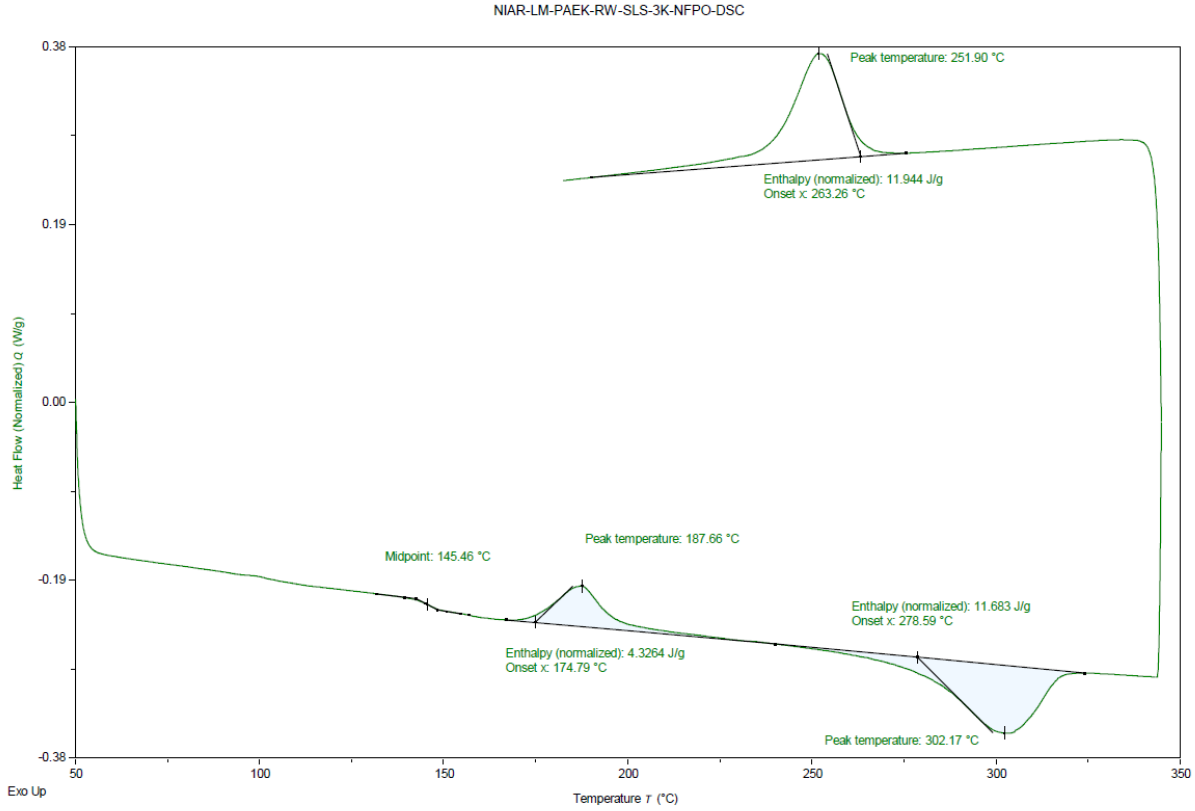
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-LM-PAEK-RW-SLS-3K-NFPO-DSC.tri

Instrument/Date: DSC2500,4/30/2024 8:22:09 PM

Sample Mass: 31.23 mg

Pan type: Tzero Aluminum

Project: NASA CFHE Resistance Welding Phase II DSC



TA Instruments Trios V5.6.0.87

7.4 LM-PAEK 1K EOFPO SLS DSC Data Summary

Sample: NIAR-LM-PAEK-RW-SLS-1K-EOFPO-DSC

Method: Heat & Cool @ 10C/min

Operator: Ping

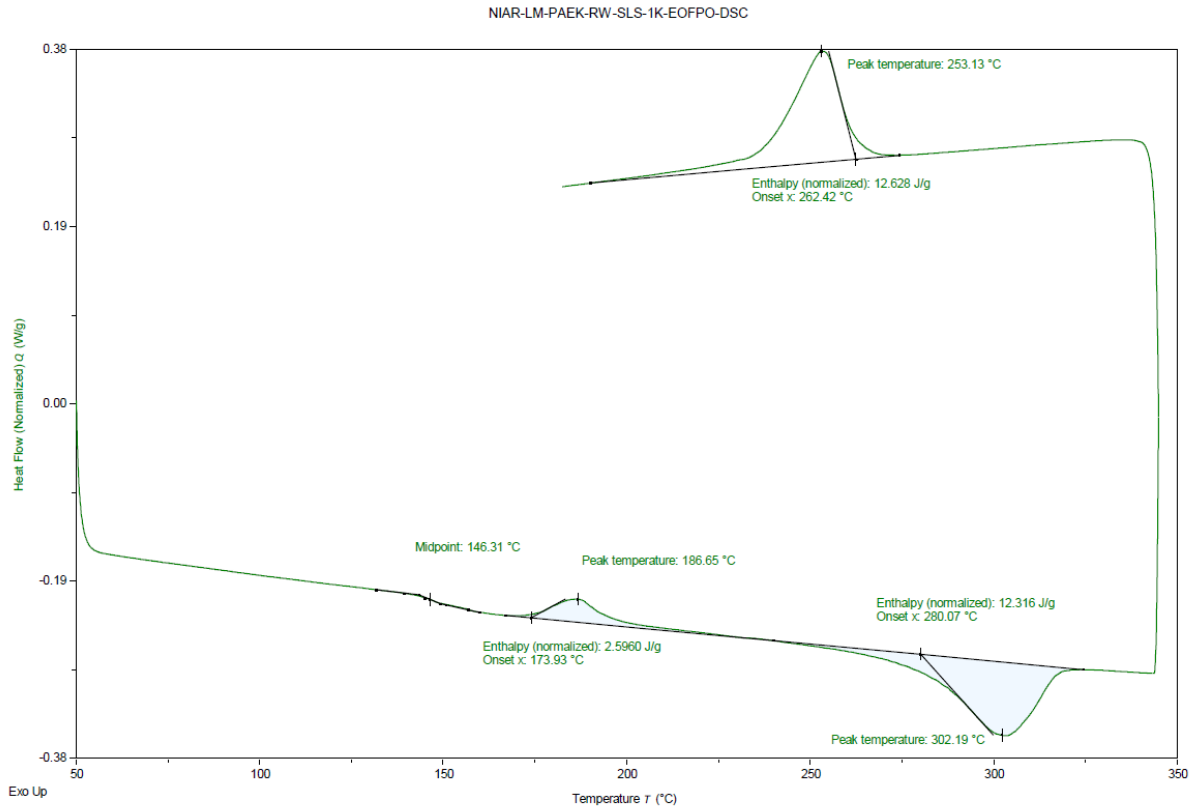
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-LM-PAEK-RW-SLS-1K-EOFPO-DSC.tri

Instrument/Date: DSC2500, 4/30/2024 5:40:05 PM

Sample Mass: 30.05 mg

Pan type: Tzero Aluminum

Project: NASA CFHE Resistance Welding Phase II DSC



TA Instruments Trios V5.6.0.87

7.5 LM-PAEK 1K NFPO SLS DSC Data Summary

Sample: NIAR-LM-PAEK-RW-SLS-1K-NFPO-DSC

Method: Heat & Cool @ 10C/min

Operator: Ping

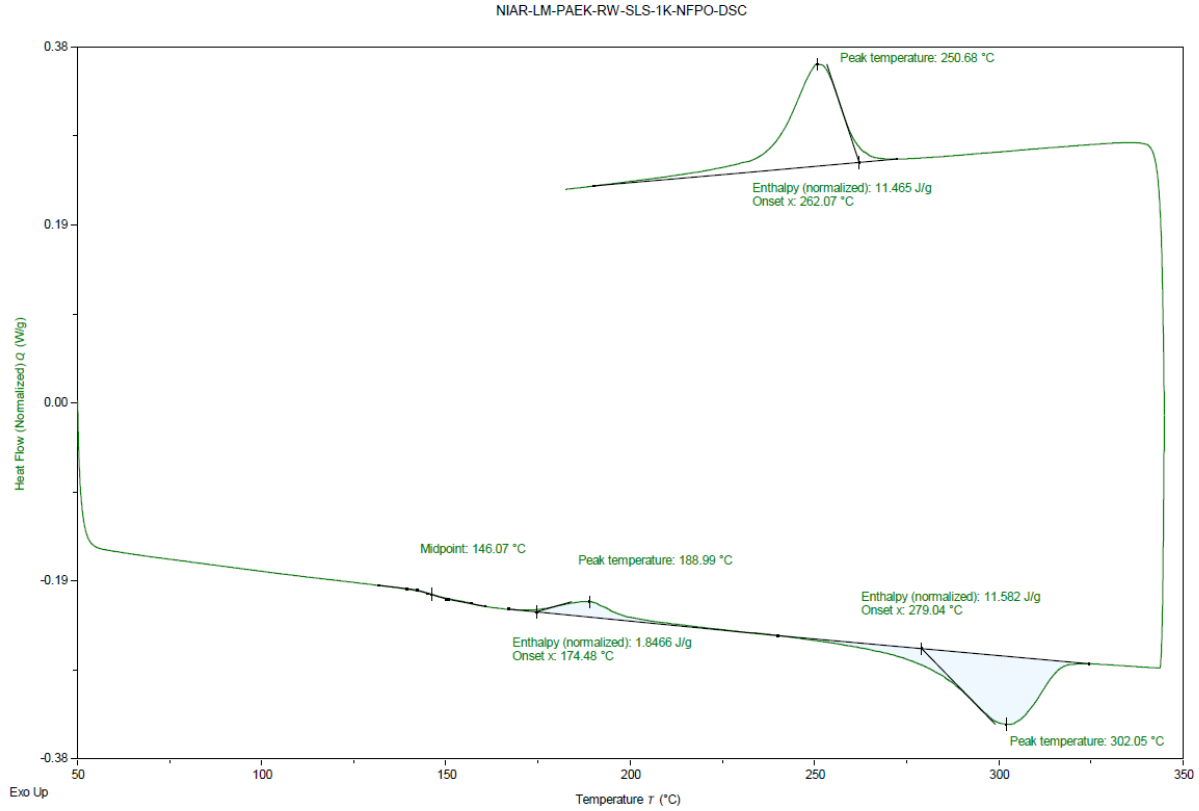
File: X:\Data\DSC\NASA\CFHE_Resistance_Welding_Phase_II\NIAR-LM-PAEK-RW-SLS-1K-NFPO-DSC.tri

Instrument/Date: DSC2500, 4/30/2024 6:34:07 PM

Sample Mass: 29.54 mg

Pan type: Tzero Aluminum

Project: NASA CFHE Resistance Welding Phase II DSC



TA Instruments Trios V5.6.0.87

7.6 PEI SLS DSC Data Summary

Sample: NIAR-PEI-RW-SLS-DSC

Method: Heat & Cool @ 10C/min

Operator: Ping

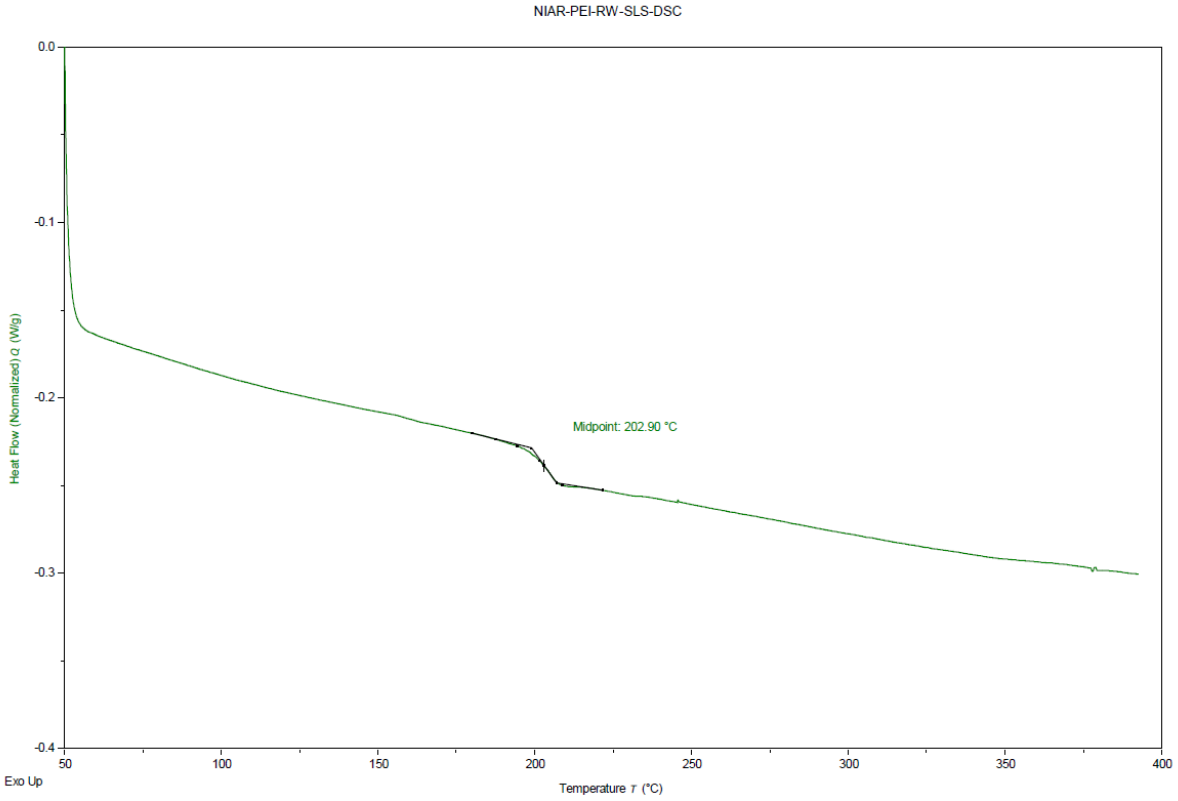
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-PEI-RW-SLS-DSC.tri

Instrument/Date: DSC2500,4/30/2024 11:20:25 AM

Sample Mass: 30.75 mg

Pan type: Tzero Aluminum

Project: NASA CFHE Resistance Welding Phase II DSC



TA Instruments Trios V5.6.0.87

7.7 PEKK SLS DSC Data Summary

Sample: LARC-PEKK-VAR-SLS-DSC

Method: Heat & Cool @ 10C/min

Operator: Ping

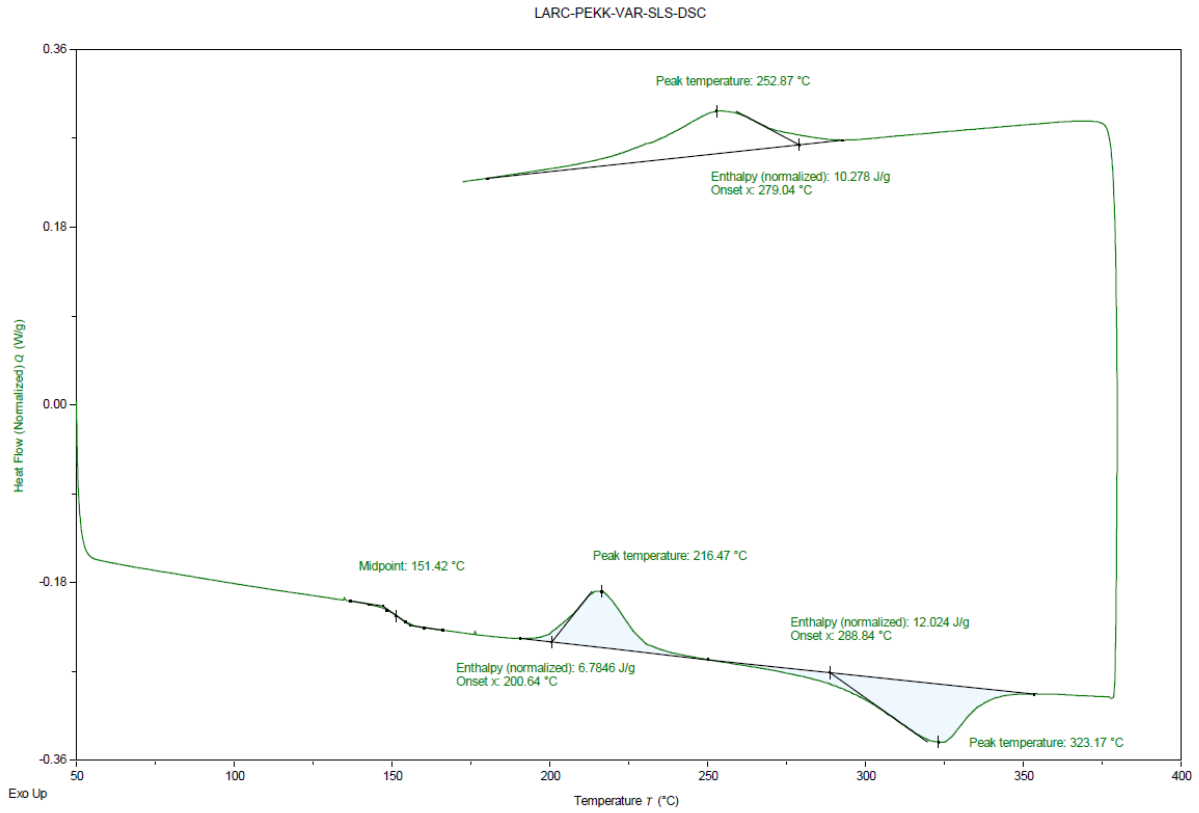
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase III\LARC-PEKK-VAR-SLS-DSC.tri

Instrument/Date: DSC2500,4/30/2024 8:42:53 AM

Sample Mass: 28.52 mg

Pan type: Tzero Aluminum

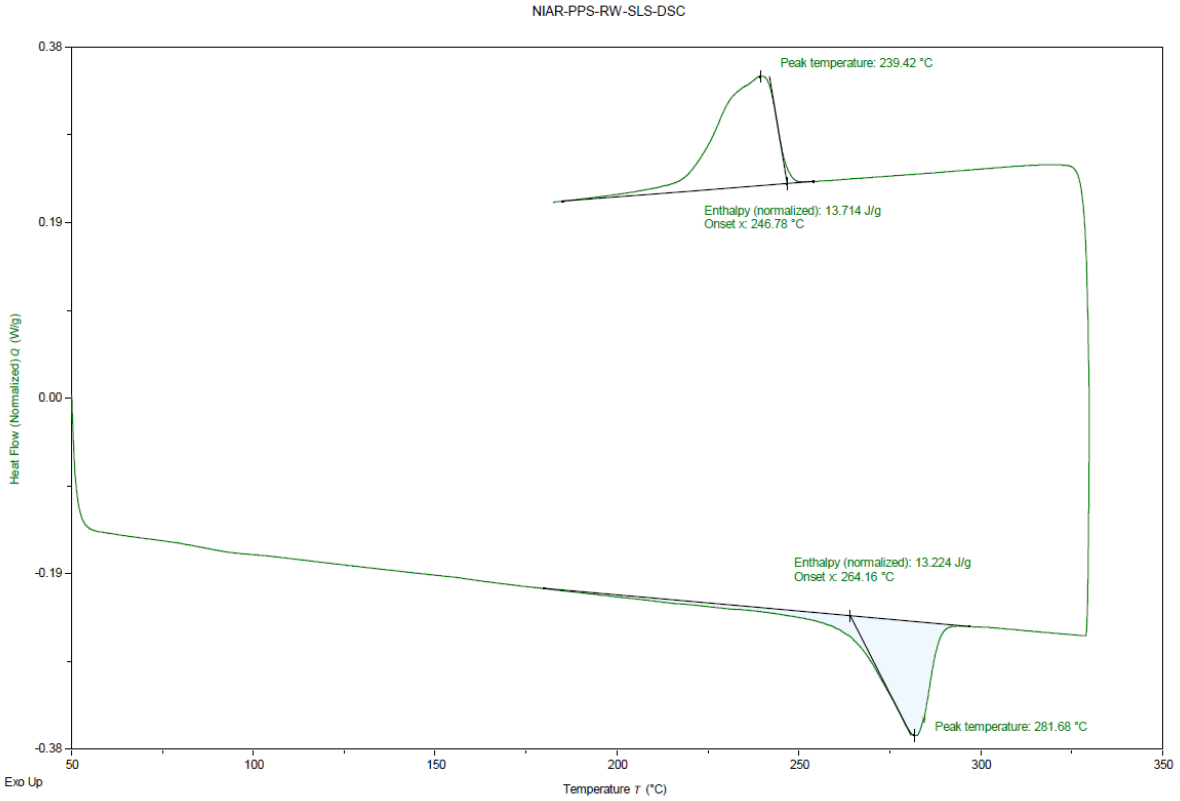
Project: NASA CFHE Resistance Welding Phase II DSC



7.8 PPS SLS DSC Data Summary

Sample: NIAR-PPS-RW-SLS-DSC
Method: Heat & Cool @ 10C/min
Operator: Ping
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-PPS-RW-SLS-DSC.tri

Instrument/Date: DSC2500,4/30/2024 12:58:59 PM
Sample Mass: 28.57 mg
Pan type: Tzero Aluminum
Project: NASA CFHE Resistance Welding Phase II DSC



TA Instruments Trios V5.6.0.87

7.9 LM-PAEK DCB DSC Data Summary

Sample: NIAR-LM-PAEK-RW-DCB-DSC

Method: Heat & Cool @ 10C/min

Operator: Ping

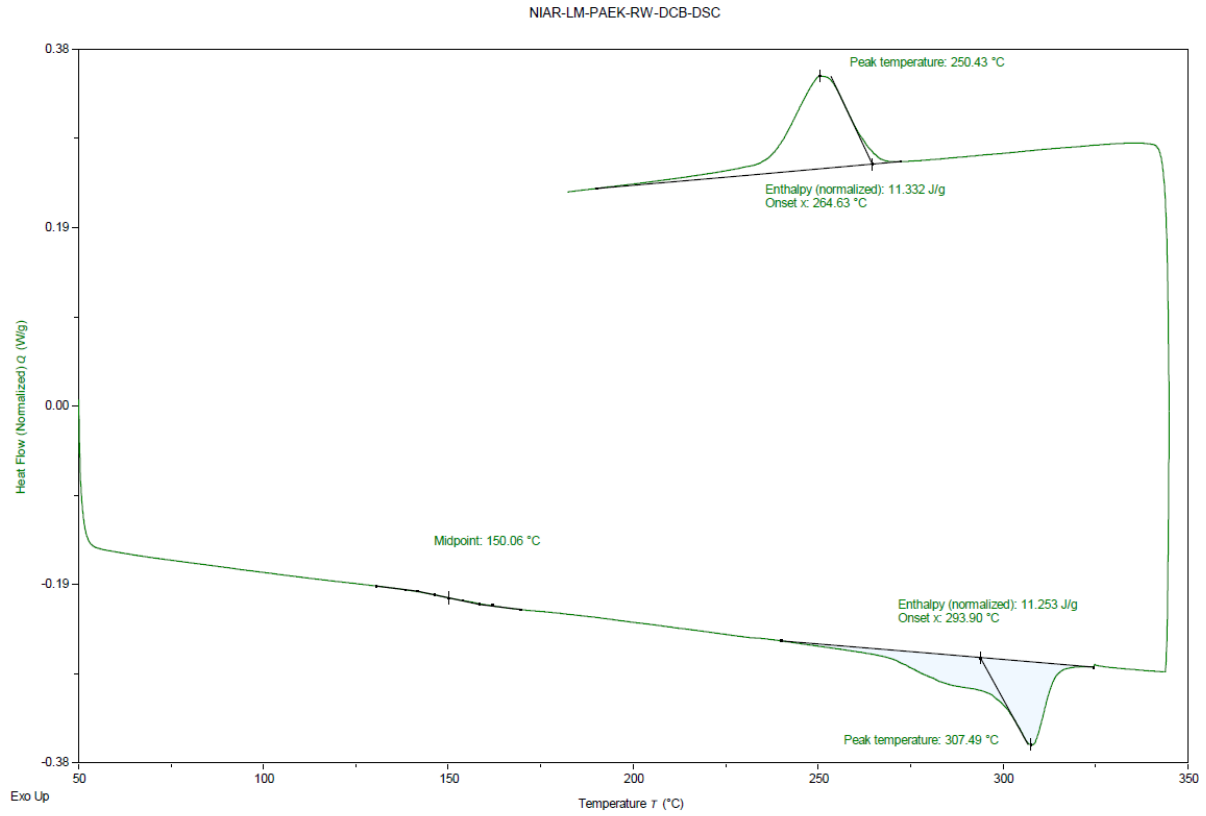
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-LM-PAEK-RW-DCB-DSC.tri

Instrument/Date: DSC2500,4/30/2024 1:50:00 PM

Sample Mass: 17.26 mg

Pan type: Tzero Aluminum

Project: NASA CFHE Resistance Welding Phase II DSC



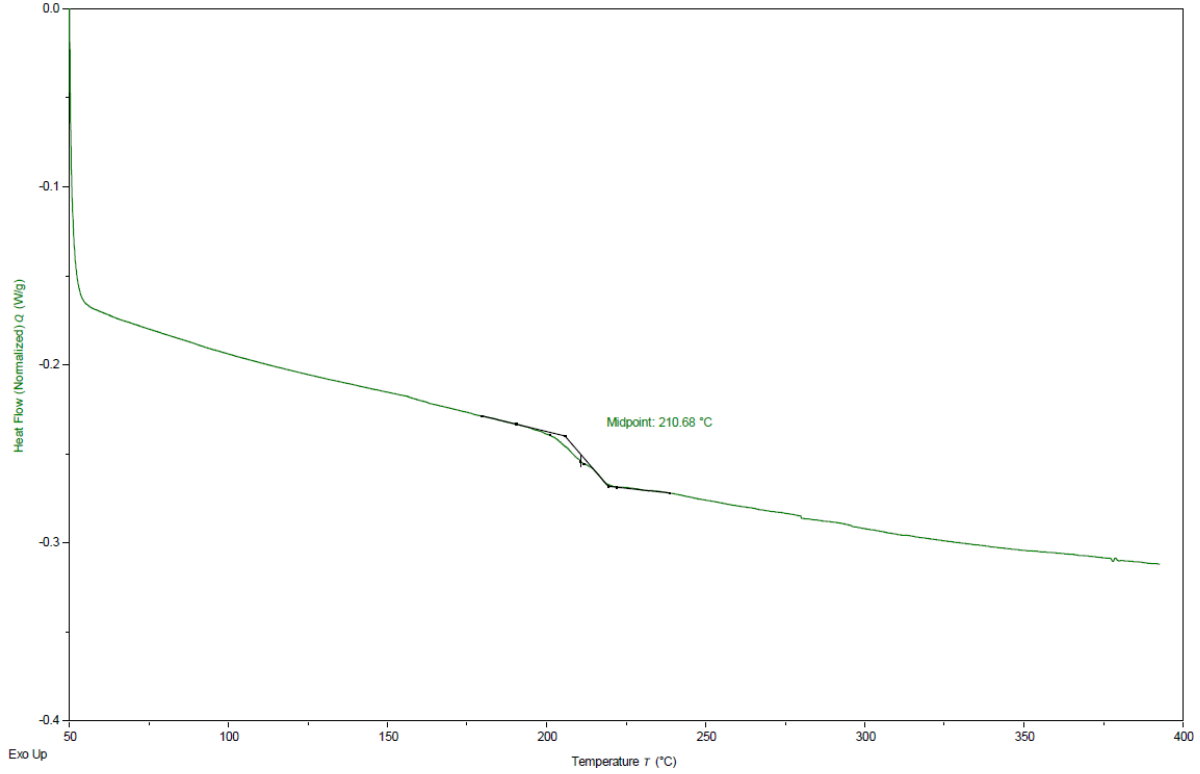
TA Instruments Trios V5.6.0.87

7.10 PEI DCB DSC Data Summary

Sample: NIAR-PEI-RW-DCB-DSC
Method: Heat & Cool @ 10C/min
Operator: Ping
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-PEI-RW-DCB-DSC.tri

Instrument/Date: DSC2500, 4/30/2024 10:35:54 AM
Sample Mass: 26.26 mg
Pan type: Tzero Aluminum
Project: NASA CFHE Resistance Welding Phase II DSC

NIAR-PEI-RW-DCB-DSC



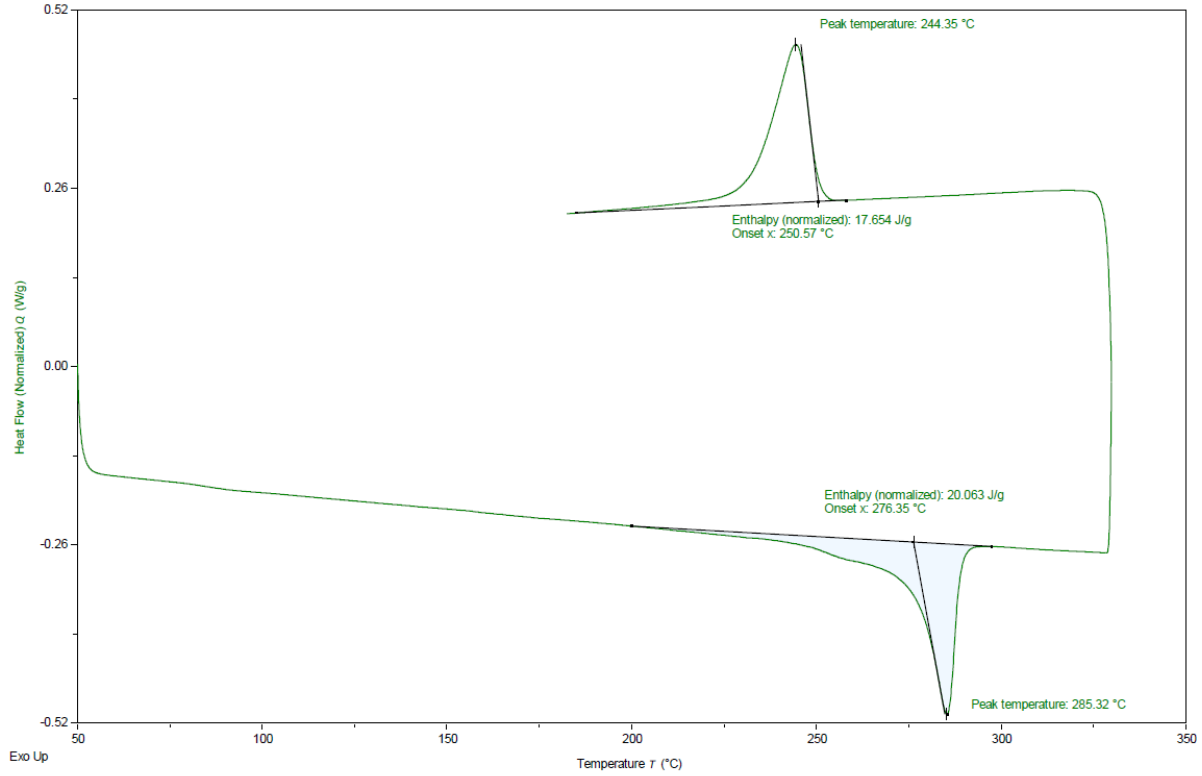
TA Instruments Trios V5.6.0.87

7.11 PPS DCB DSC Data Summary

Sample: NIAR-PPS-RW-DCB-DSC
Method: Heat & Cool @ 10C/min
Operator: Ping
File: X:\Data\DSC\NASA\CFHE Resistance Welding Phase II\NIAR-PPS-RW-DCB-DSC.tri

Instrument/Date: DSC2500,4/30/2024 9:44:53 AM
Sample Mass: 32.41 mg
Pan type: Tzero Aluminum
Project: NASA CFHE Resistance Welding Phase II DSC

NIAR-PPS-RW-DCB-DSC



TA Instruments Trios V5.6.0.87

8.0 Conclusion – Recommendations

Through the manufacturing of these coupons there are a few main takeaways. It is possible to use a Carbon Fiber Heating Element to weld thermoplastic composite together but it would most likely benefit the joint strength if a thinner heating element was used, as the failure almost always happens as the heating element instead of the substrate. It is important to weld all the way to the edge of the substrate as the failure always initiates at the edge as seen in the high speed images, although mitigation of fiber distortion at the edge must occur to prevent porosity at the weld line as we saw in the photomicrograph results.

Overall, this research has showed that using a carbon fiber heating element in thermoplastic welding is a viable option. Studies must also be completed in order to improve the consistency of sequential welding and the overall speed as this technique would most likely be used to scale up to weld larger structures.

