Stratasys DDM Group

Coefficient of Thermal Expansion Test Report

Test House:

NIAR – Wichita Kansas

Contact – Shin Mah

Revision Dates:

Original	***2009-12-01***	***First Release, CTE Data table – ULTEM, PPSF, SR30, PC***
Revision A	***2011-09-17***	***Detail procedure with raw test data***
Revision B	***2011-09-21***	***Corrected Phase 2 Material Types in test conf table***
Revision C	***2011-12-20***	***Added two new materials – SR100 & ABS ESD7***

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OVERVIEW

Fused deposition modeling is being utilized for a variety of tooling and end use parts applications that required elevated temperatures, like composite layup tooling. For these applications users needed to understand the coefficient of thermal expansion (CTE) to appropriately design the tools or parts. This test report provides the data that has been collected and the third party tests houses that were utilized to obtain that data. Only accredited third party test facilities that are recognized in the industry will be included in this report.

TEST RESULTS SUMMARY

Stratasys Product	Test Procedure	Test Facility	µm/(m·C˚)	in/(in·F˚)	Doc. Rev
PC	ASTM E228	NIAR	79.23	4.46E-05	Original
SR30	ASTM E228	NIAR	115.53	6.50E-05	Original
PPSF	ASTM E228	NIAR	69.83	3.93E-05	Original
ULTEM 9085 Natural	ASTM E228	NIAR	65.27	3.67E-05	Original
SR 100 <End>	ASTM E228	NIAR	98.32 (35˚C-100˚C) 187.6 (100˚C-130˚C)	5.47E-05 (95˚F-212˚F) 10.42E-05 (212˚F-266˚F)	C C
SR 100 <Edge>	ASTM E228	NIAR	84.21 (35˚C-105˚C)	4.68E-05 (95˚F-221˚F)	C
ABS ESD7 <End>	ASTM E228	NIAR	80.76 (-40˚C-70˚C) 389.5 (80˚C-105˚C)	4.49E-05 (-40˚F-158˚F) 21.64E-05 (176˚F-221˚F)	C C
ABS ESD7 <Edge>	ASTM E228	NIAR	76.30 (-40˚C-60˚C)	4.24E-05 (-40˚F-140˚F)	C

Test Methods	
Test Method:	ASTM E228
Test House:	NIAR
Machine:	TA TMA Q400
Test Fixture:	Expansion Probe
Test Method:	Controlled Force 0.05N
Heating Rate:	5ºC/min (9ºF/min)

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Temperature Range:		
ULTEM	-60ºC +170ºC	-73ºF +338ºF
SR30	-60ºC +110ºC	-73ºF +230ºF
PC	-60ºC +140ºC	-73ºF +284ºF
PPSF	-60ºC +200ºC	-73ºF +392ºF
SR 100	35ºC +200ºC	95ºF +392ºF
ABS ESD7	-60ºC +120ºC	-73ºF +248ºF

TEST PROCEDURE

ASTM E228 Test Procedure was used to assess CTE for Stratasys Materials. Phase 1 investigated how the variety of build orientations and build styles would affect the CTE of an FDM produced part or tool? Because PPSF was the highest temperature material and could be tested to the highest values, it was selected for the initial case study. It was an assumption of the Phase 1 assessment, that higher delta temperatures would accentuate any potential anisotropic behaviors due to FDM processing. In Phase 2, the balance of the FDM materials were evaluated for CTE based on the lessons learned from the Phase 1 Assessment. Phase 3 added two new materials SR100 soluble materials and ABS ESD7 material.

PHASE 1 – ISOTROPIC BEHAVIOR ASSESSMENT

Two factors were investigated to understand their impacts on CTE:

1. Build Orientation
    a. Edge – both edge and flat were determined to have the same filament orientation so only edge was tested. In this case the coupon was built with its long side lying down on the build table. This configuration effectively tests the CTE in the axis of the extruded filament.
    b. End – this test sample was build with the long edge of the coupon normal to the build table (standing up). This configuration effectively tests the CTE across the width of the extruded filament.
2. Build Style
    a. Solid – This sample is built with default setting for a solid part
    b. Sparse – this sample is built with gaps in the part to determine if localize CTE effects become a factor that changes the overall CTE of the FDM part.

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TEST TABLE

Four configurations (1-4) and three samples (a,b,c) of each configuration were tested.

Sample #	Material	Build Orientation	Fill
Sample 1A	PPSF	End	Solid
Sample 1B	PPSF	End	Solid
Sample 1C	PPSF	End	Solid
Sample 2A	PPSF	End	Sparse
Sample 2B	PPSF	End	Sparse
Sample 2C	PPSF	End	Sparse
Sample 3A	PPSF	Edge	Solid
Sample 3B	PPSF	Edge	Solid
Sample 3C	PPSF	Edge	Solid
Sample 4A	PPSF	Edge	Sparse
Sample 4B	PPSF	Edge	Sparse
Sample 4C	PPSF	Edge	Sparse

RESULTS

Metric

				CTE				
Sample #	**Material**	**Build Orient**	**Fill**	**[µm/(m·°C)]**				
Sample 1A	PPSF	End	Solid	62.81	Average	65.93	Average	69.83
Sample 1B	PPSF	End	Solid	71.20				
Sample 1C	PPSF	End	Solid	63.77	St. Dev.	4.59	St. Dev.	3.47
Sample 2A	PPSF	End	Sparse	74.03	Average	71.74		
Sample 2B	PPSF	End	Sparse	69.13				
Sample 2C	PPSF	End	Sparse	72.07	St. Dev.	2.47		
Sample 3A	PPSF	Edge	Solid	72.13	Average	70.92		
Sample 3B	PPSF	Edge	Solid	70.83				
Sample 3C	PPSF	Edge	Solid	69.81	St. Dev.	1.16		
Sample 4A	PPSF	Edge	Sparse	69.17	Average	70.74		
Sample 4B	PPSF	Edge	Sparse	73.63				
Sample 4C	PPSF	Edge	Sparse	69.43	St. Dev.	2.50		

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English

Sample #	Material	Build Orient	Fill	CTE [in/(in·°F)]				
Sample 1A	PPSF	End	Solid	3.54E-05	Avg	3.71E-05	Avg	3.93E-05
Sample 1B	PPSF	End	Solid	4.01E-05				
Sample 1C	PPSF	End	Solid	3.59E-05	St. Dev.	2.58E-06	St. Dev.	1.95E-06
Sample 2A	PPSF	End	Sparse	4.17E-05	Avg	4.04E-05		
Sample 2B	PPSF	End	Sparse	3.89E-05				
Sample 2C	PPSF	End	Sparse	4.06E-05	St. Dev.	1.39E-06		
Sample 3A	PPSF	Edge	Solid	4.06E-05	Avg	3.99E-05		
Sample 3B	PPSF	Edge	Solid	3.99E-05				
Sample 3C	PPSF	Edge	Solid	3.93E-05	St. Dev.	6.55E-07		
Sample 4A	PPSF	Edge	Sparse	3.89E-05	Avg	3.98E-05		
Sample 4B	PPSF	Edge	Sparse	4.14E-05				
Sample 4C	PPSF	Edge	Sparse	3.91E-05	St. Dev.	1.41E-06		

Raw Data is provided in Appendix A

FINDINGS

The CTE values of each of the samples within a configuration were consistent. In addition, the samples across the different configurations were also consistent. Because there were no obvious differences in the test results that indicate any significant difference in CTE based on build orientation or build style, it was determined that a CTE for PPSF could be represented with a single average value of the test samples.

PHASE 2 – MATERIAL ASSESSMENT

Based on the PPSF Phase 1 finding, it was determined that Phase 2 testing could be conducted on a single build orientation and style. The samples were built on edge with solid build parameters for each of the materials tested.

Three samples for each material were tested and the average value published as the representative CTE value for each material.

TEST TABLE

Sample #	Material	Build Orientation	Fill
Sample 1A	PC	Edge	Solid
Sample 1B	PC	Edge	Solid
Sample 1C	PC	Edge	Solid
Sample 2A	ULTEM	Edge	Solid
Sample 2B	ULTEM	Edge	Solid
Sample 2C	ULTEM	Edge	Solid
Sample 3A	SR30	Edge	Solid
Sample 3B	SR30	Edge	Solid
Sample 3C	SR30	Edge	Solid
Sample 4A	PPSF	Edge	Solid
Sample 4B	PPSF	Edge	Solid
Sample 4C	PPSF	Edge	Solid
Test Parameters:			
Machine: TA TMA Q400			
Test Fixture: Expansion Probe			
Test Method: Controlled Force 0.05N			
Heating Rate: 5ºC/min			
Temperature Range:			
-60ºC to 140ºC (PC)			
-60ºC to 170ºC (Ultem)			
-60ºC to 110ºC (SR30)			
-60ºC to 200ºC (PPSF)			

RESULTS

Metric

Sample #	Material	Build Orientation	Fill	CTE [µm/(m·°C)]		
Sample 1A	PC	Edge	Solid	80.46	Average	79.23
Sample 1B	PC	Edge	Solid	79.57		
Sample 1C	PC	Edge	Solid	77.66	St. Dev.	1.43
Sample 2A	Ultem	Edge	Solid	62.80	Average	65.27
Sample 2B	Ultem	Edge	Solid	67.78		
Sample 2C	Ultem	Edge	Solid	65.22	St. Dev.	2.49
Sample 3A	SR30	Edge	Solid	115.20	Average	115.53
Sample 3B	SR30	Edge	Solid	111.90		
Sample 3C	SR30	Edge	Solid	119.50	St. Dev.	3.81
Sample 4A	PPSF	Edge	Solid	72.13	Average	70.71
Sample 4B	PPSF	Edge	Solid	70.83		
Sample 4C	PPSF	Edge	Solid	69.17	St. Dev.	1.48

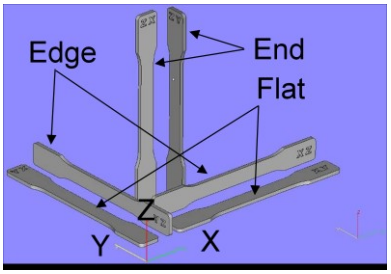
English

Sample #	Material	Build Orientation	Fill	CTE [in/(in·°F)]		
Sample 1A	PC	Edge	Solid	4.53E-05	Average	4.46E-05
Sample 1B	PC	Edge	Solid	4.48E-05		
Sample 1C	PC	Edge	Solid	4.37E-05	St. Dev.	8.05E-07
Sample 2A	Ultem	Edge	Solid	3.54E-05	Average	3.67E-05
Sample 2B	Ultem	Edge	Solid	3.82E-05		
Sample 2C	Ultem	Edge	Solid	3.67E-05	St. Dev.	1.40E-06
Sample 3A	SR30	Edge	Solid	6.48E-05	Average	6.50E-05
Sample 3B	SR30	Edge	Solid	6.30E-05		
Sample 3C	SR30	Edge	Solid	6.73E-05	St. Dev.	2.15E-06
Sample 4A	PPSF	Edge	Solid	4.06E-05	Average	3.98E-05
Sample 4B	PPSF	Edge	Solid	3.99E-05		
Sample 4C	PPSF	Edge	Solid	3.89E-05	St. Dev.	8.35E-07

Raw Data is provided in Appendix B

PHASE 3 – SR100 & ABS ESD7

Both of the Phase 3 materials were found to have anisotropic CTE properties. Therefore, tests were conducted in the End and Edge build styles. Designers should evaluate the operational temperature range for which the materials are being used and account for the CTE growth accordingly. The SR100 material is a soluble material that is not typically used for low temperature part applications so it was not tested at the low temperatures. It is however often used for soluble composite cure tooling and therefore the SR100 was tested over a temperature range from ambient to the Tg of the material.



SR100

Metric

TMA Results

Stratasys 2011 SR100 CTE Samples

Sample #	Orientation	Temperature Range (°C)	Coefficient of Thermal Expansion [µm/(m·°C)]			Change in CTE from Dimension Change Signal Tg [°C]	Tg [°F]		Tg [°F]
Sample 1	End	35°C to 100°C 100°C to 130°C 140°C to 155°C	99.85 195.1 1550			132.93	271.27	Average	271.97
								St. Dev.	0.65
Sample 2	End	35°C to 100°C 100°C to 130°C 140°C to 155°C	95.86 190.9 1506			133.38	272.08		
Sample 3	End	35°C to 100°C 100°C to 130°C 140°C to 155°C	99.26 176.7 1726			133.64	272.55		
Sample 1 Sample 2 Sample 3	Edge	35°C to 105°C	83.76 84.37 84.50	Average St. Dev.	84.21 0.40				

Raw Data is provided in Appendix C

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ABS ESD7

Metric

TMA Results

Stratasys 2011 ABS ESD7 CTE Samples

Sample #	Orientation	Temperature Range (°C)	Coefficient of Thermal Expansion [µm/(m·°C)]			Change in CTE from Dimension Change Signal Tg [°C]	Tg [°F]
Sample 1	End	-40°C to 70°C N/A	82.59 N/A			N/A	N/A
Sample 2	End	-40°C to 70°C 80°C to 105°C	83.38 363.8			79.68	175.42
Sample 3	End	-40°C to 70°C 90°C to 105°C	76.31 416.8			86.38	187.48
Sample 1 Sample 2 Sample 3	Edge	-40°C to 60°C	77.45 76.02 75.44	Average St. Dev.	76.30 1.03		

Raw Data is provided in Appendix C

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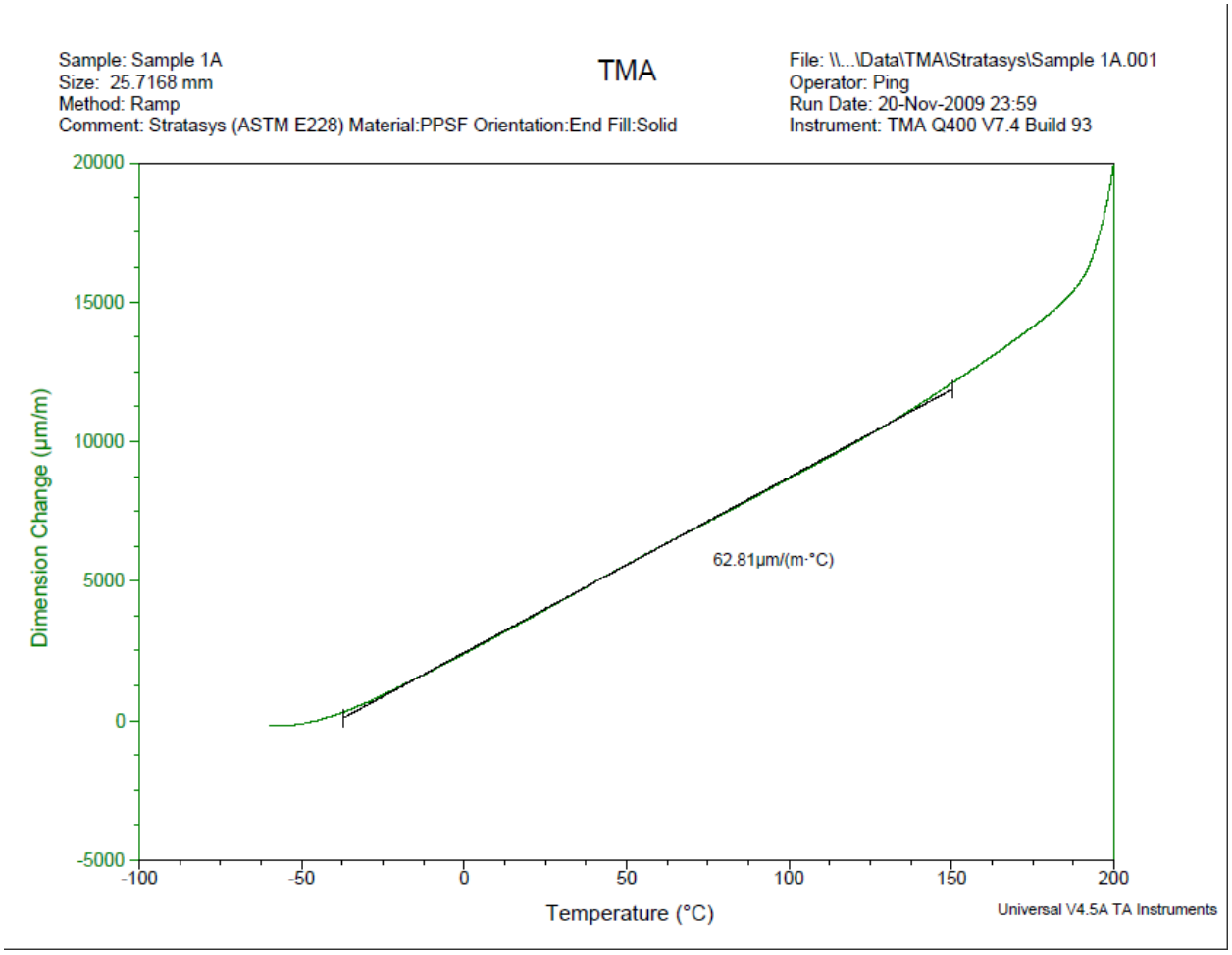
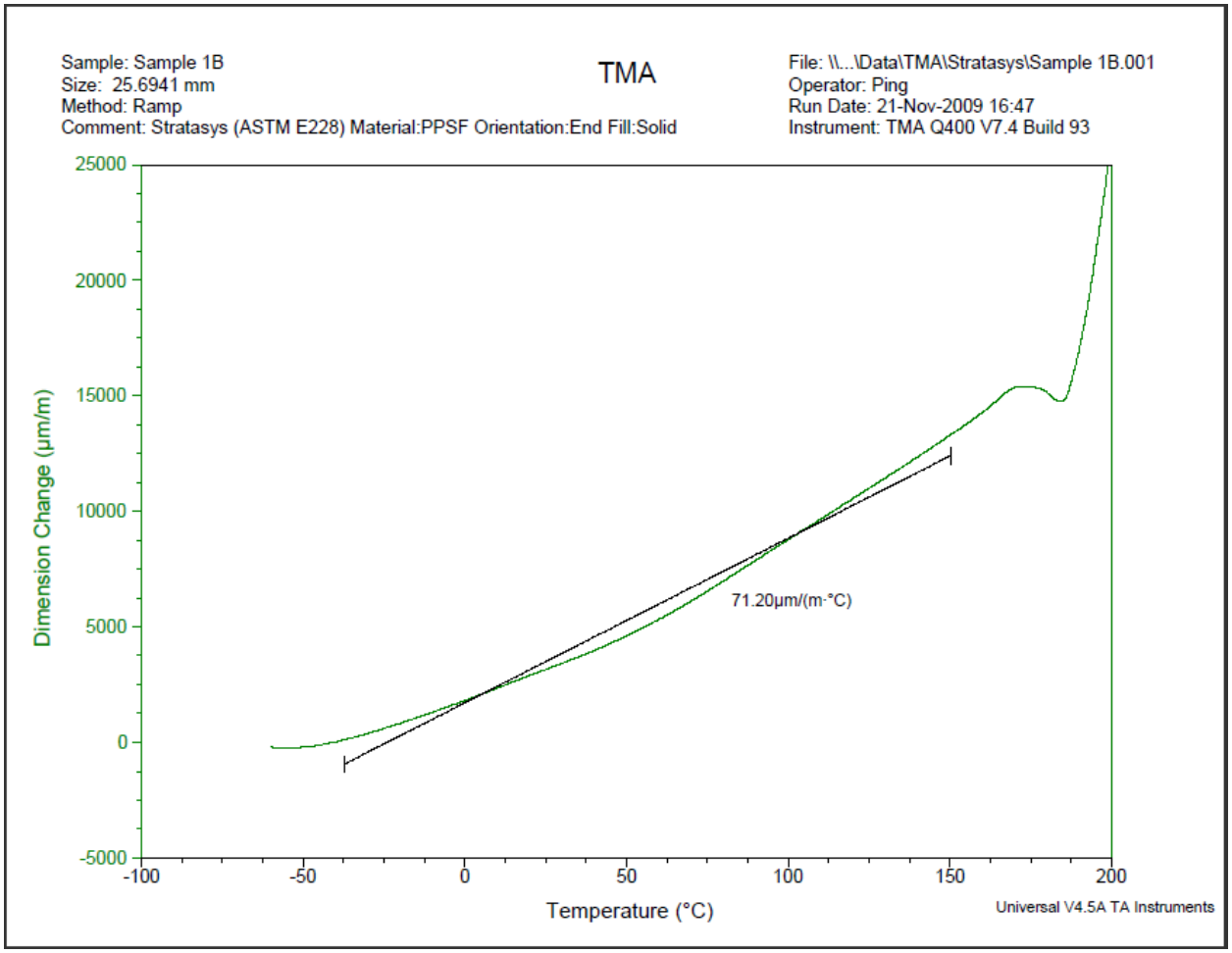
APPENDIX A – PHASE 1 DETAIL DATA



CTE TEST REPORT



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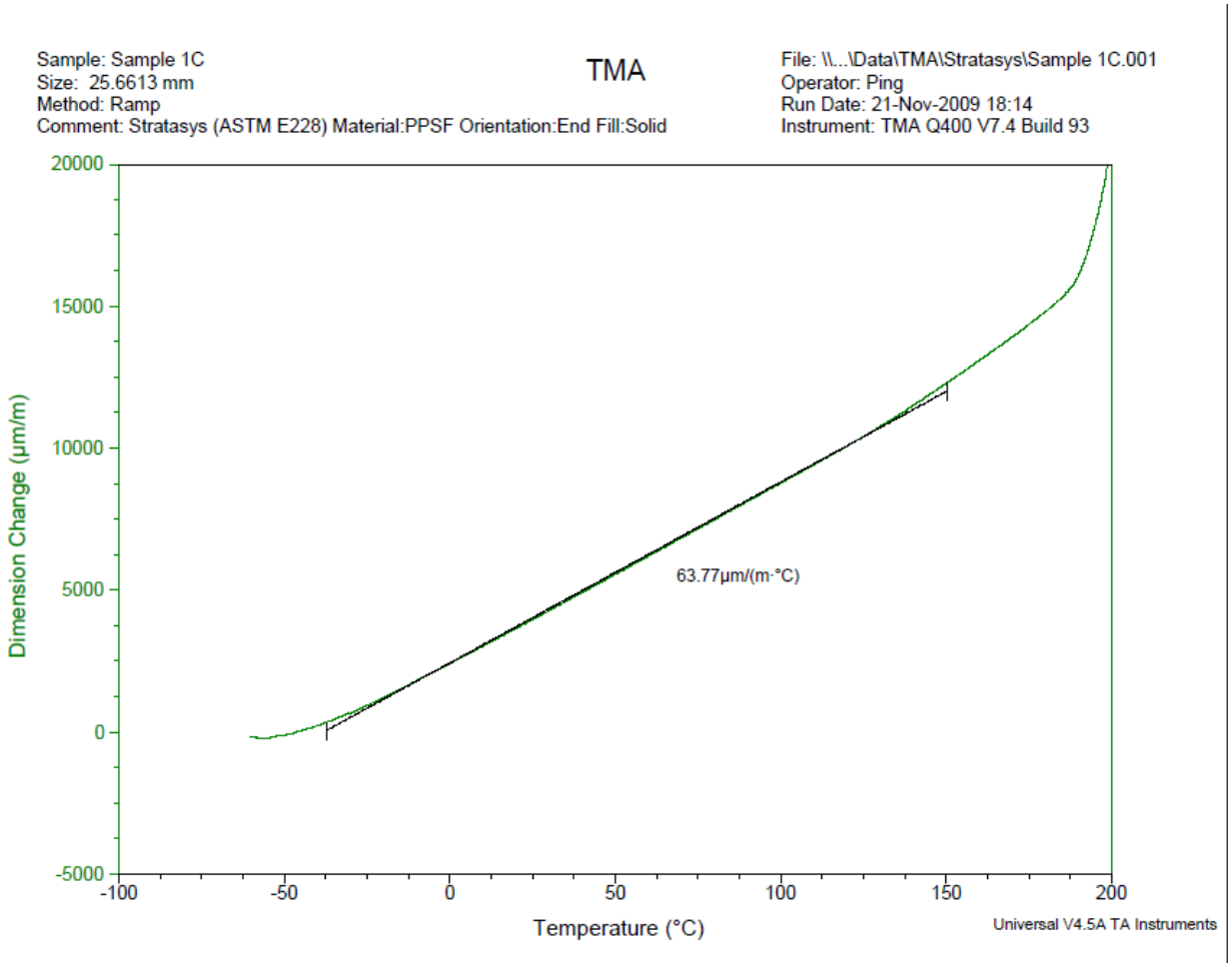

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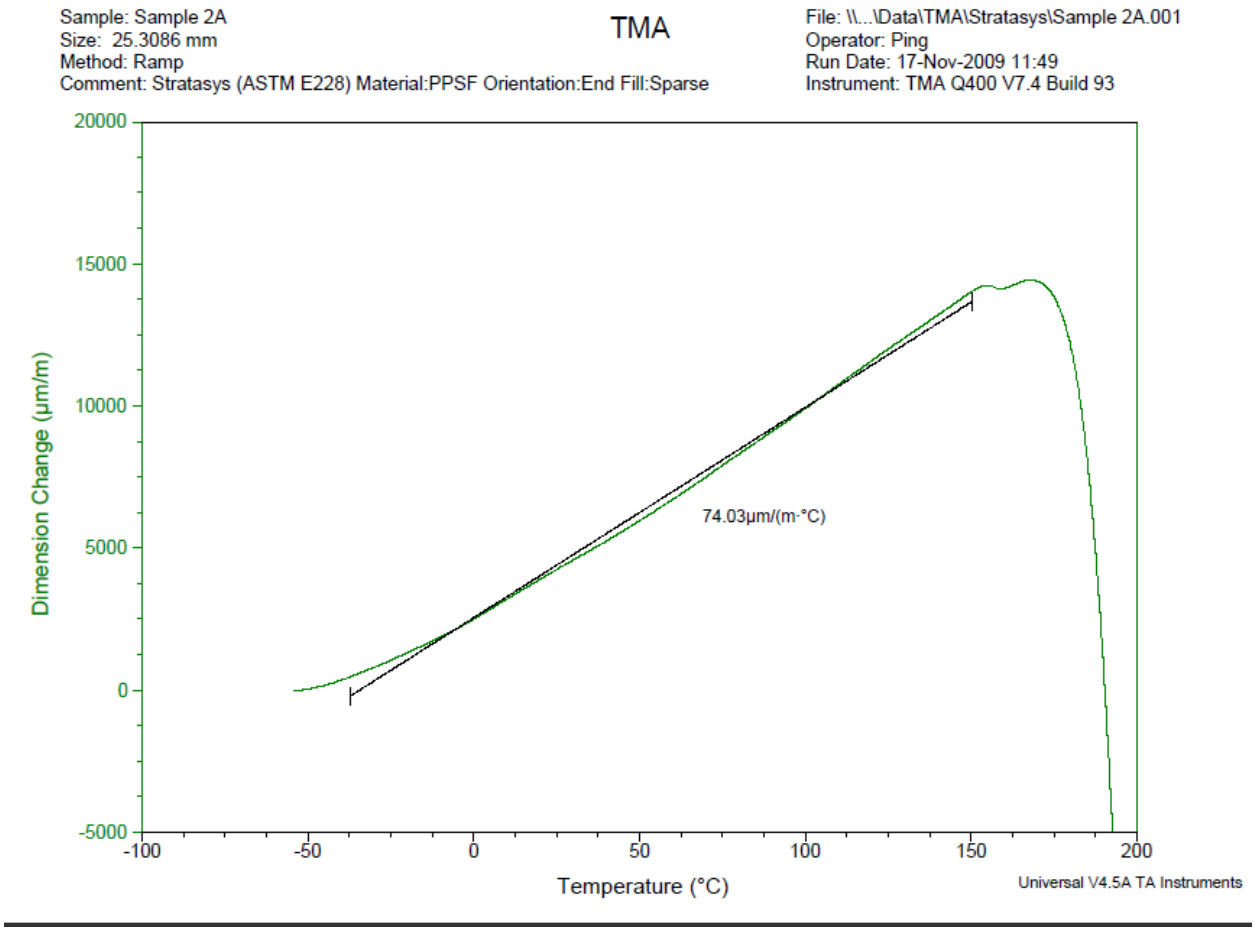

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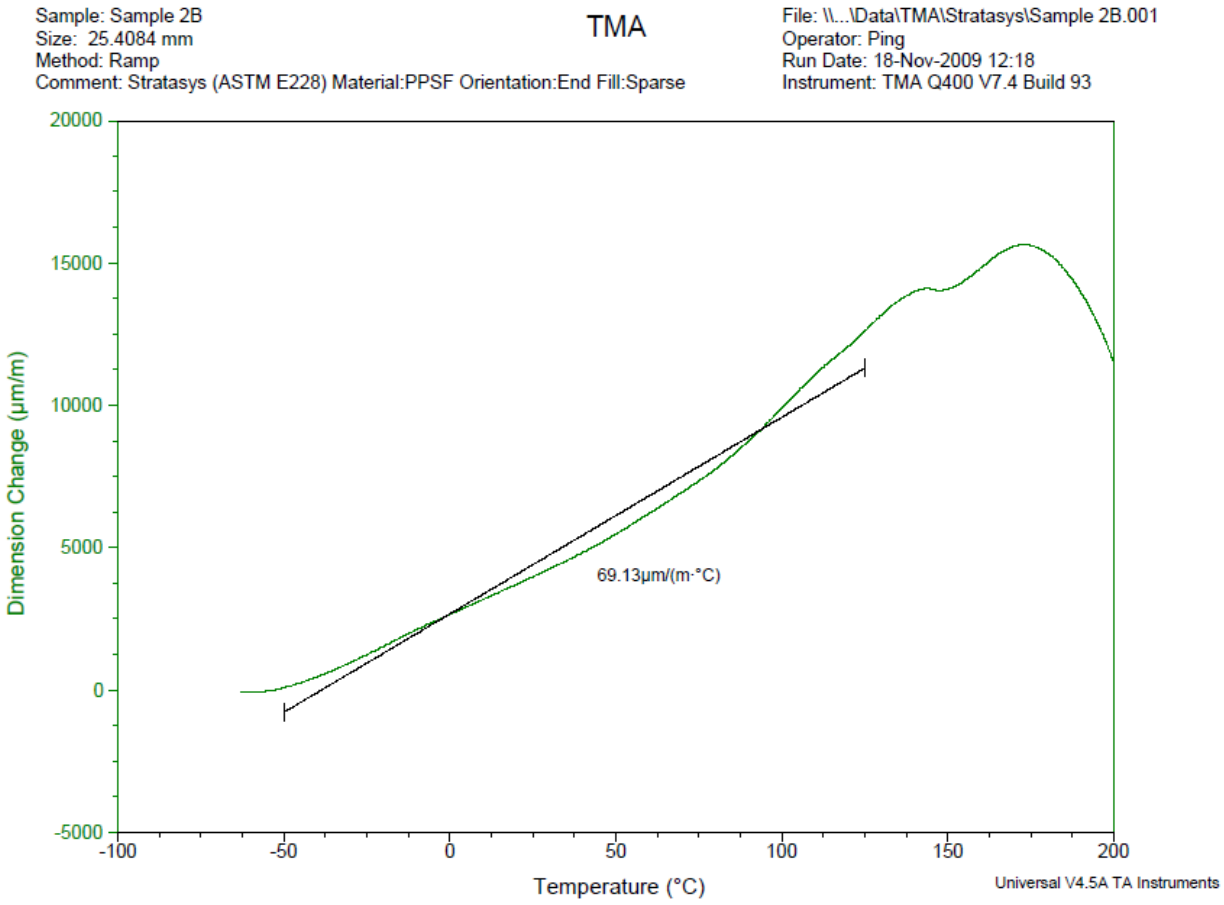

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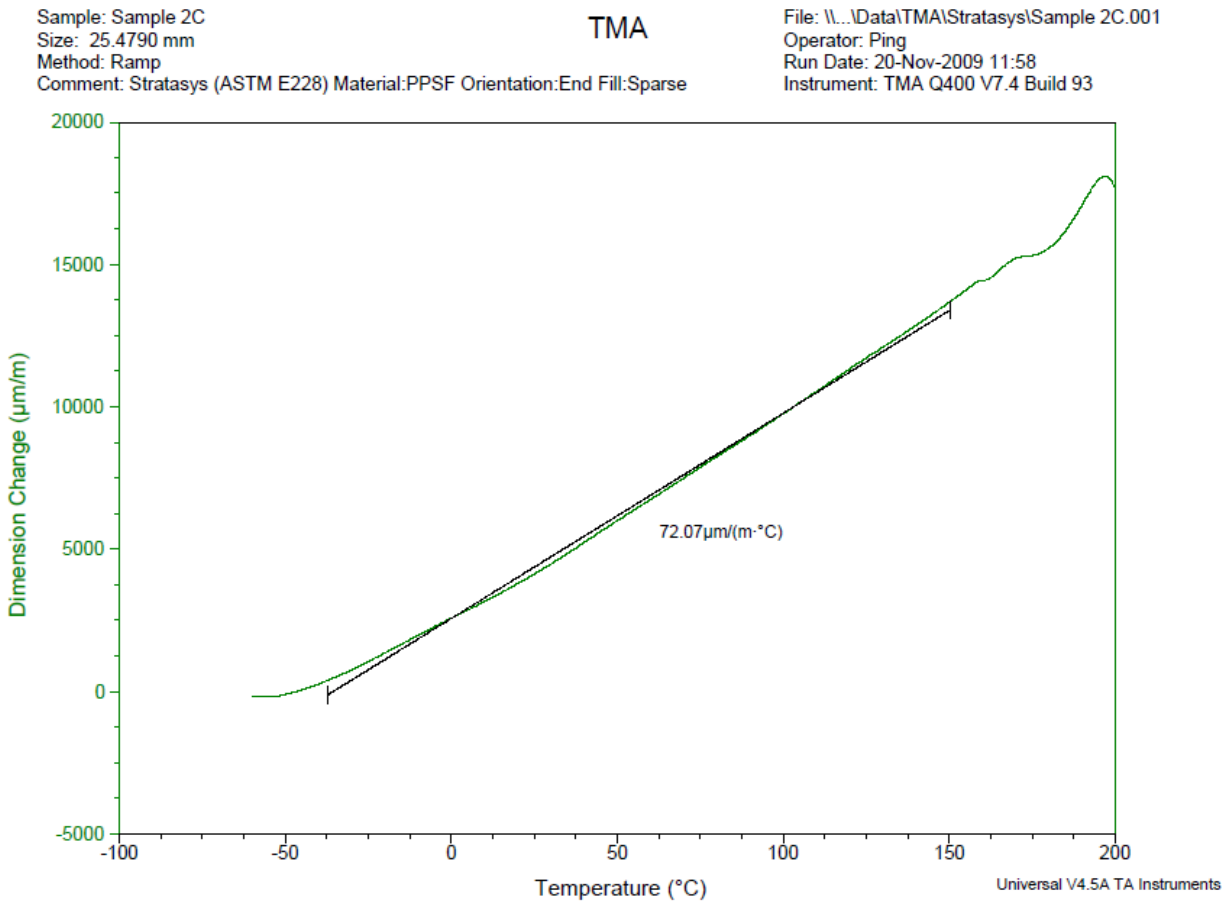

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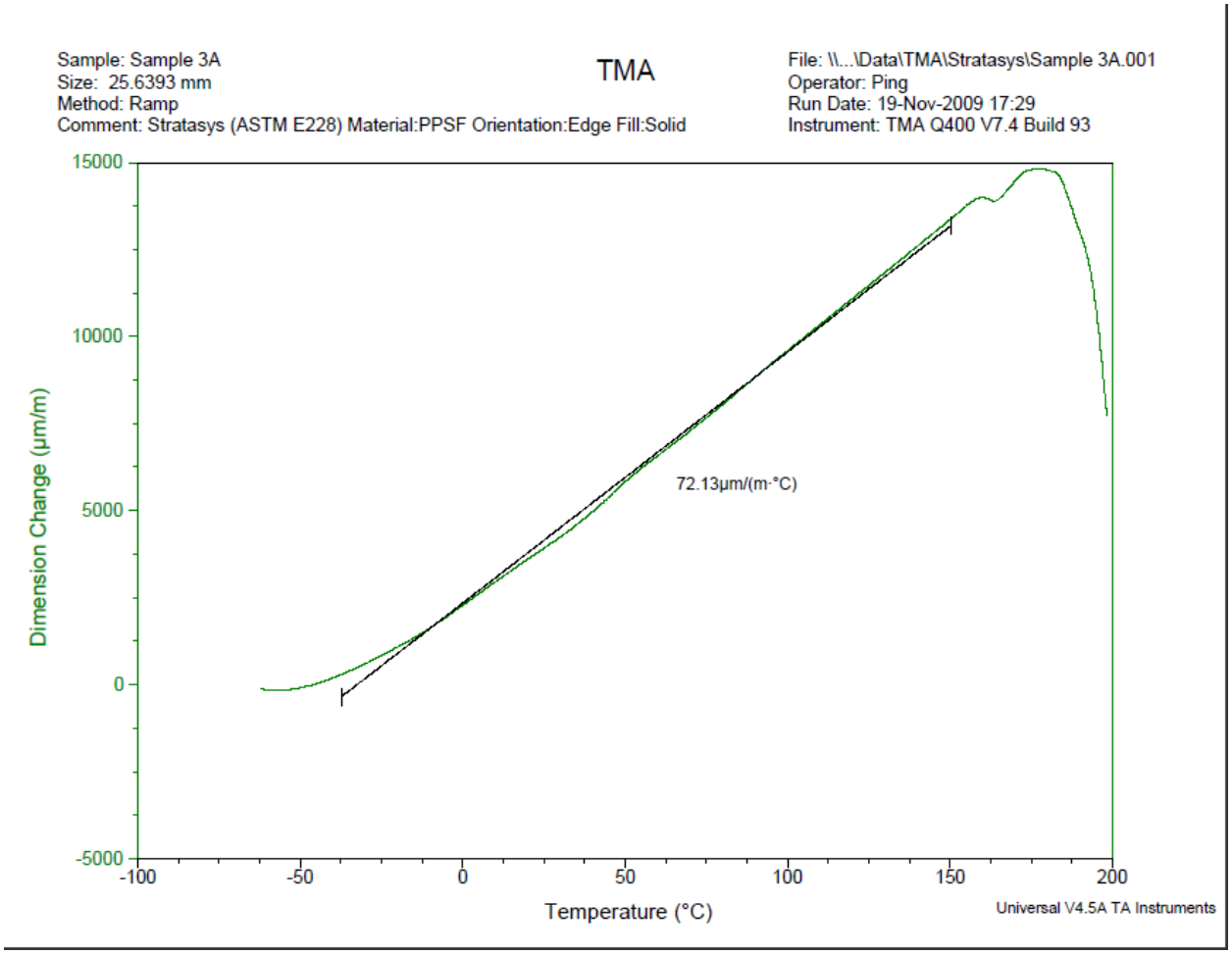

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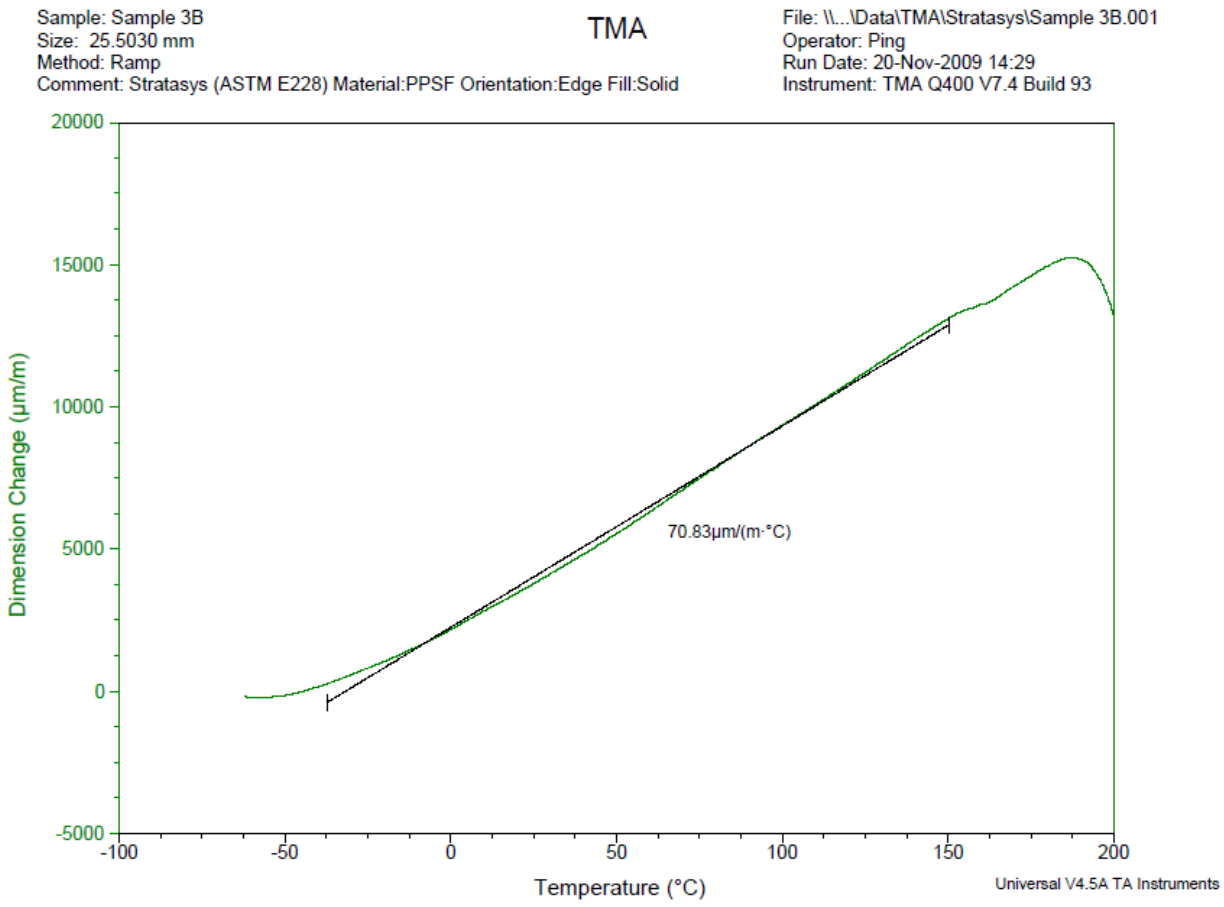

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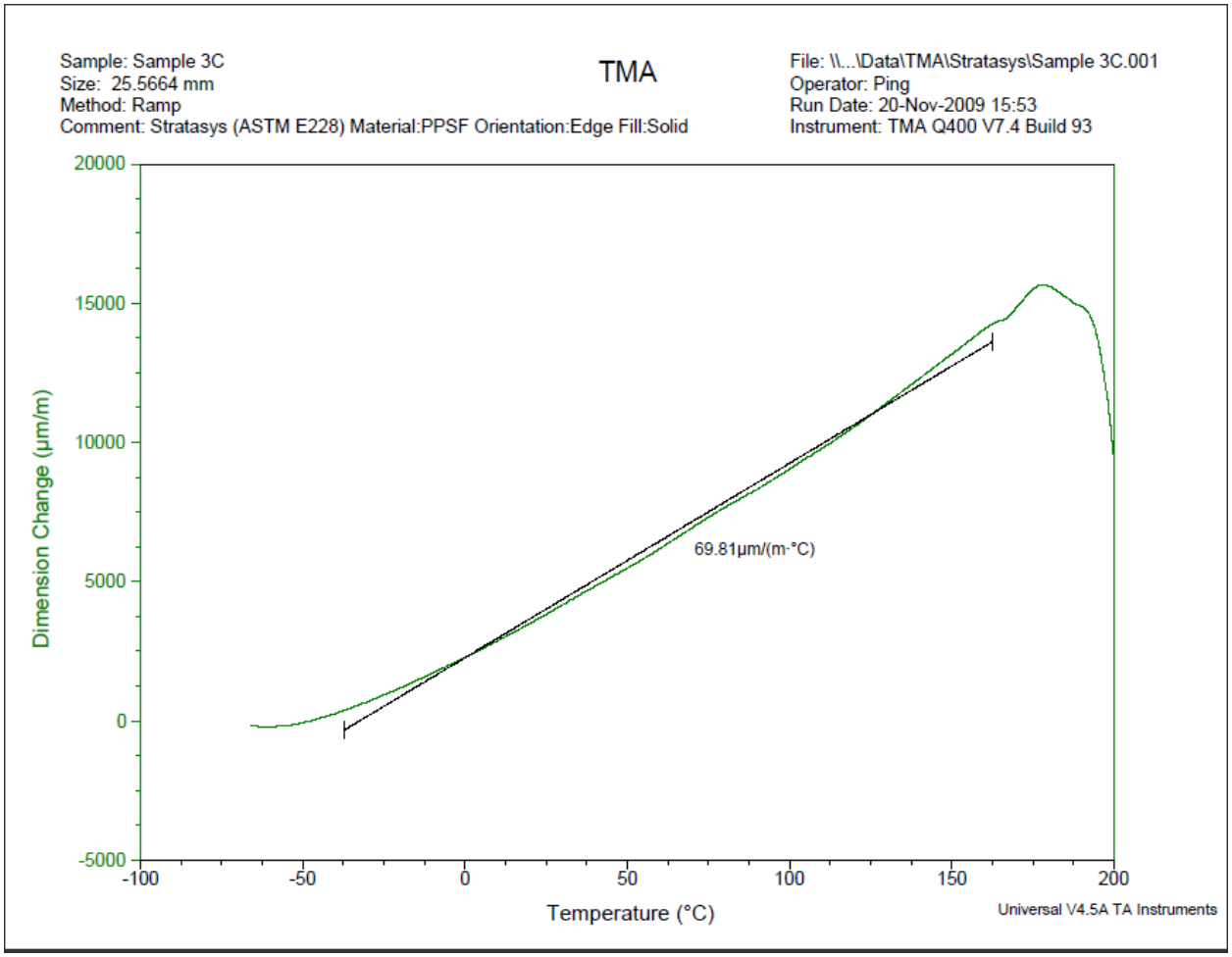

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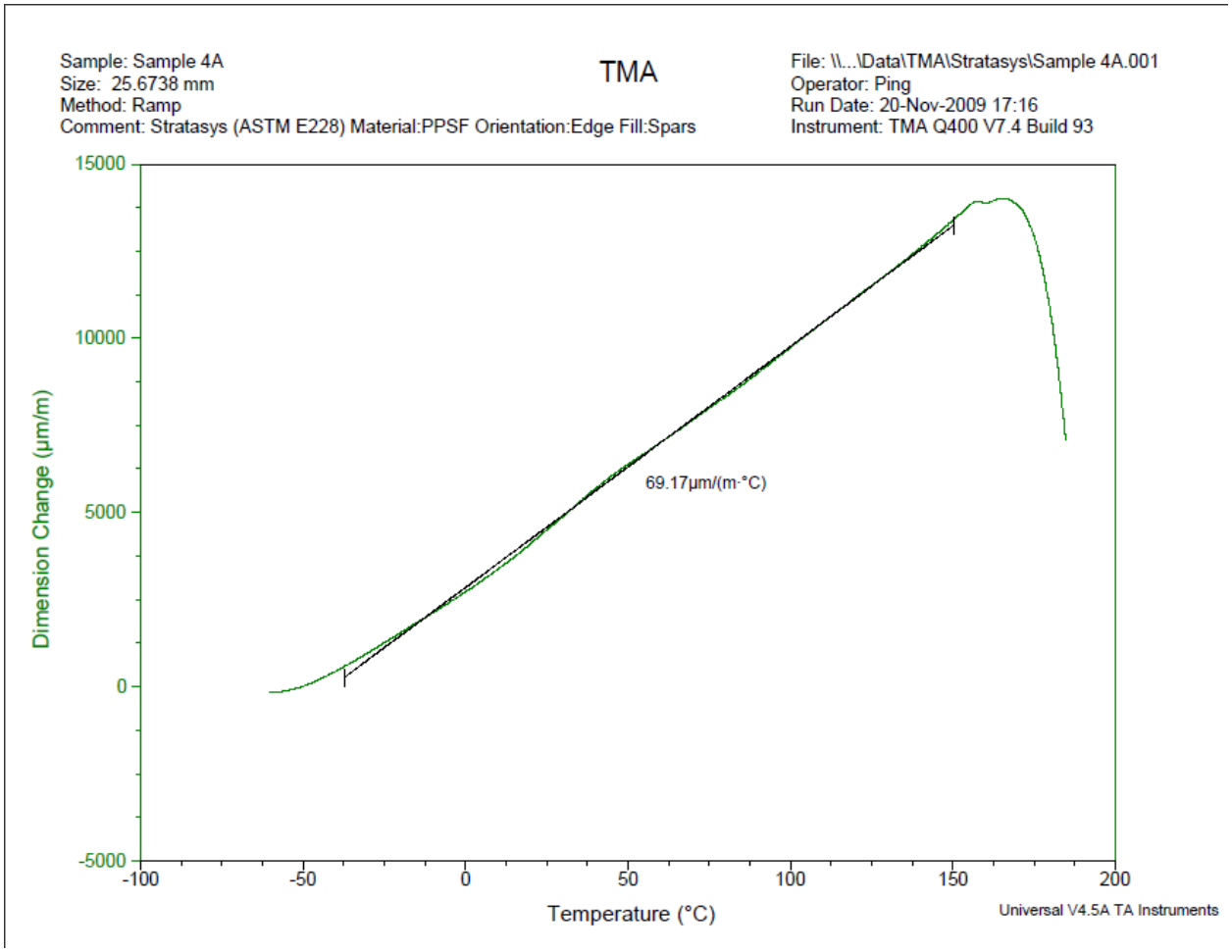

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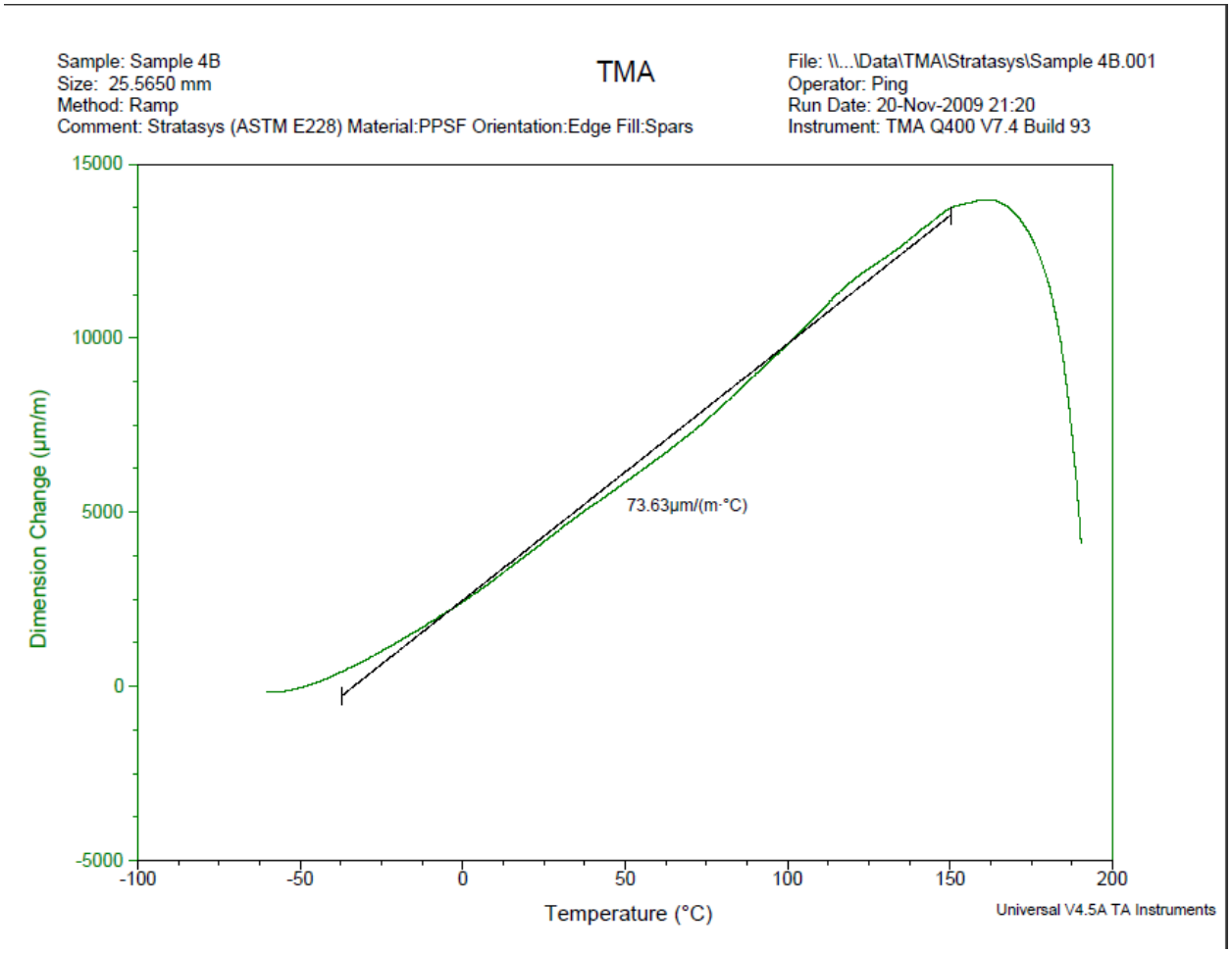

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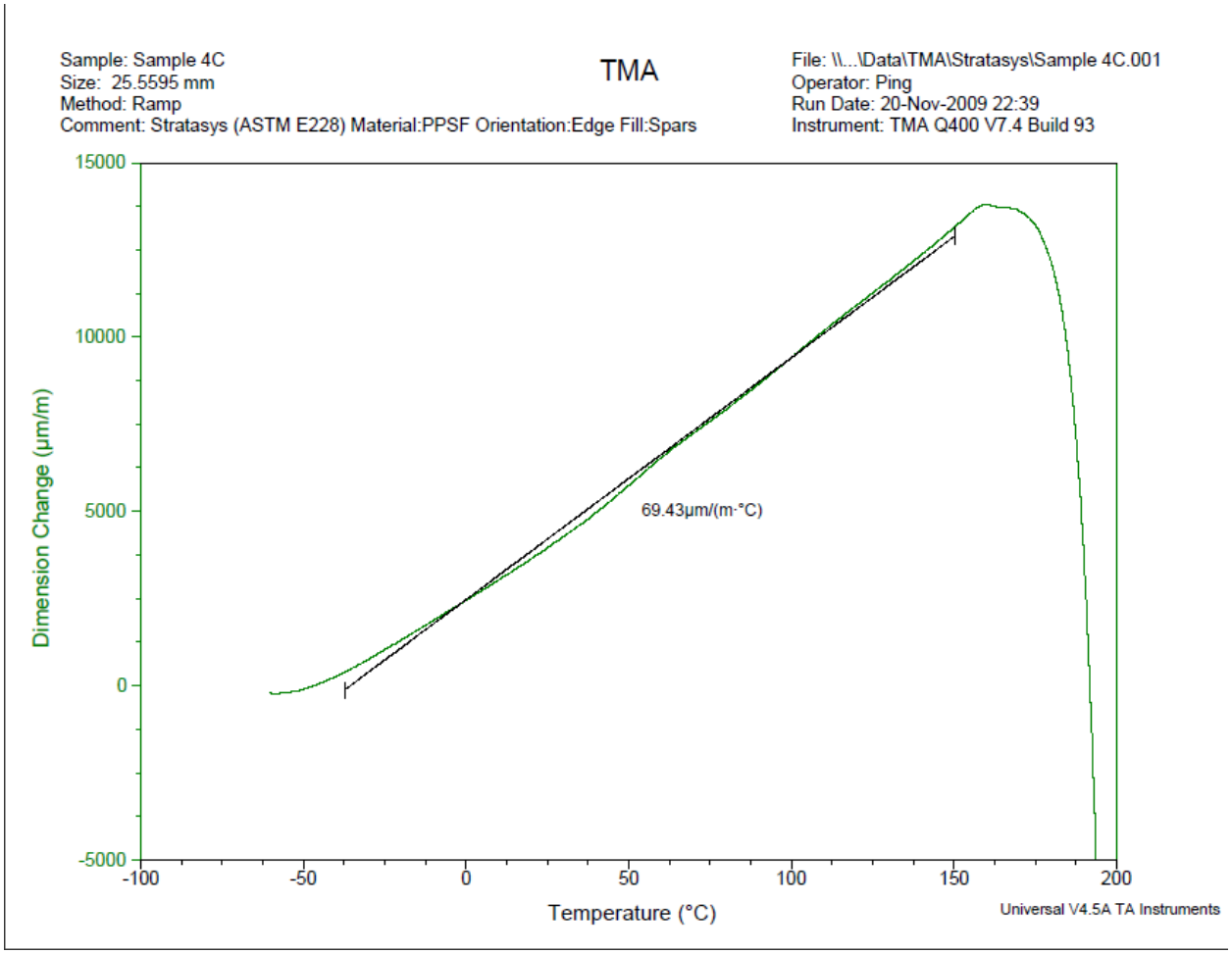

APPENDIX B – PHASE 2 DETAIL DATA

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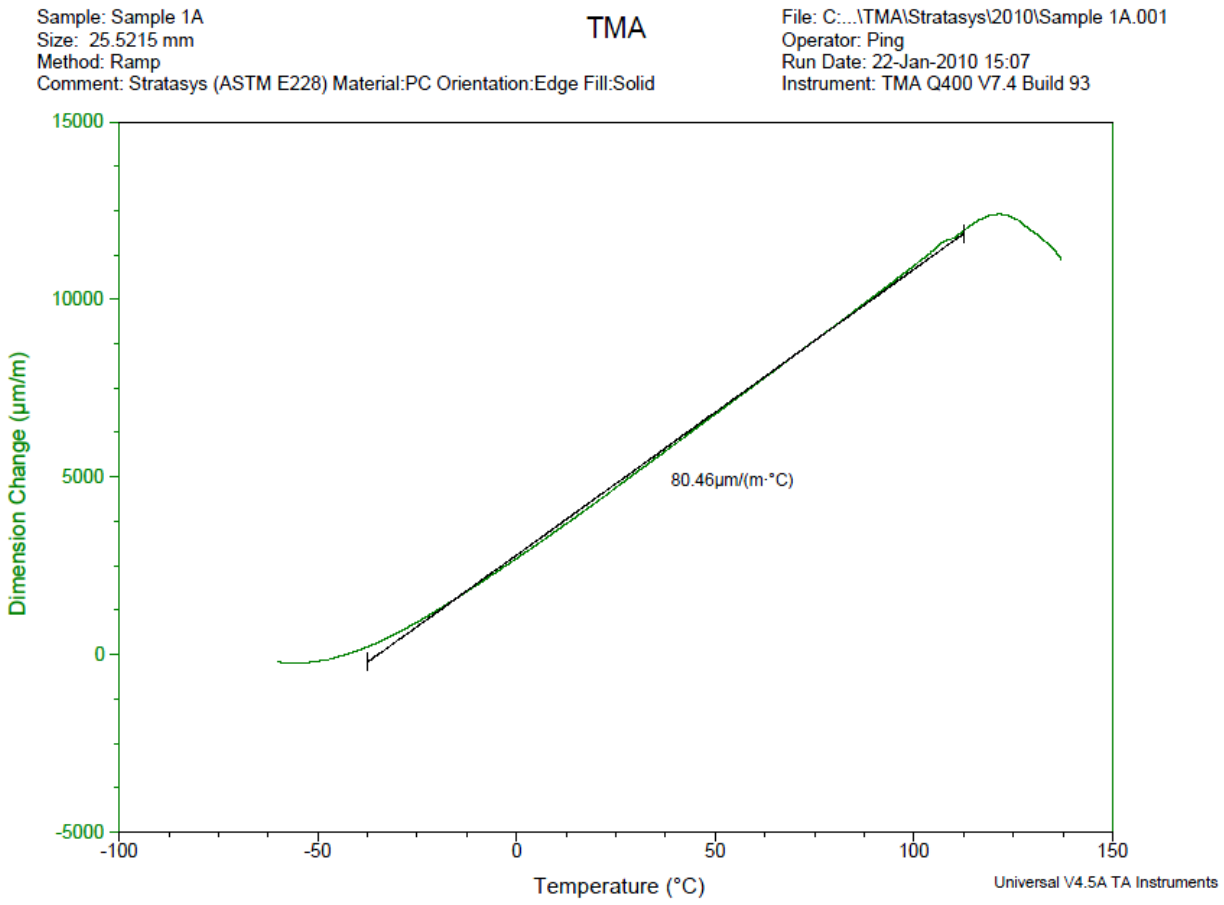

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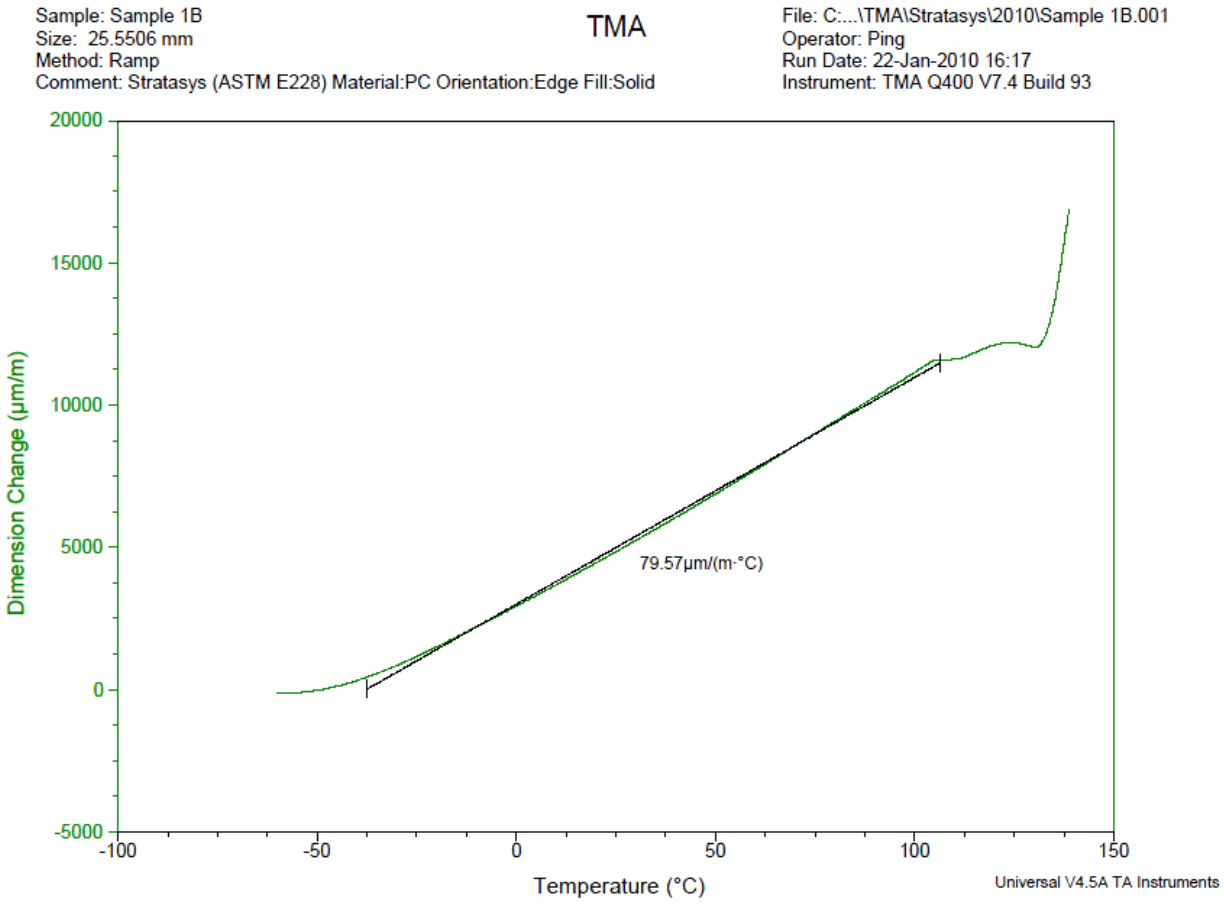

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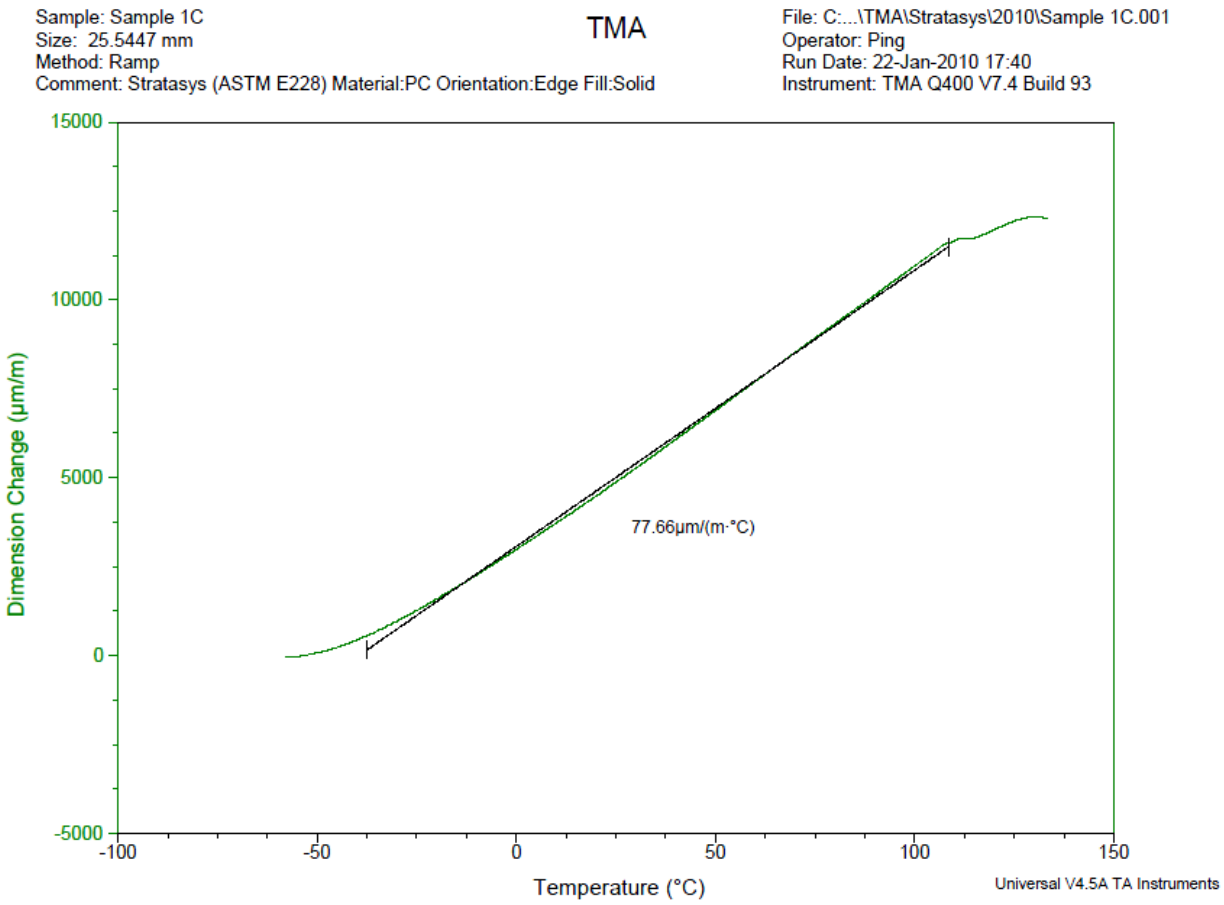

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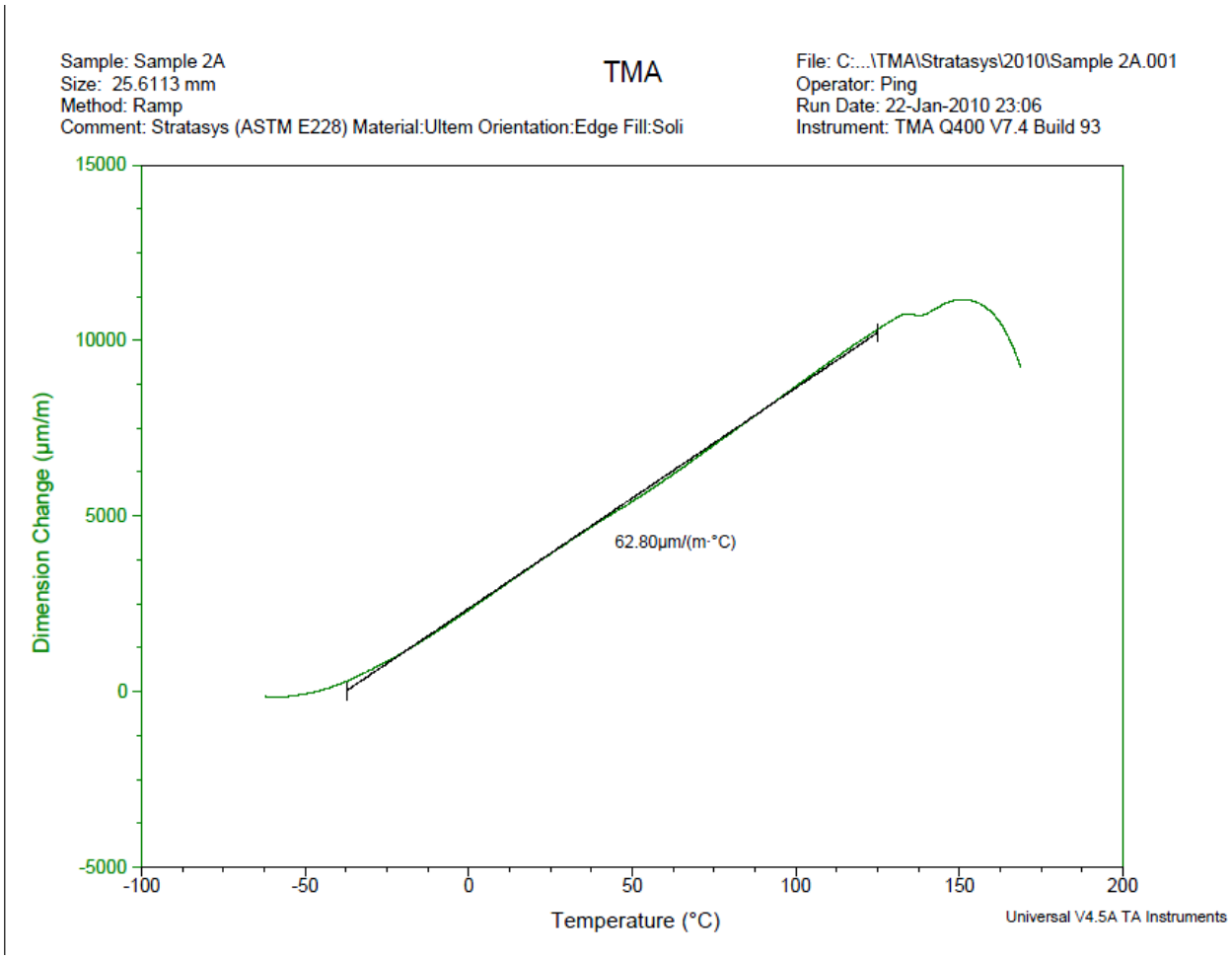
ULTEM



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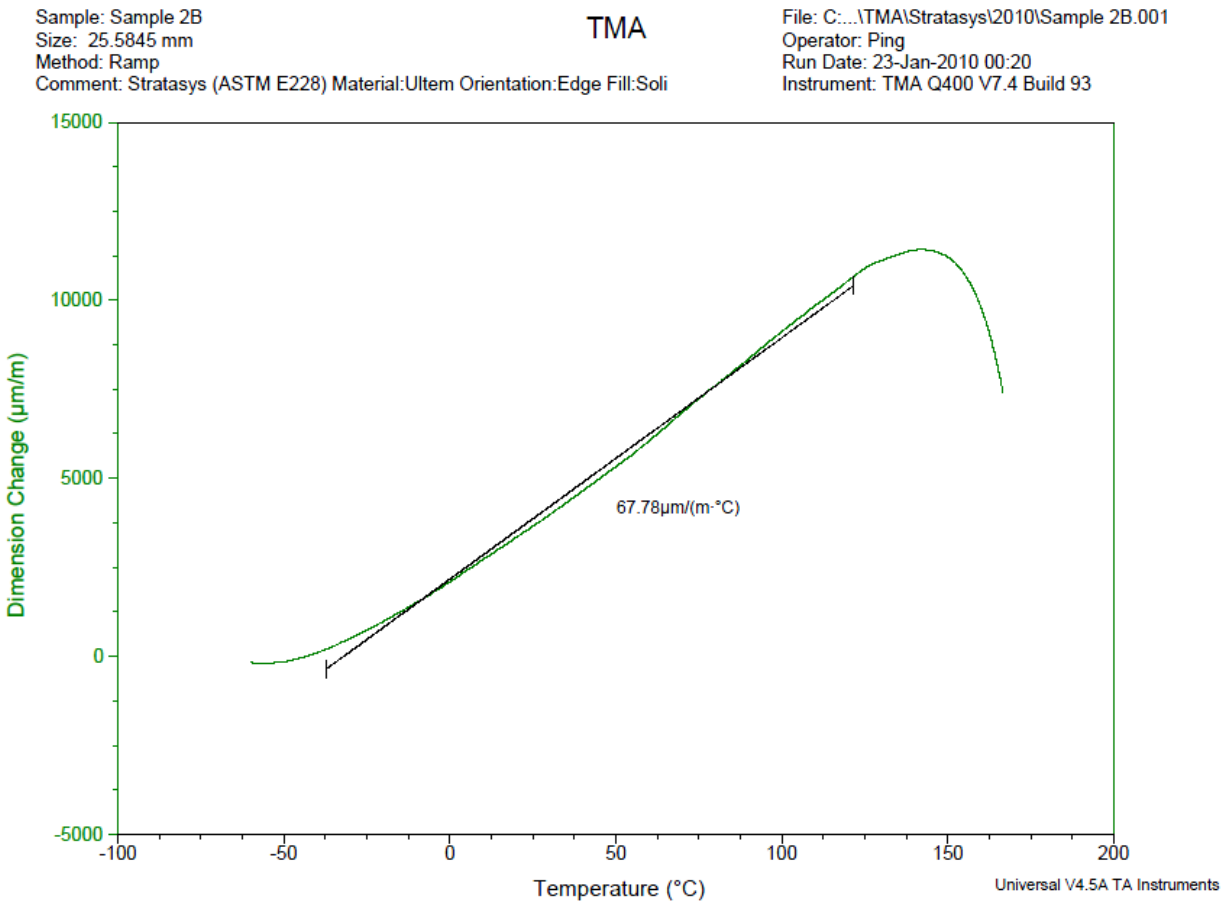

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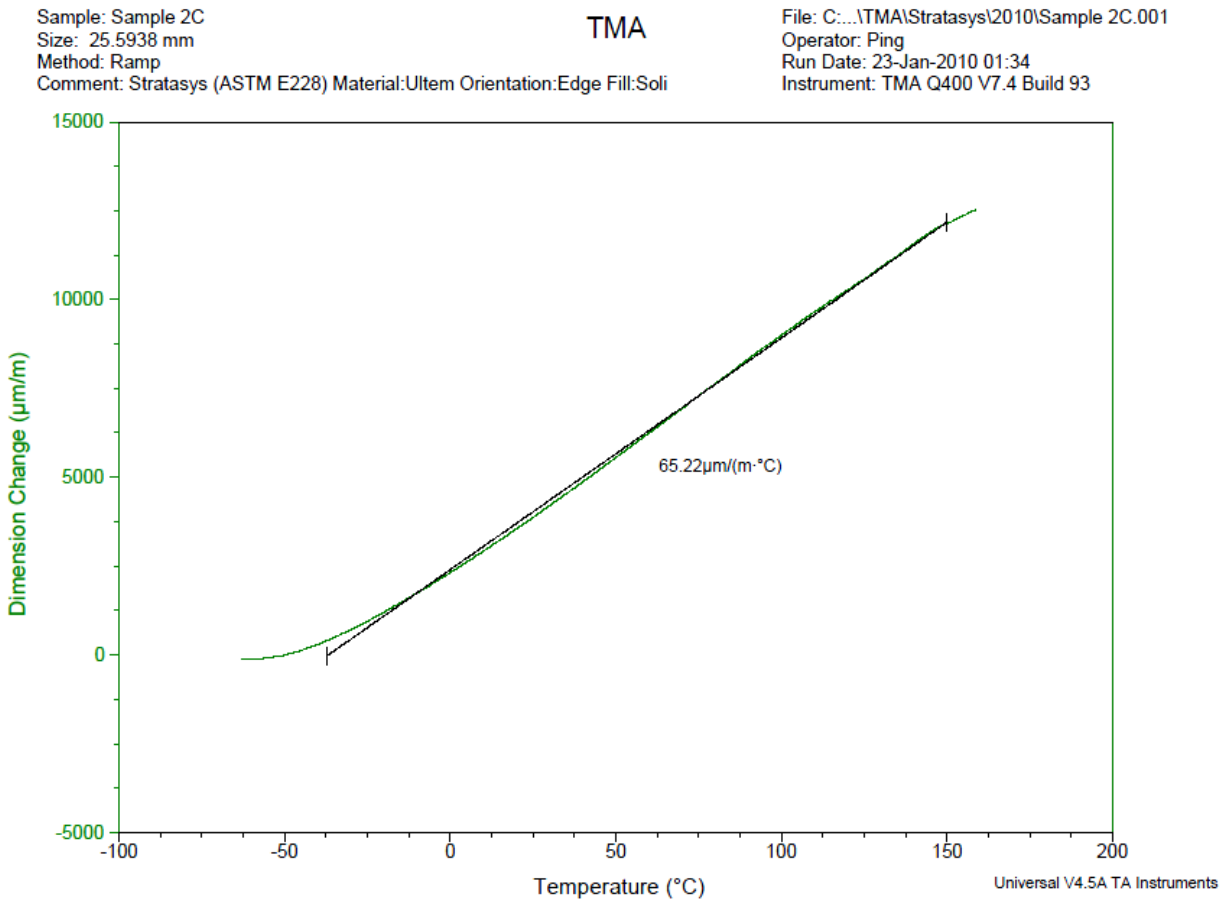

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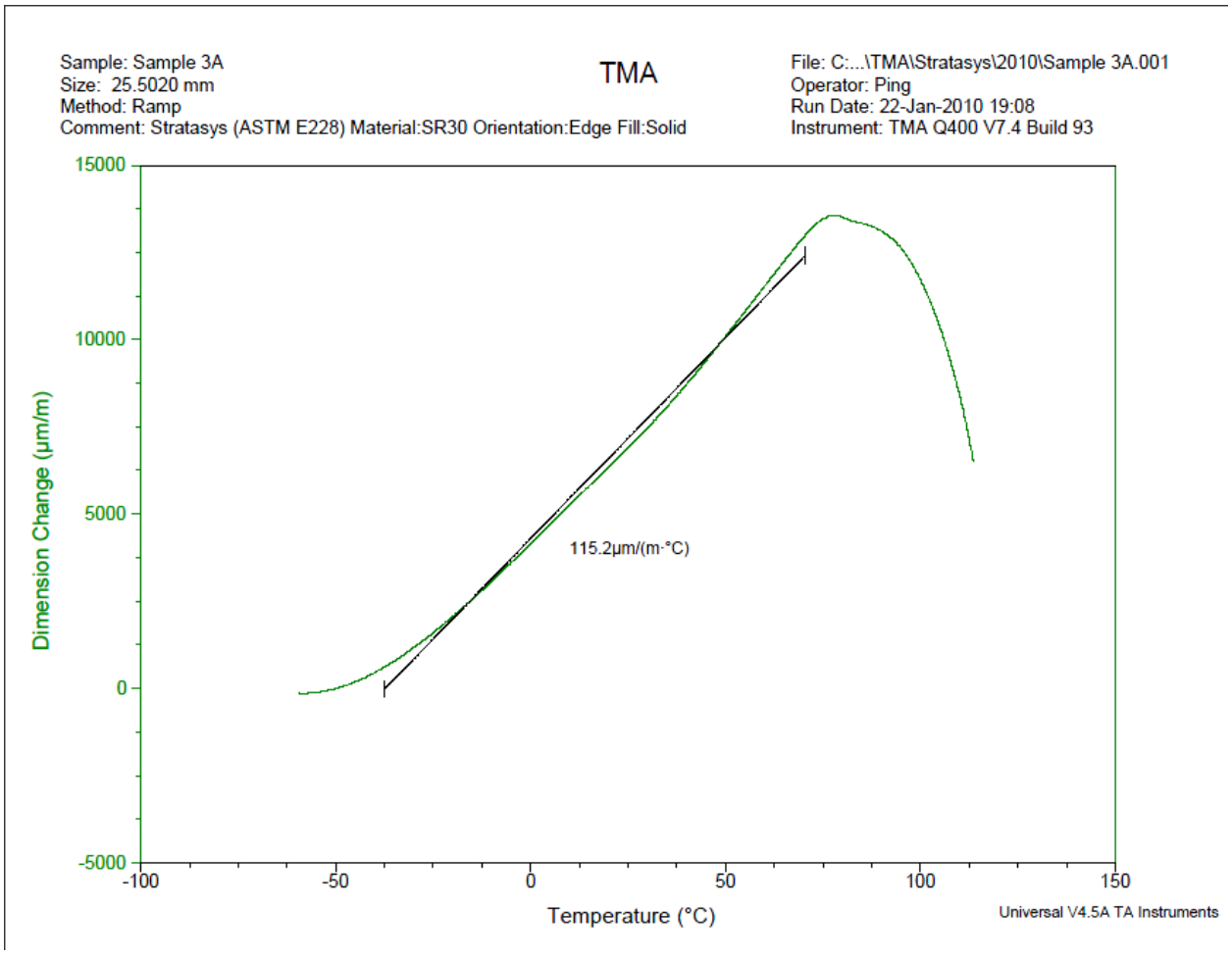
SR30



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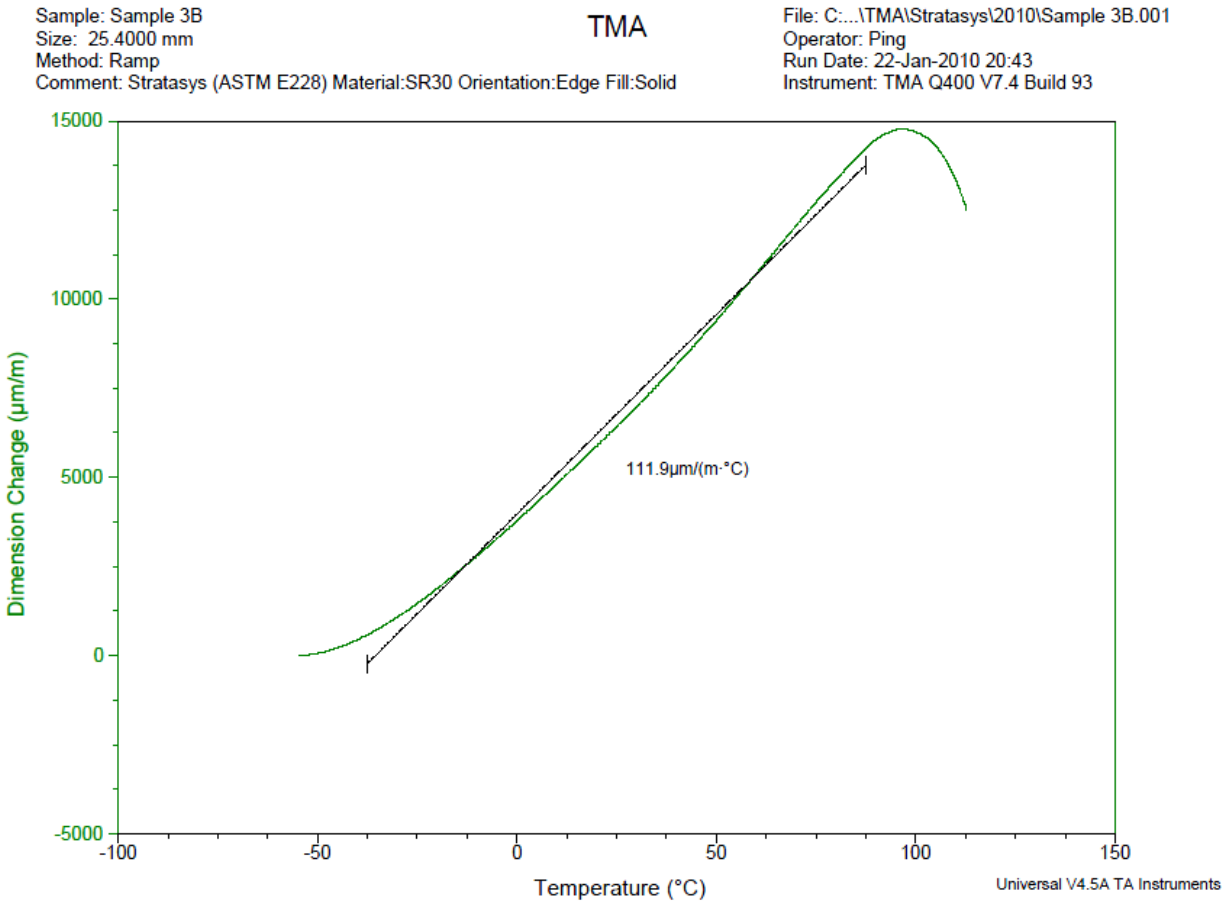

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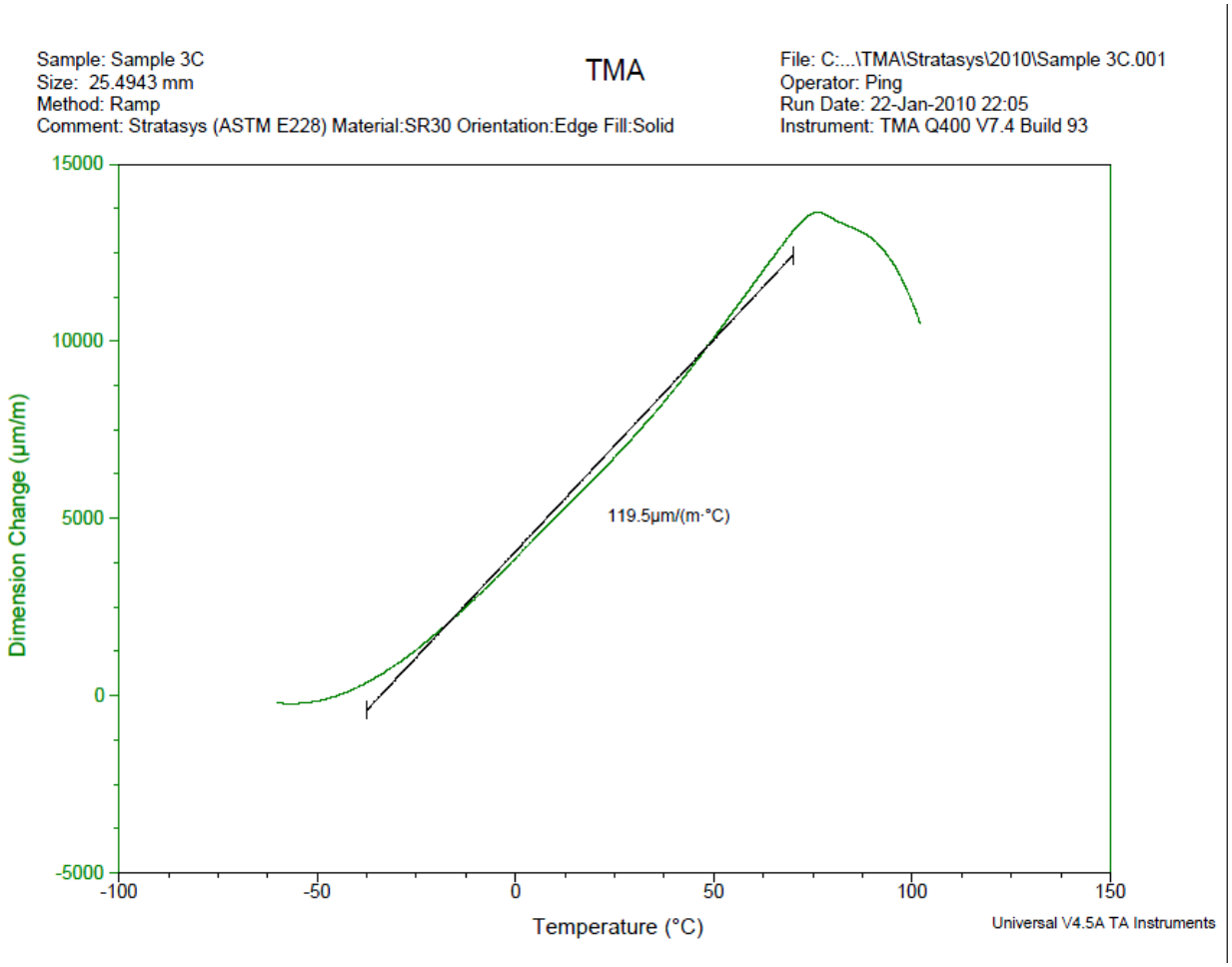
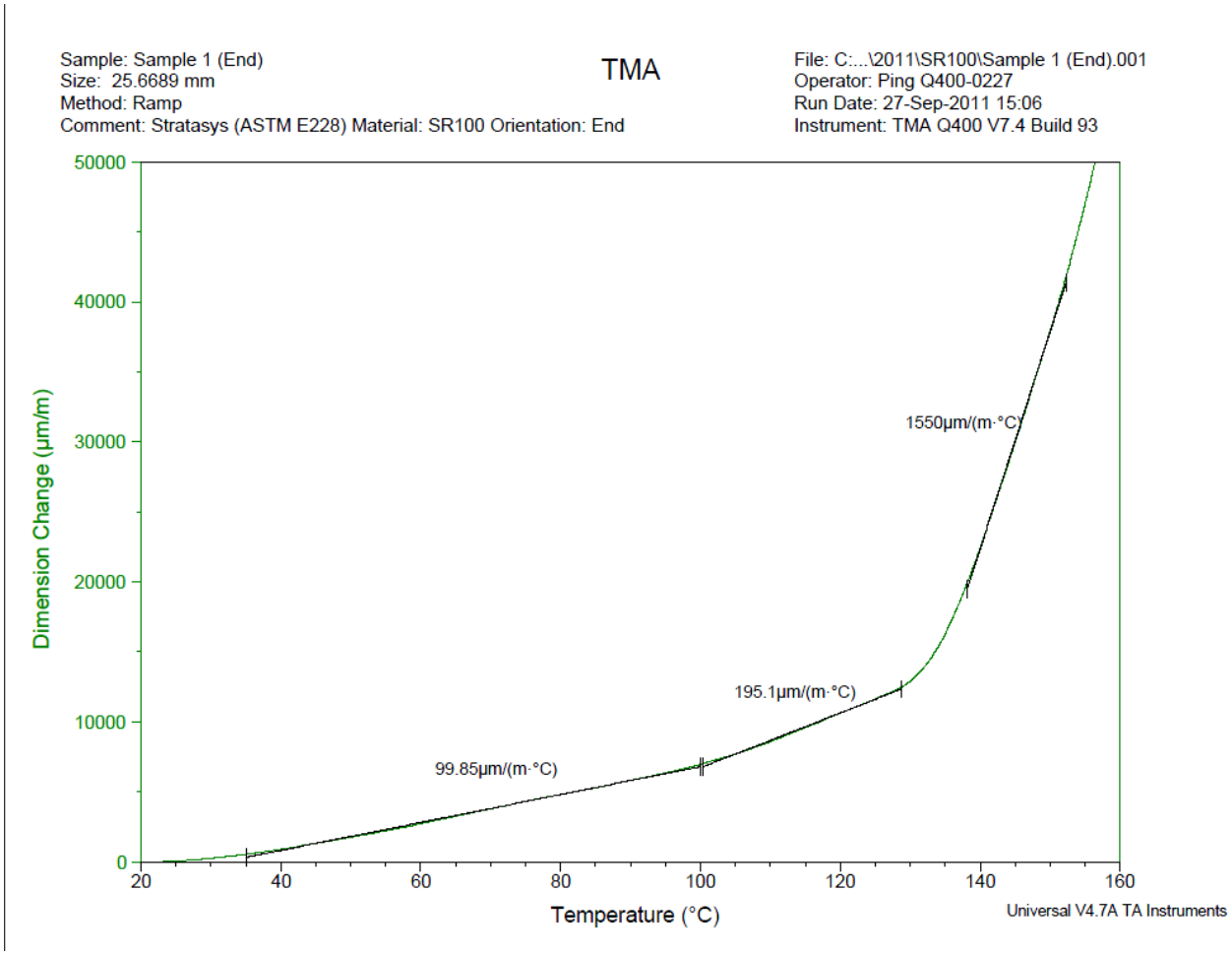


APPENDIX C - PHASE 3

SR100



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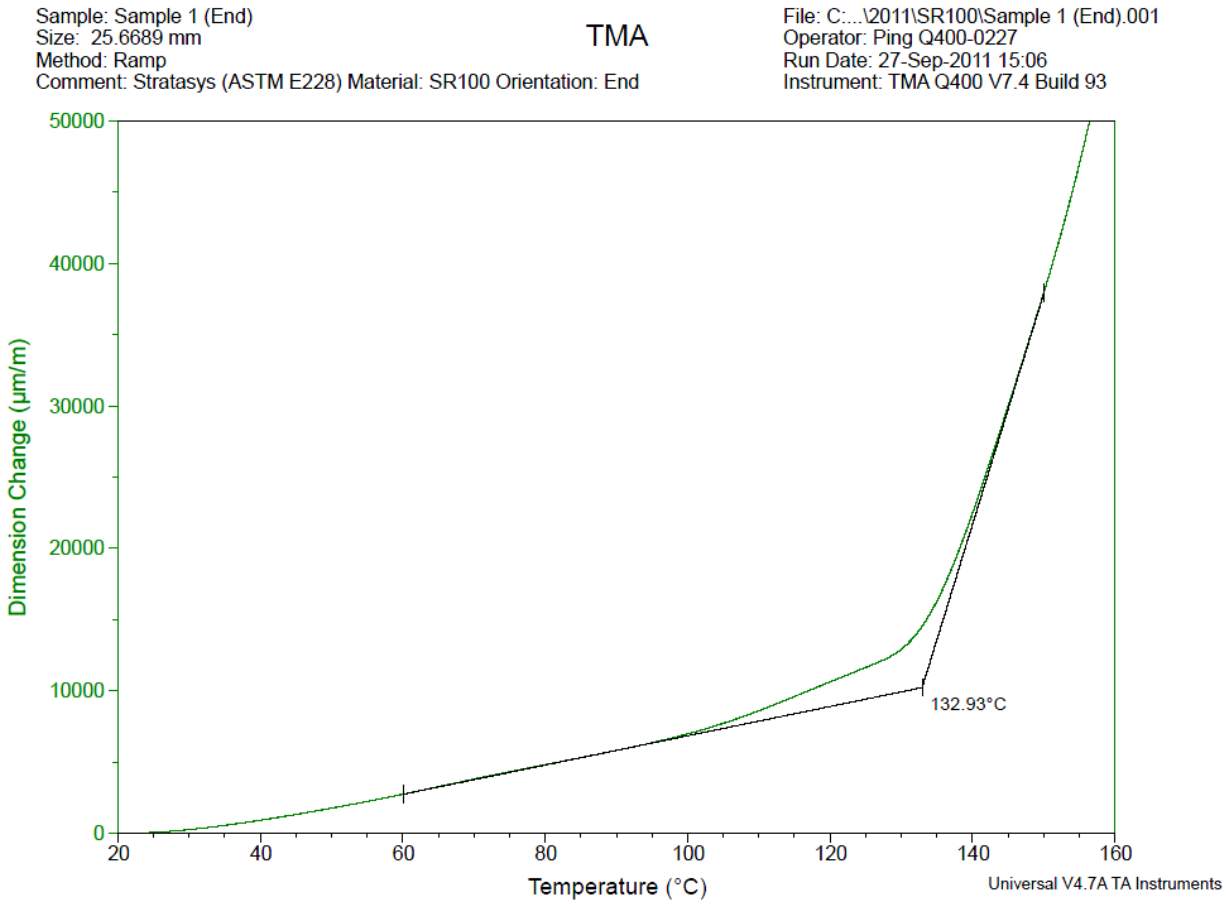

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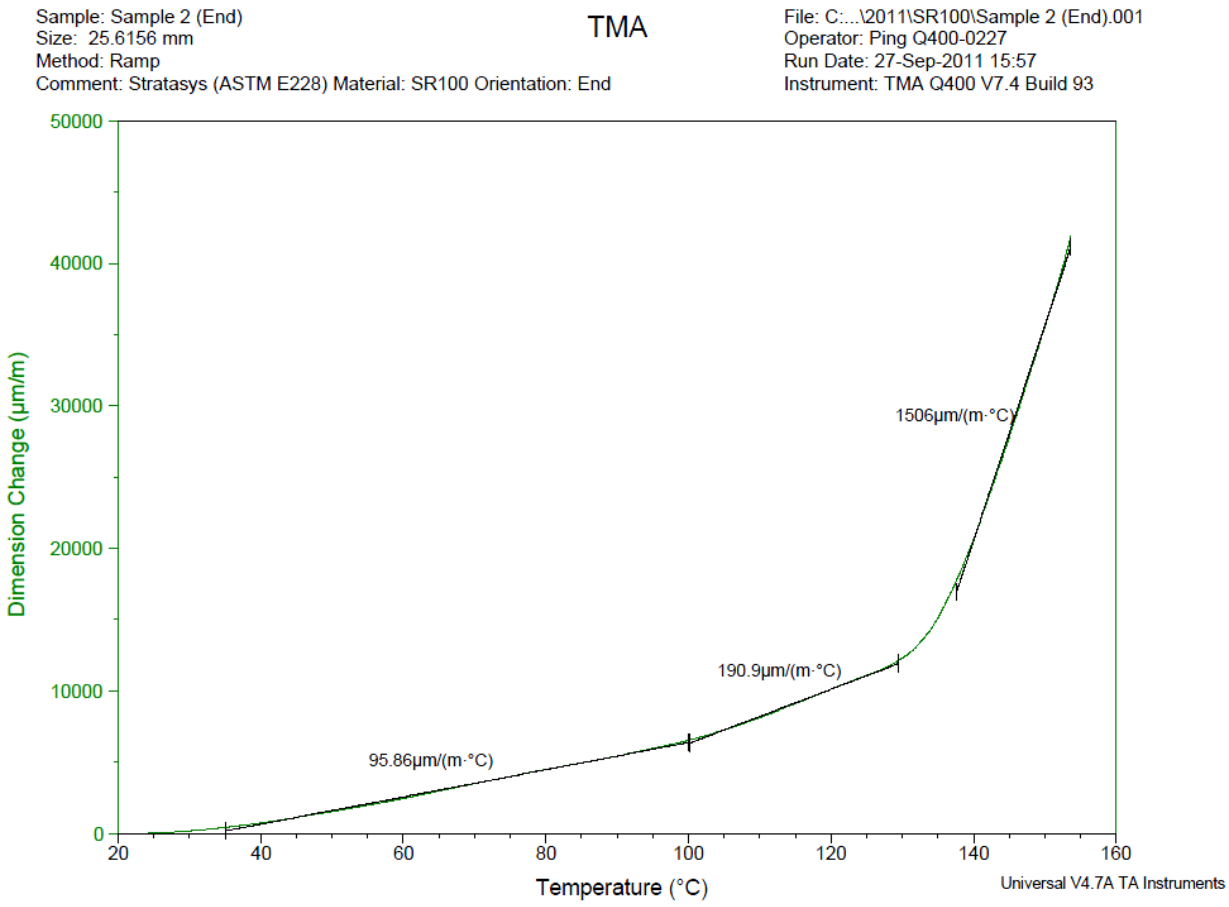

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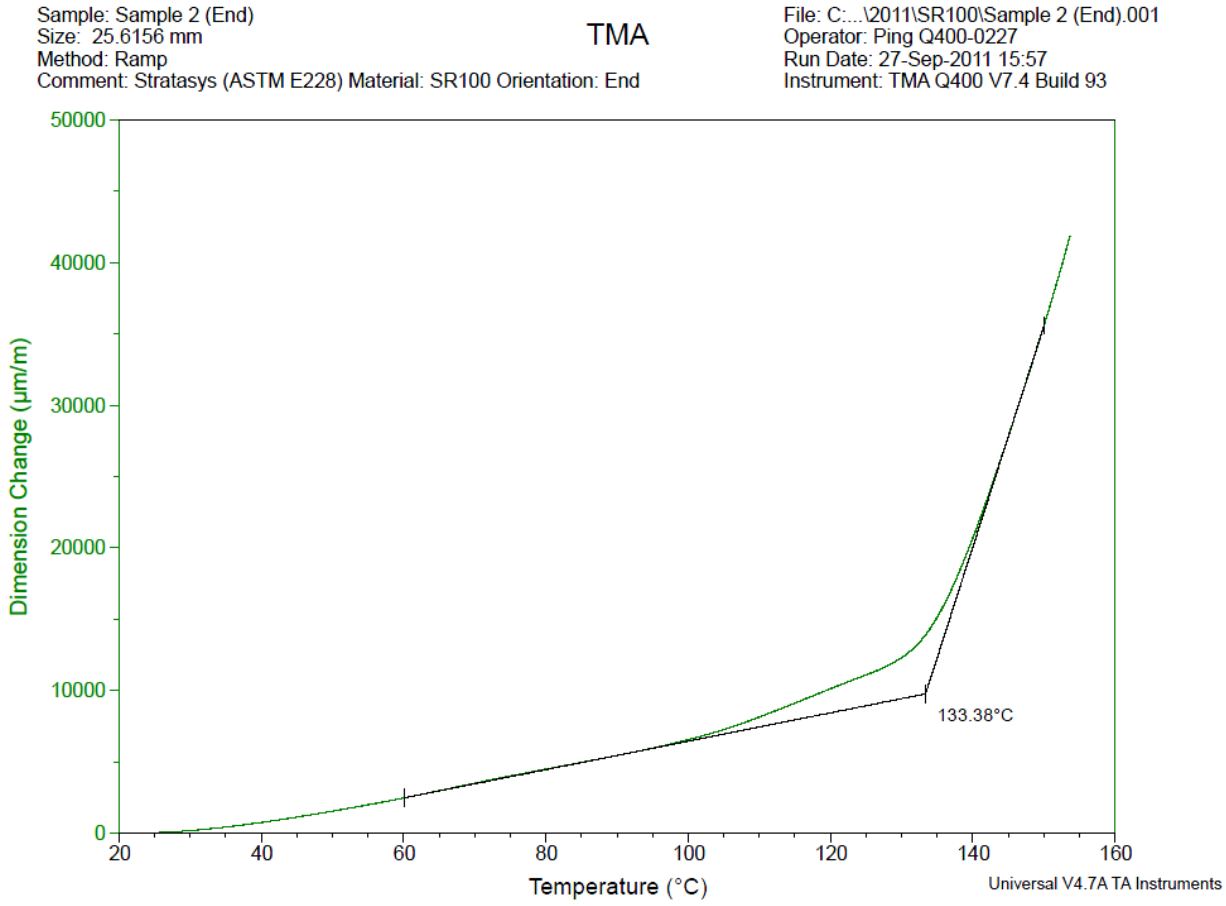

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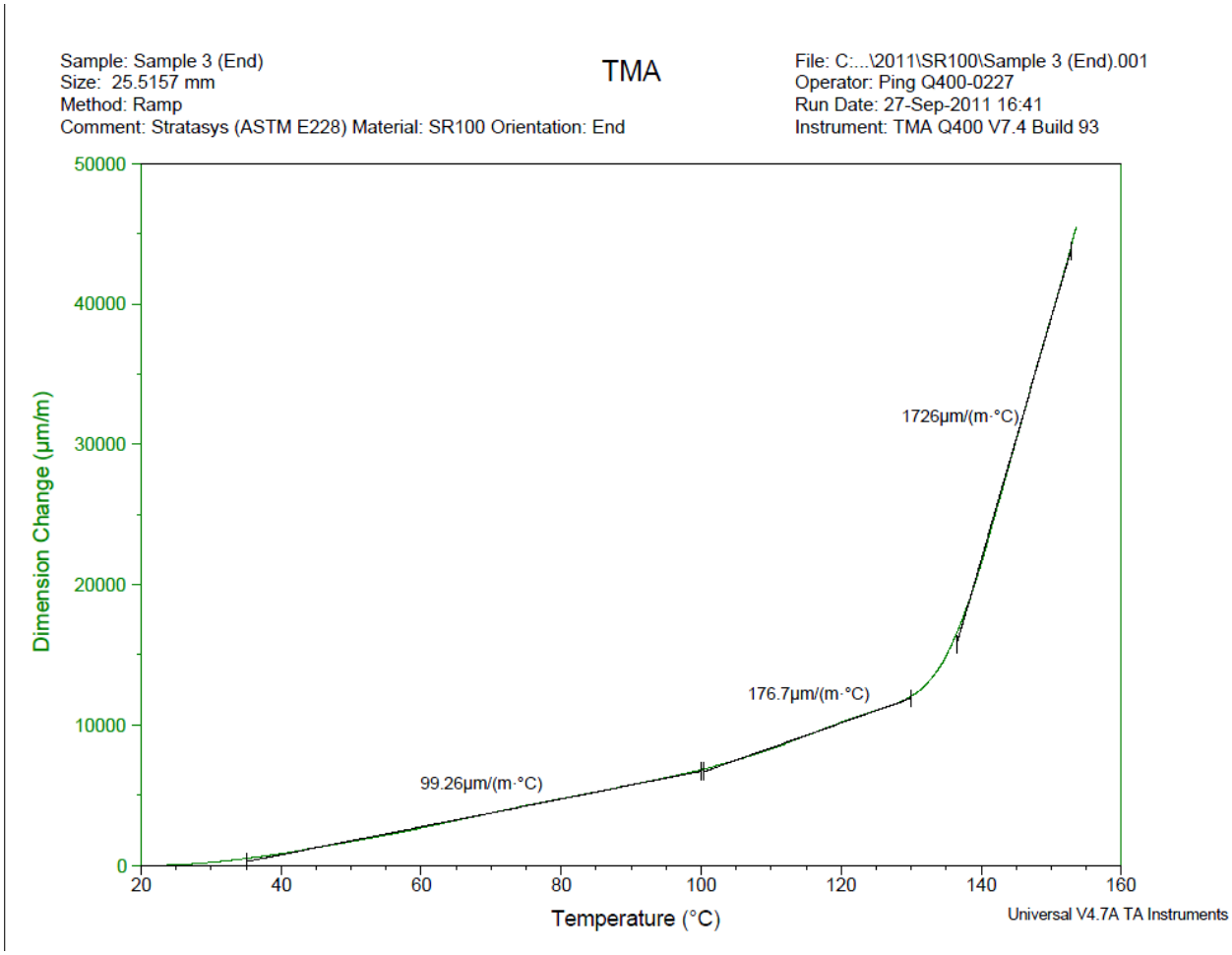

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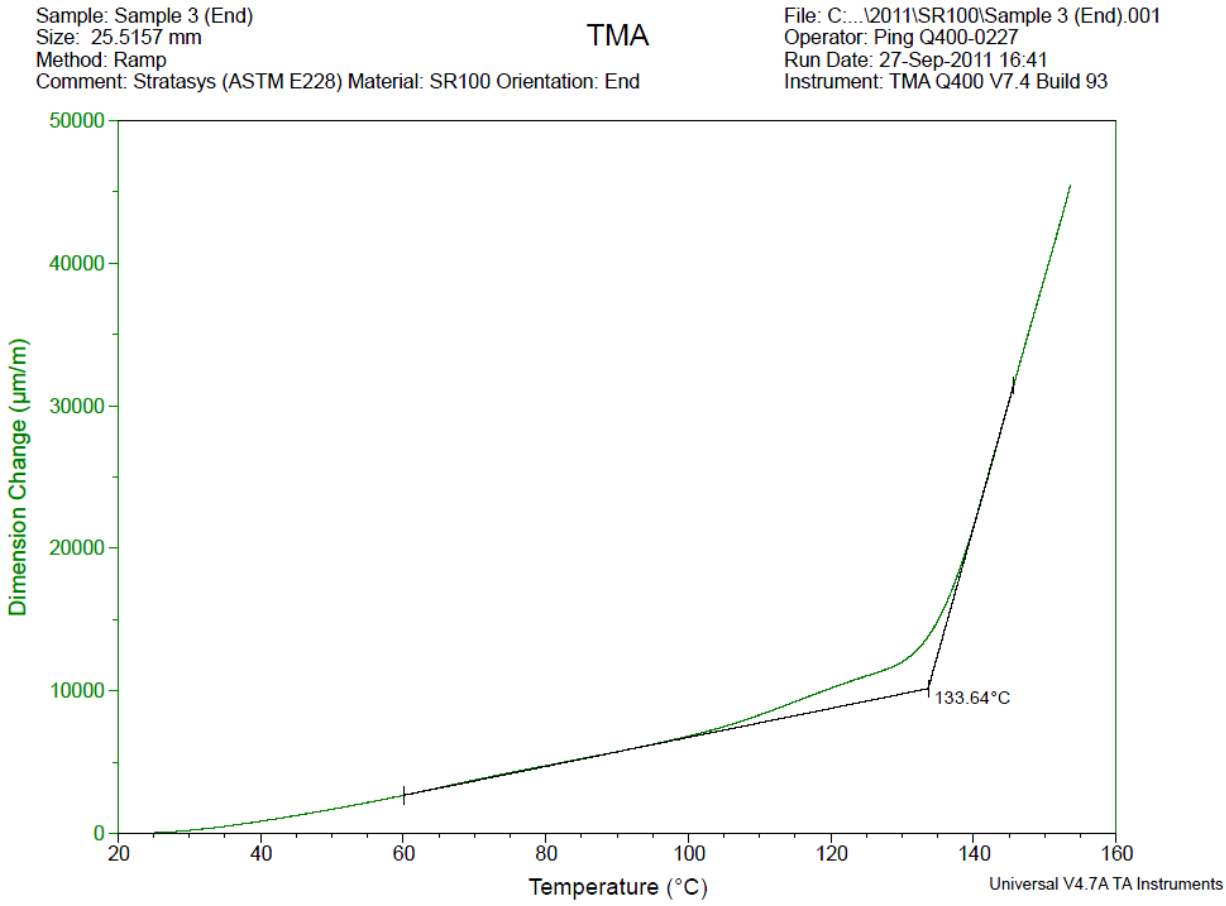

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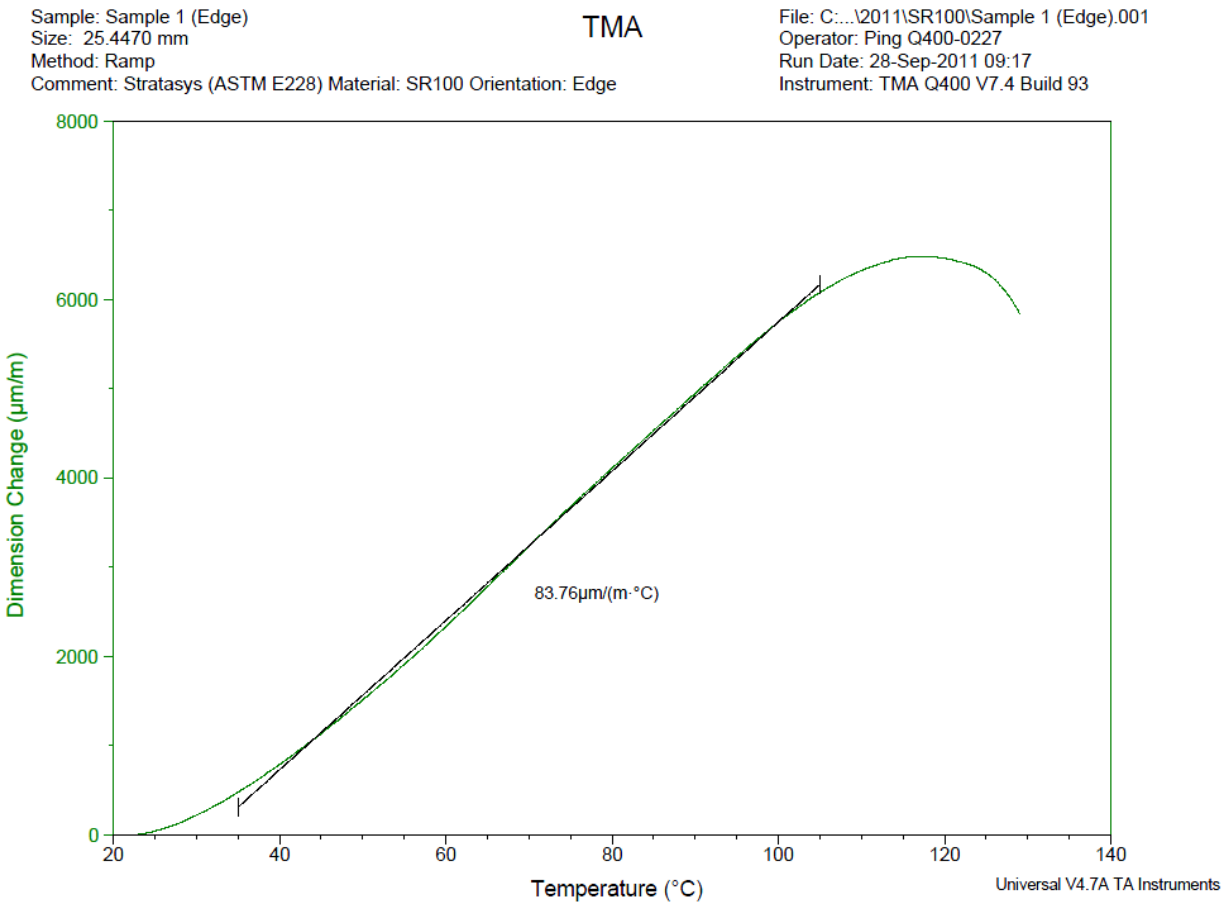

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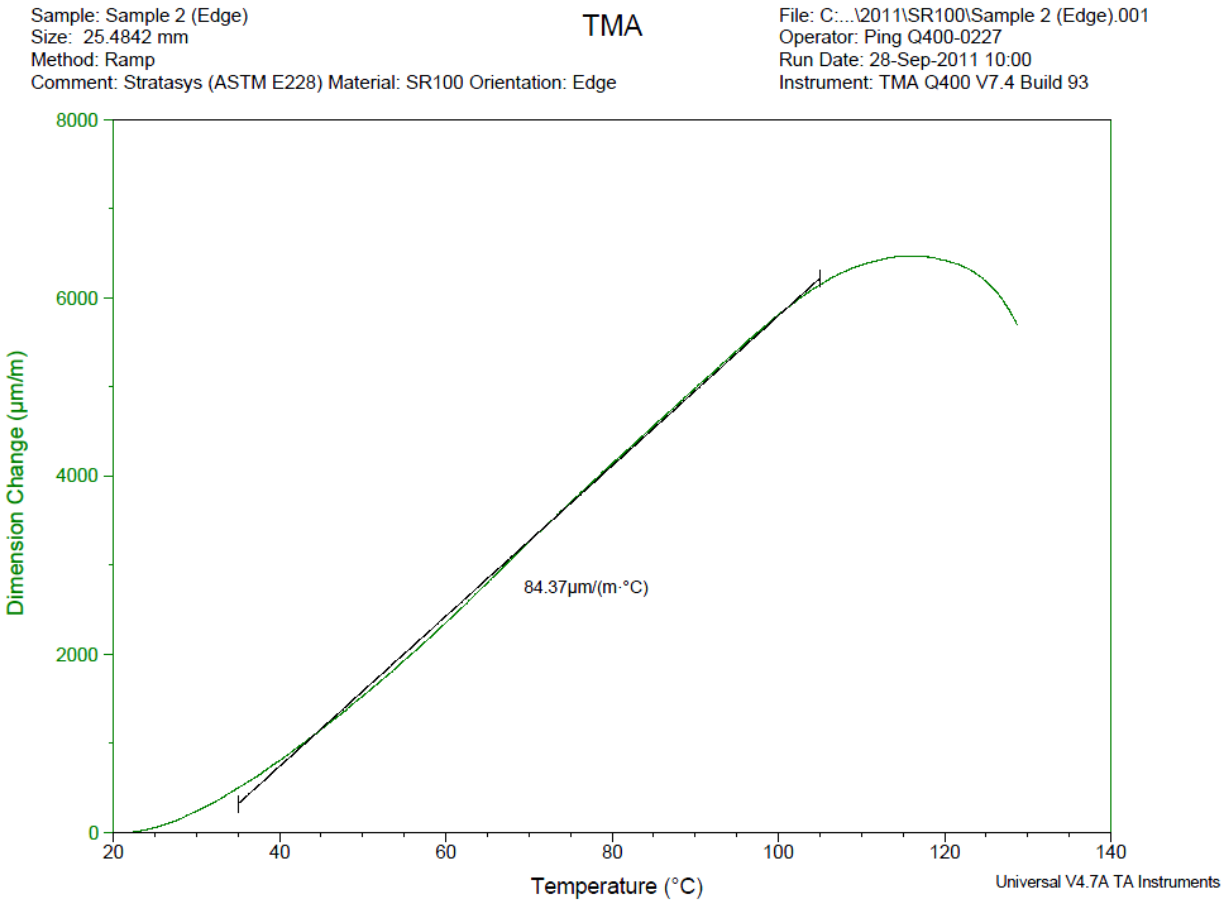
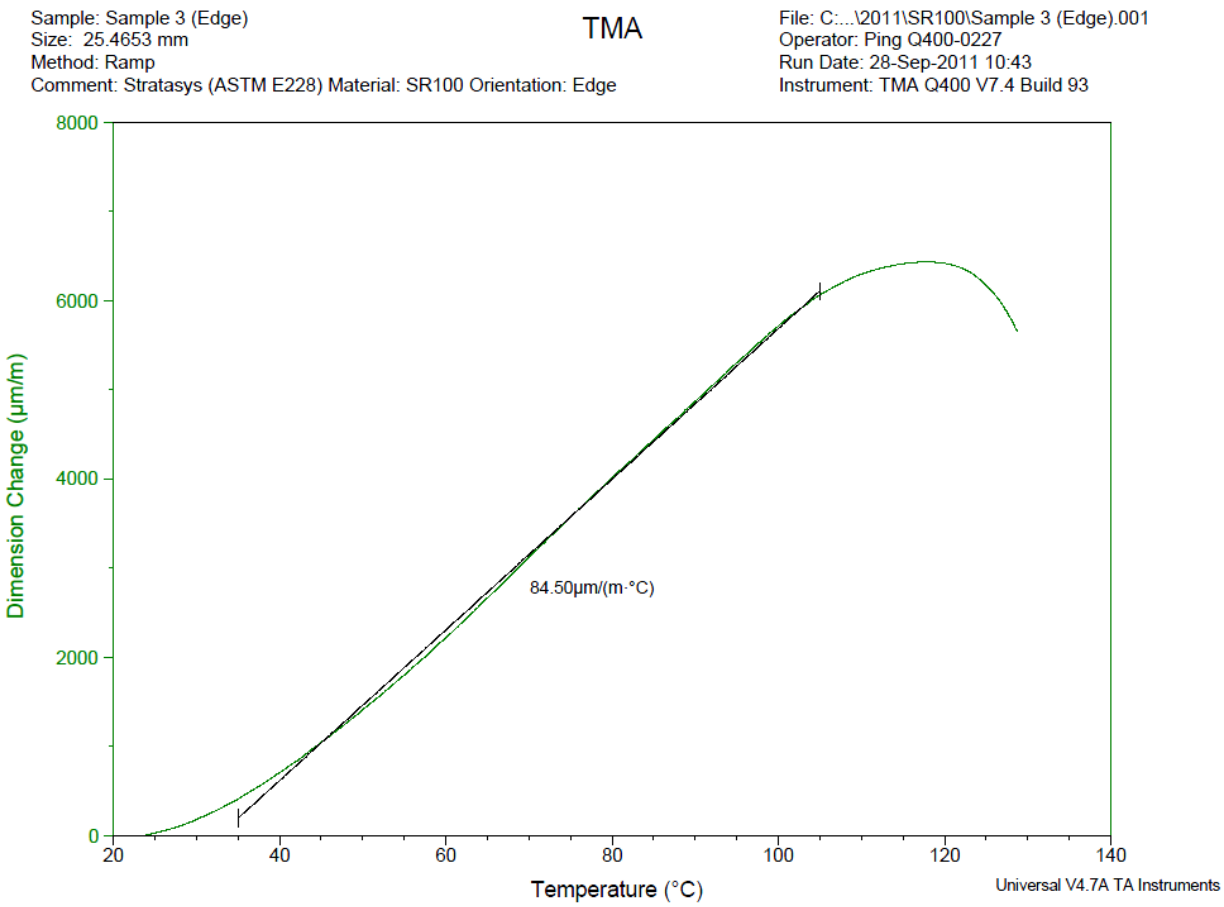
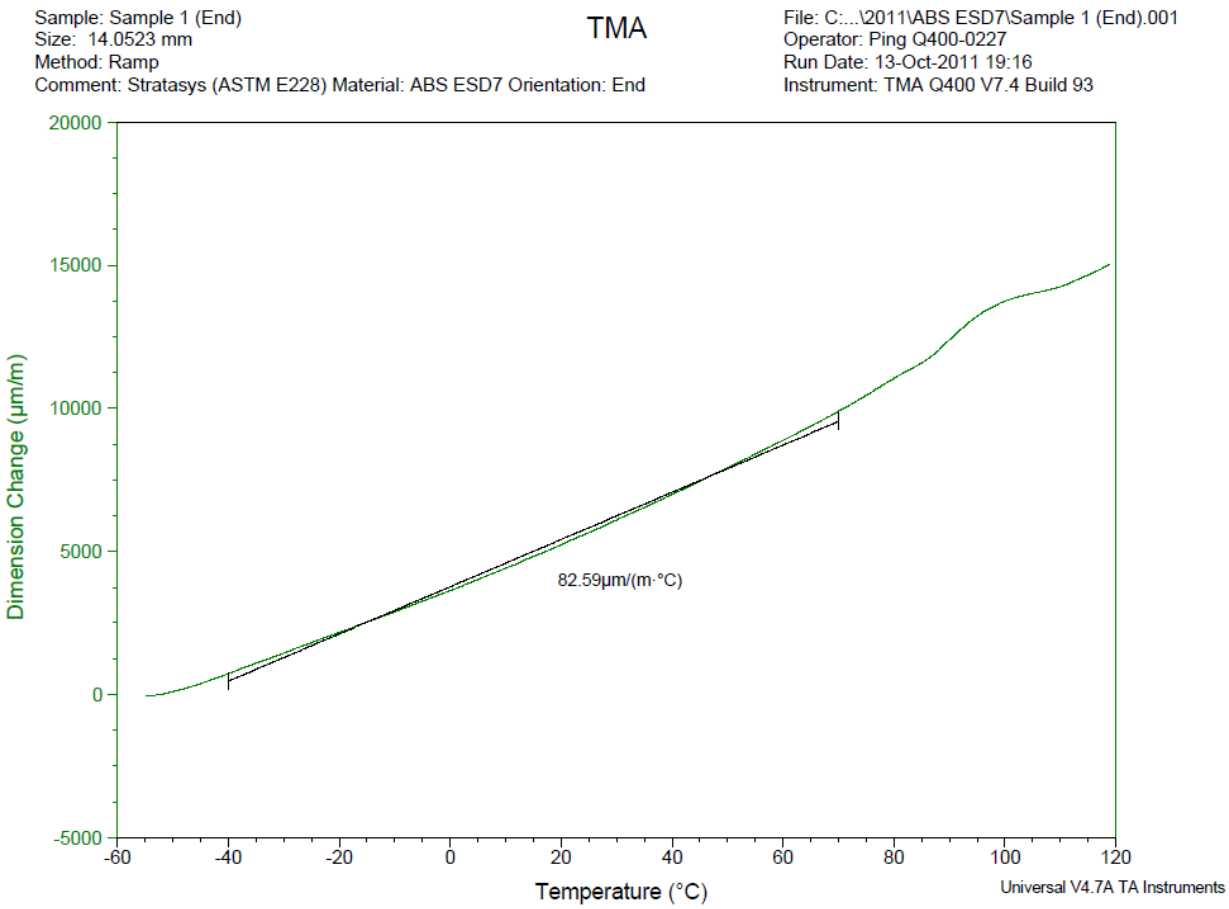


CTE TEST REPORT



CTE TEST REPORT

ABS ESD7



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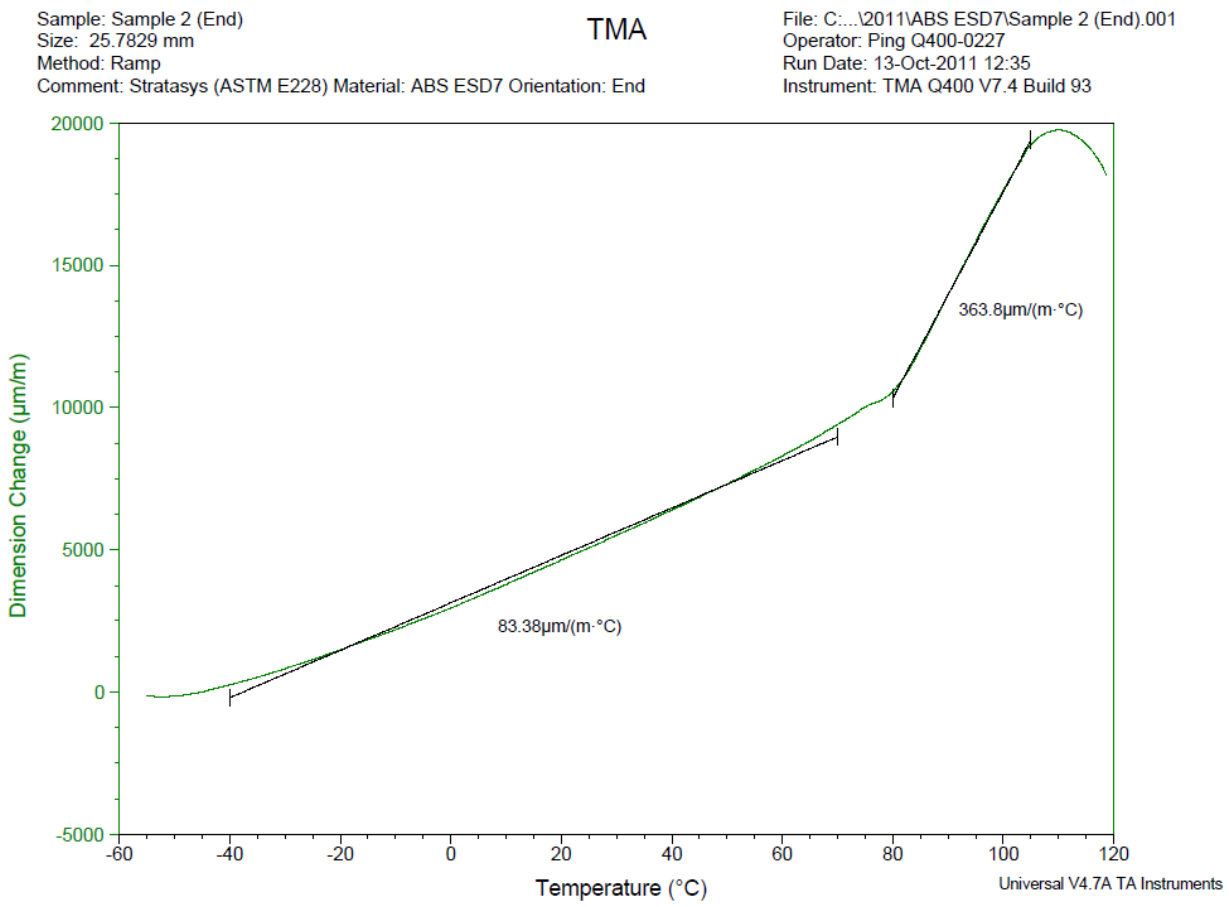

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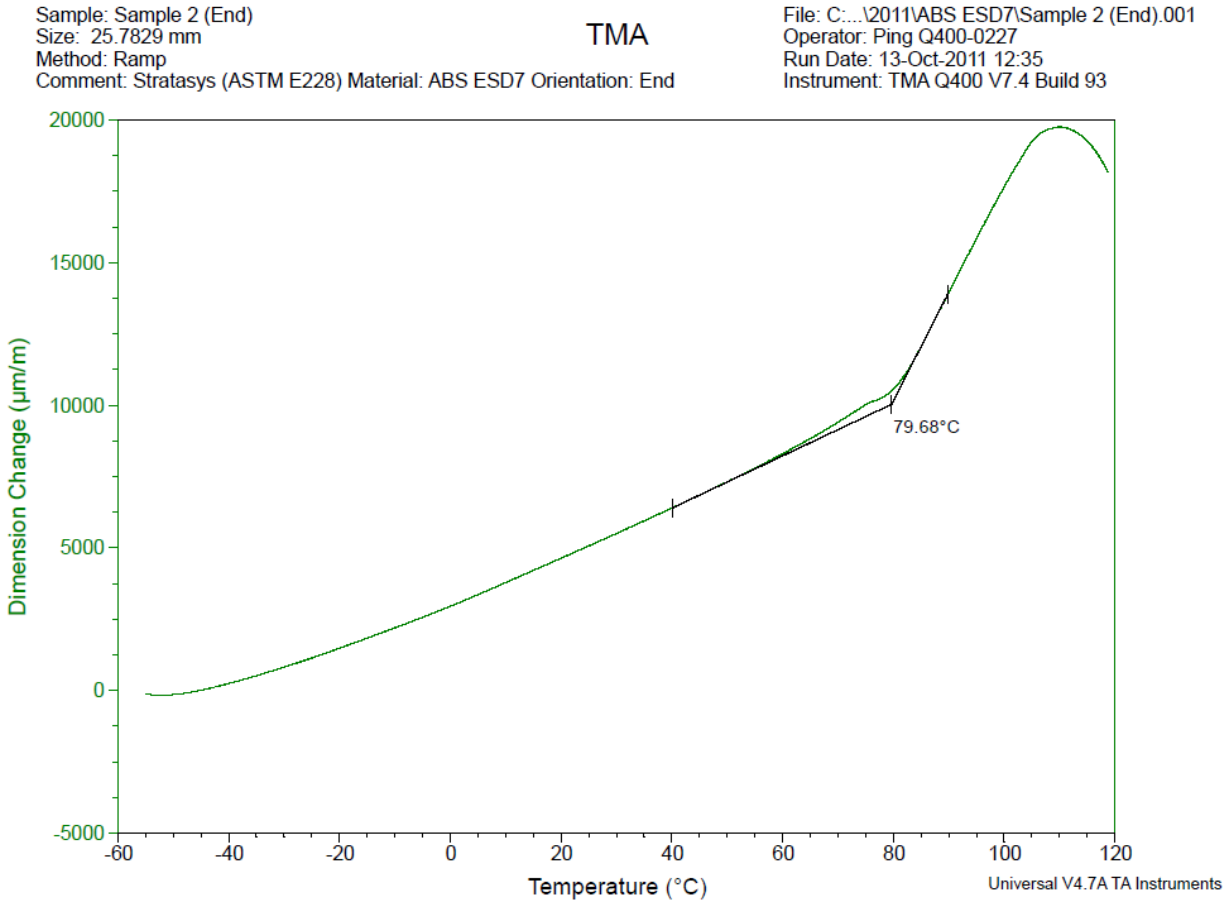

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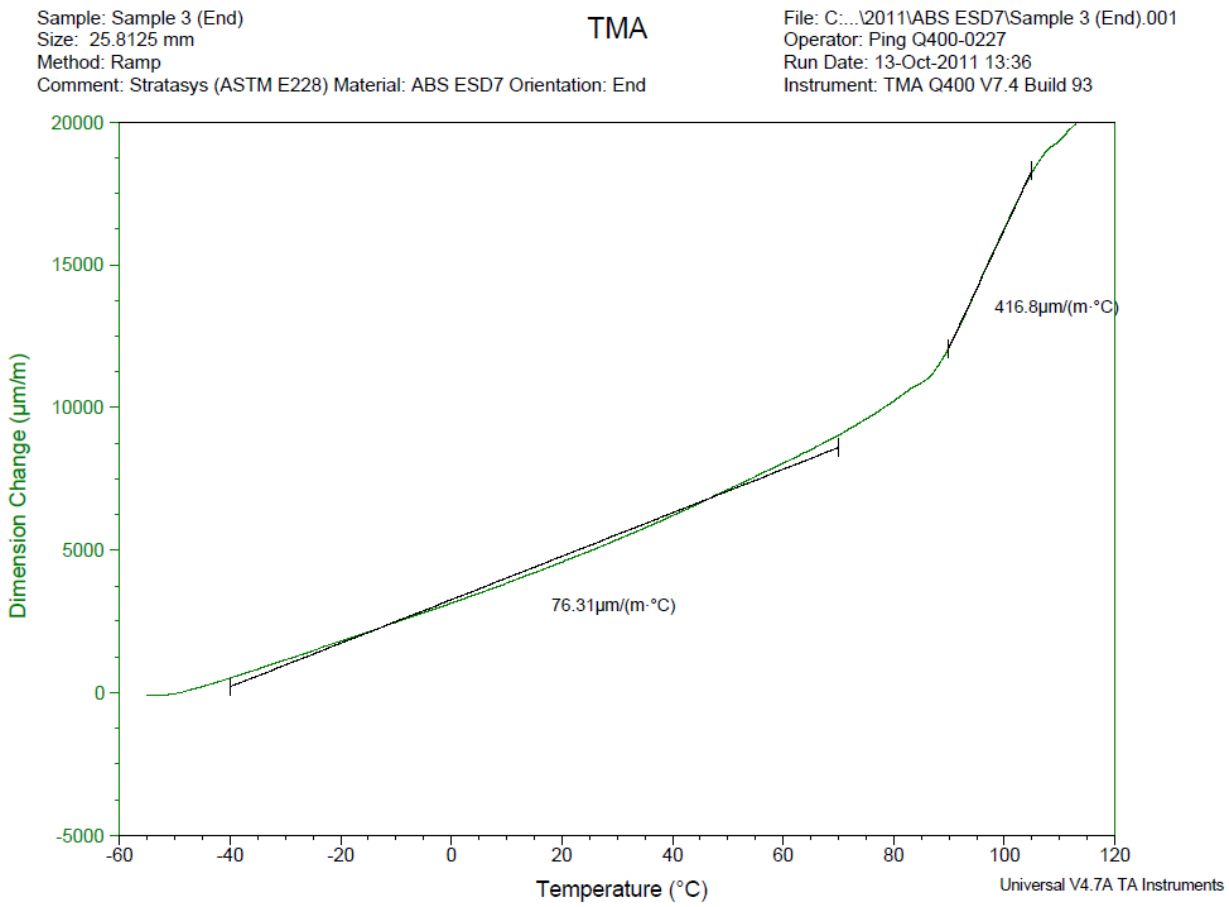

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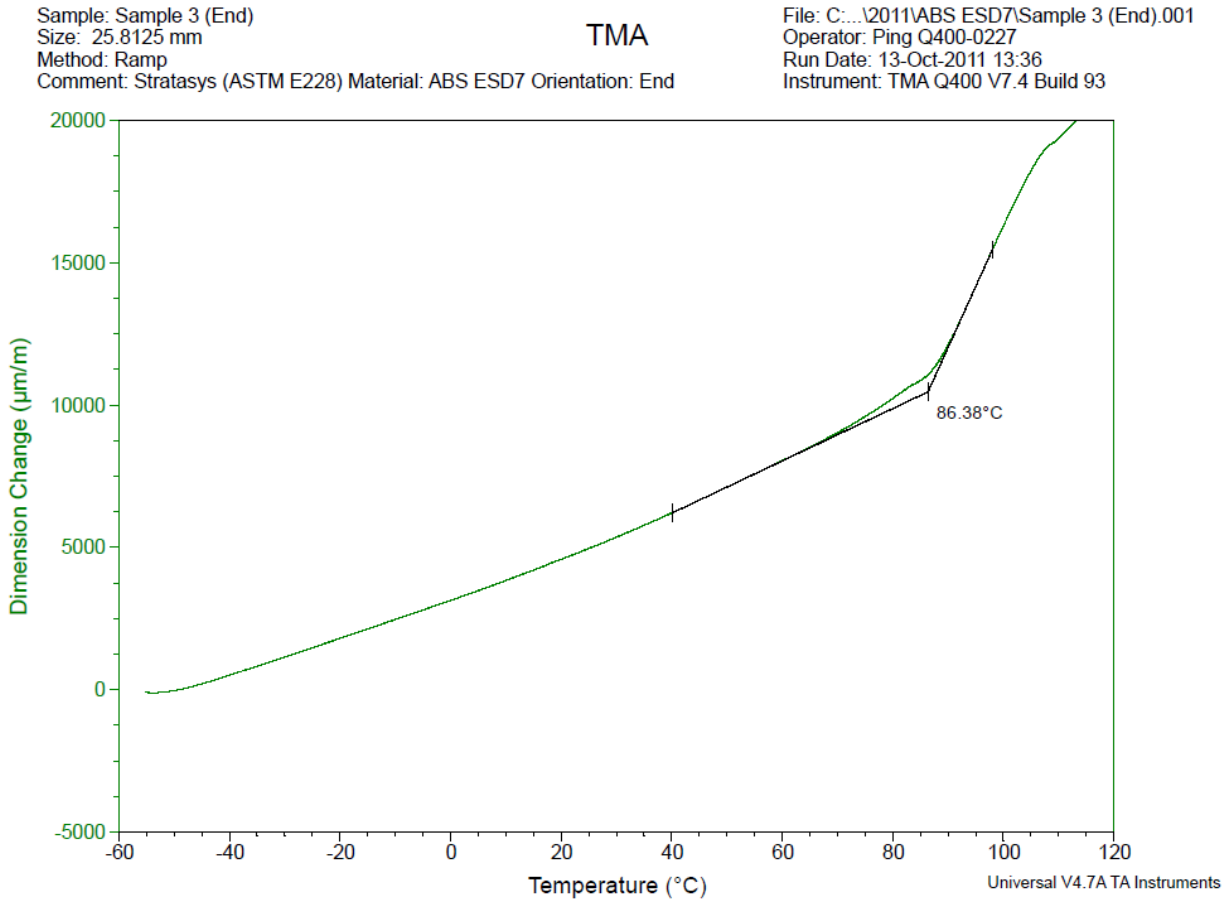

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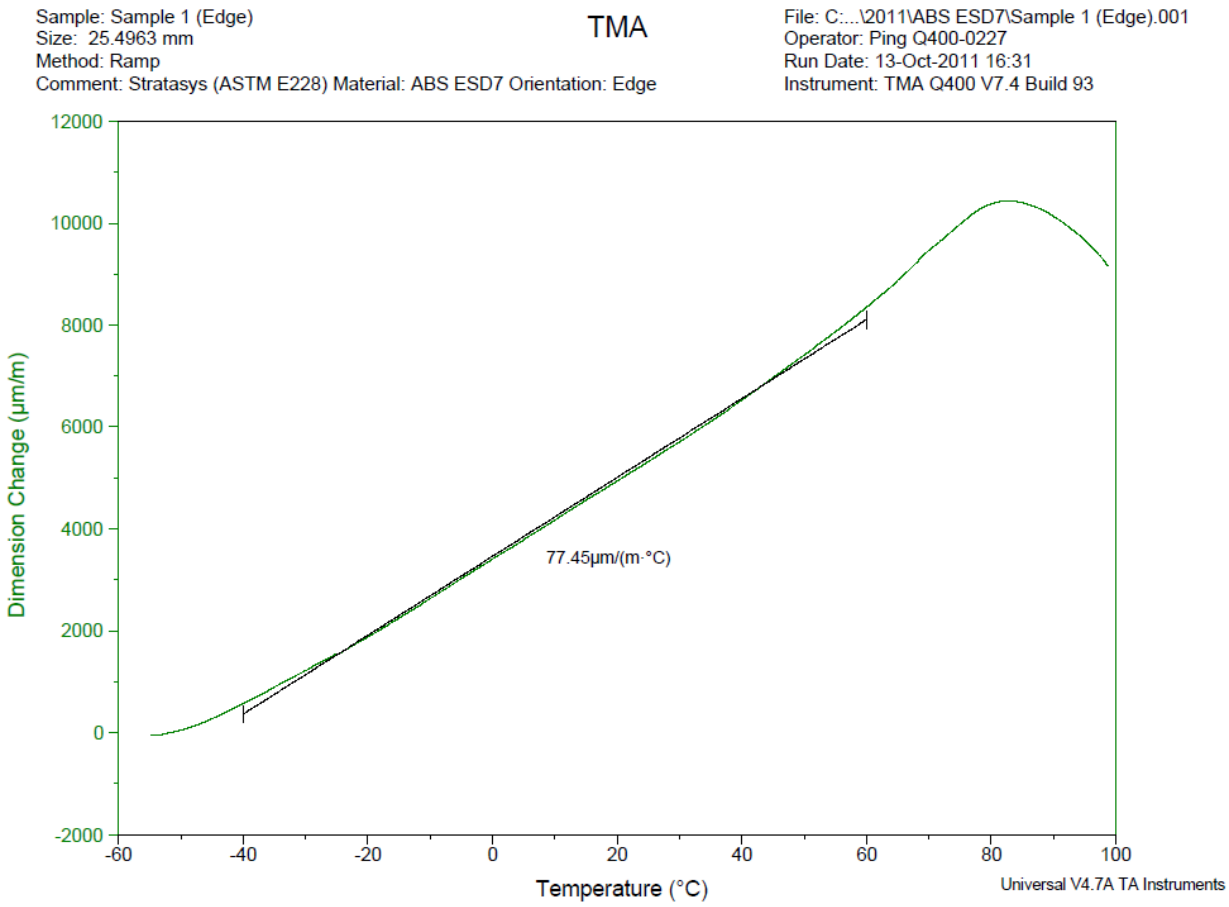

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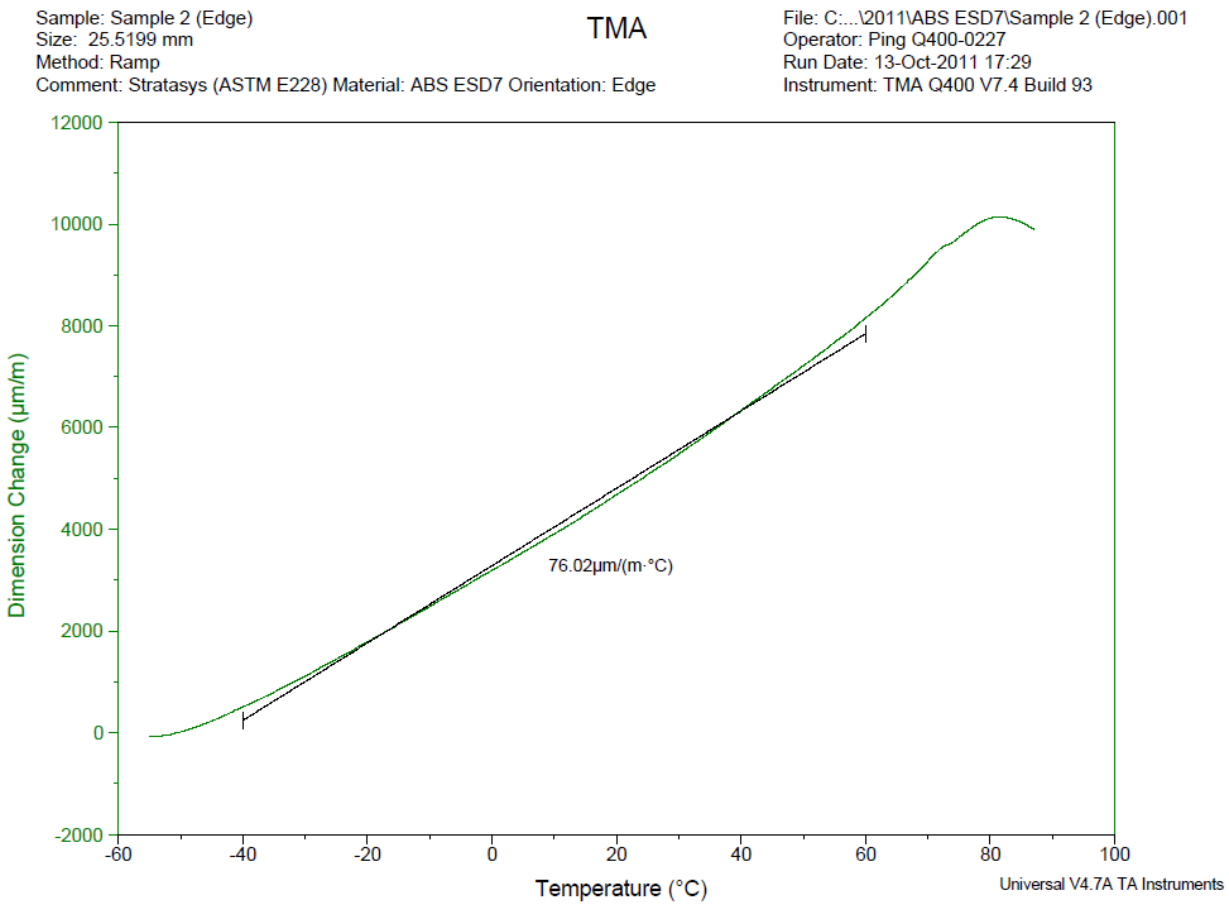

CTE TEST REPORT