TEST REPORT

THERM-A-GAP™ GEL 20 Reliability Report

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Executive Summary

THERM-A-GAP^{TM} GEL 20 (referred as GEL20 in the rest of report) is a high-performance, thermally cured polymeric composite gel for effective heat dissipation of electronic devices in various applications. The one-component cross-linked soft gelatinous structure provides superior performance and long-term thermal stability over conventional thermal grease and paste due to its unique thixotropy and surface-tackiness. This material is designed to be dispensed in applications requiring low compression forces and minimal thermal resistance for optimized thermal performance. This document outlines the examination of the physical and thermal reliability of this high-performance gap filler. Samples of manufacturing batches of GEL 20 were subjected to long-term environmental aging under dry heat conditions, vertical gap filling testing exposed to thermal shock from –40 ℃ to 85 ℃, vibrations at ambient temperature and vibration testing according to GMW3172.

The thermal performance of GEL 20 was examined after being subjected to multiple environmental stress tests. The thermal conductivity of GEL 20 was unaffected by 200 hour dwelling at 200 °C, and 1000 temperature cycles from -40 to 85 ℃. The thermal performance reliability is a result of the lower thermal impedance at the substrate/ GEL 20 interface, caused by the gel wetting out the substrate surface.

GEL 20 demonstrates physical integrity and the capability to maintain positioning in applications with varying gap distance. After a continuous temperature shock from –40 to 85 °C for more than 1000 cycles, this material shows no vertical movement and cracking when dispensed into gaps perpendicular to gravitational forces.

THERM-A-GAP^{TM} GEL 20™ exhibits superior long-term physical and thermal reliability. This material demonstrates resistance to the thermal oxidative degradation associated with continuous application temperatures of up to 150 ℃. This gelatinous material also displays excellent thermal reliability under various physical stresses, such as vertical gap orientation, thermal oxidation, and thermal shock cycling.

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1. Introduction

The purpose of the document is to examine the physical and thermal reliability of GEL 20. Samples of GEL 20 were subjected to long term heat aging.

2. Vertical gap filling test

Thermal shock test in combination with Temperature Aging shall verify that the component is immune to thermal fatigue and contact degradation that is caused by temperature changes and possible miss-matching of the CTE of materials.

2.1 Temperature aging at 125℃ x 1000 hours

2.1.1 Purpose

Long term aging was performed on GEL 20 between aluminum nitride substrates to evaluate the thermal performance reliability over time. The material was subjected to an extended dwell time of 1000 hours at 125°C.

2.1.2 Materials

2.1.2.1 Six 70x70x1mm aluminum nitride substrates
2.1.2.2 Teflon Shims, at 0.5mm 1.5mm &2.5mm thickness.
2.1.2.3 Six clamps
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2.1.3 Sample Preparation

2.1.3.1 0.7g samples of GEL 20 material were dispensed onto the center of aluminum nitride substrates.
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2.1.3.3.5 The previous steps are repeated for assemblies made with other shims.

2.1.4 Test Procedure

2.1.4.1 The assemblies were removed from their clamps and thermal grease was applied to the outside of the aluminum nitride substrates.
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2.1.4.4 Six samples were placed into a 125°C oven vertically, so the panels would be perpendicular to force of gravity.
2.1.4.5 After 1000 hours of dwell time, the samples were removed from their respective environments, allowed to equilibrate at room temperature for 2hrs, and repeat the test for thermal impedance.

2.1.5 Results

2.1.5. 1 125 ℃@1000hrs Result Summary Table

Sample Description	Gap(mm)	Thermal Impedance Before Aging (K-in.^2/W)	Thermal Impedance After Aging (K-in.^2/W)	% Changes
Gel20	0.5	0.283	0.295	-4.07%
Gel20	1.5	1.089	1.050	-3.58%
Gel20	2.5	2.590	2.095	-19.1%

Thermal Impedance Changes

2.1.5.2 Result Discussion

As shown in above table, the thermal impedance of GEL 20 with fixture declined 4 to 19 percentages after 1000hrs aging at 125℃, which mean GEL 20 thermal performance was better than that of original testing. The improvement was proposed to be results of better wetting after long time aging.

2.2 Thermal Shock Test

2.2.1 Purpose

This test is intended to simulate the gravitational effects on the mechanical integrity of the thermal GEL 20 in applications with a gap perpendicular to the gravitational force. It is to evaluate the physical integrity and ability of GEL 20 to maintain its position and integrity in vertical applications at stringent environment changes, -40 ºC to 85 ºC Thermal shock as per GMW3172 9.4.2.

2.2.2 Materials

2.2.2.1 Three test fixtures made from glass & aluminum plates.
2.2.2.2 1.5mm metal shims
2.2.2.3 Espec TSE-11-A thermal shock chamber

A figure of the test fixture is provided below.

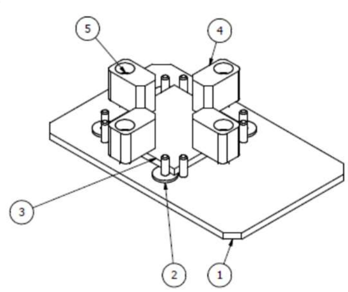

Figure 2 the fixture diagram for thermal shock cycling, where GEL 20 samples were set between glass slab (3) and roughened aluminum plate (1), and the thickness of GEL 20 were determined by the height of shims (2). The system were fixed by plastic component (4) controlled by spring screw (5).

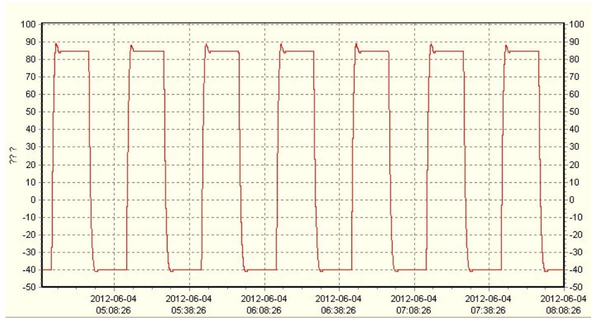

Figure 3 Temperature curve of thermal shock test

2.2.3 Test Procedure

This test shall verify that the component is immune to thermal fatigue and contact degradation that is caused by temperature changes and possible miss-matching of the CTE of materials.

2.2.3.1 Prepare test fixtures, place spacers.
2.2.3.2 Dispense 1.5g of GEL 20 onto aluminum plates gently. (the specimen should be dispensed with needle at fixed position to avoid bubbles)
2.2.3.3 Put glass sheet onto sample, press with care to avoid bubbles, clamp holders, this process should be done in 1min.
2.2.3.4 Put assembled fixtures into temperature cycling chamber, The assemblies were placed into a temperature cycling system for with the panels oriented vertically, so the panels would be perpendicular to force of gravity.
2.2.3.5 After 1000 temperature cycles, take out assemblies, check any sliding down or cracking occurred. Record sliding down distance, take photos if any cracking.

2.2.4 Results
2.2.4.1 Result Summary Table

Samples	Sample Description	Gap(mm)	Slump Distance(mm)
B1	Gel 20	1.5	0
B2	Gel 20	1.5	0
B3	Gel 20	1.5	0

Vertical Gap Slump After 1000 hours


Photos of specimens before & after thermal shock

2.2.4.2 Result Discussion
As shown in above table and photos, GEL 20 kept its shape and position very well and no sliding or cracking was observed after 1000 thermal shocking (-40~85℃)aging

3.0 Long-Term Aging Test

Temperature aging test shall verify the material's immunity to degradation resulting from the effects of high temperature.
Humid heat test shall verify the material's immunity to high humidity that may lead to functional and material degradation

3.1 Humidity Heat (85℃/85% R.H.) Test

3.1.1 Purpose
Long term humidity heat test was performed on GEL 20 between aluminum nitride substrates according to IEC 60068-2-38 to evaluate the thermal performance reliability at outdoor application.
The material was subjected to 85°C temperature 85% R.H. Humidity aging for 1000hours.

3.1.2 Test Procedure
Test procedure of humidity heat test is the same as long term heat aging test.
The test was conducted with U-can humidity heat chamber at 85°C temperature 85%R.H. Humidity.
Please refer to section 2.1.2 to 2.1.4 for detail procedure.

3.1.3 Results
3.1.3.1 85℃/85RH Result Summary Table

Sample Description	Gap(mm)	Thermal Impedance Before Aging (K-in.^2/W)	Thermal Impedance After Aging (K-in.^2/W)	% Changes
Gel20	0.5	0.495	0.482	-2.63%
Gel20	1.5	1.219	1.198	-1.72%
Gel20	2.5	2.269	1.761	-22.38%

3.1.3.2 Result Discussion

As shown in above table, the thermal impedance of GEL 20 with fixture declined 1.7 to 22 percentages after 1000hrs aging at 85℃/85RH, which mean GEL 20 thermal performance was better than that of original testing. The improvement was also proposed to be results of better wetting after long time aging.

3.2. High temperature steady aging

3.2.1 Purpose

Temperature aging was performed on GEL 20 between aluminum nitride substrates to evaluate the thermal performance reliability at extremely high temperature.
The material was subjected to 200℃ temperature for 200 hours.

3.2.2 Test Procedure

Test procedure of high temperature heat test is the same as long term heat aging test except temperature and test duration parameters.
Please refer to section 2.1.2 to 2.1.4 for detail test procedure.

3.2.3 Results

3.2.3.1 Result Summary Table

Results	Before Aging (W/m-K)	After Aging (W/m-K)
Average Thermal Conductivity @ 0.08" thickness	2.44	2.50

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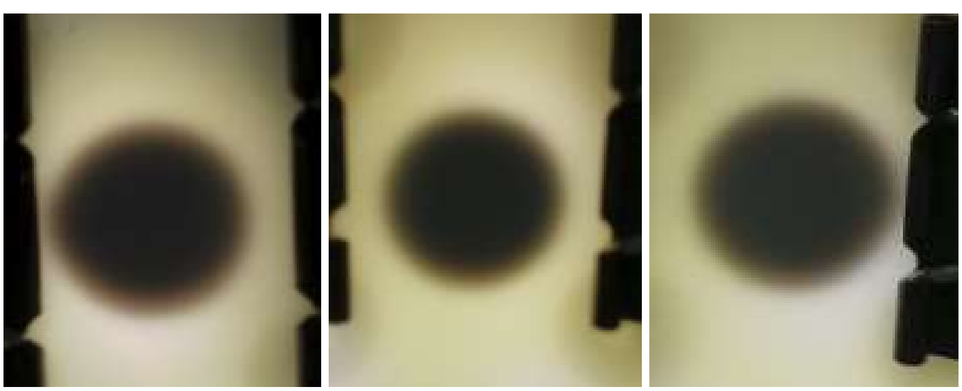
3.2.3.2 Specimen photos



Assemblies after 200 hours aging:

3.2.3.3 Result Discussion

As shown in above table, the thermal conductivity of GEL 20 increased from 2.44 to 2.50 after 200hrs aging at 200℃, which mean GEL 20 thermal performance was better than that of original testing. The photos above indicated that after aging GEL 20 kept its shape and position very well.

4.0 Vibration Test

This tests shall verify that the component is immune from the effects of vibration when it is located on the engine or transmission.

4.1 Vibration Test ETSI (For telecom application)

4.1.1 Purpose

This test was used to evaluate the effect of vibration on the thermal performance and check if there will be any sliding of GEL 20 after vibration.

4.1.2 Materials

4.1.2.1 Twelve 70x70x1mm aluminum nitride substrates
4.1.2.2 Teflon Shims, at 0.5mm 1.5mm&2.5mm thickness.
4.1.2.3 Twelve clamps
4.1.2.4 Three 4”x 4” glass panel & three 4”x 4” aluminum panel

4.1.3 Sample Preparation

4.1.3.1 Three samples at each thickness are prepared.
4.1.3.2 Dispense the appropriate amount of GEL 20 onto the center of a ceramic substrate according to the weights listed in the table below.

Sample Thickness ,mm	Gel Weight,g
0.5	0.7
1.5	2.1
2.5	3.5

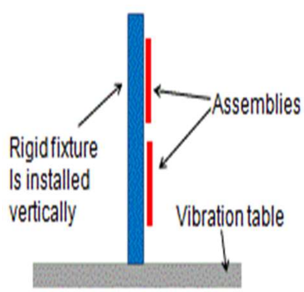
4.1.3.3 Place the appropriate shims at the corners of the substrate. For minimum bond line samples, no shims are needed.
4.1.3.4 A second ceramic substrate was place on top of the material.
4.1.3.5 A small clamp was placed onto the assembly to hold the shims in place and maintain the sample at the appropriate thickness.
4.1.3.6 This sample preparation procedure was repeated for 2 samples at 0.5mm,1.5mm, and 2.5mm sample thicknesses.

4.1.4 Test procedure

4.1.4.1 The sample assemblies were carefully removed from their clamps and thermal grease was applied to the outside of the ceramic substrates.
4.1.4.2 Thermal impedance was measured at 35℃ and 20psi per ASTM D5470.

4.1.4.3 After recording the thermal impedance, the samples were removed from the tester, the thermal grease was removed from the outside of the assembles, and the clamps were replaced.
4.1.4.4 The samples were then sent to an outside testing facility and subjected to 24 hours of vibration as per ETSI EN 300 019-2-4 Section 3.5 Sinusoidal .The temperature was maintained at 100°C.
Test parameters: 4m/s^2 acceleration, frequency from 9 to 200Hz, 1 actave per min, 8 hours in each vertical & planar direction.
4.1.4.5 After being subjected to the vibration conditions the samples were tested for thermal impedance.

For Glass Fixture:
4.1.4.6 Two samples of GEL 20 were dispensed onto a glass panels 0.5" apart, with 1"separation from the top edge of the glass.
4.1.4.7 Shims were placed at the edges of the aluminum panel and a clean glass panel was placed on top. The GEL 20 samples compressed between the glass panels result in a 1" diameter surface contact area on each surface.
4.1.4.8 Two clamps are fastened to the left and right side of the assembly.
4.1.4.9 The previous steps are repeated for assemblies made with other shims.
4.1.4.10 The samples were then sent to an outside testing facility and subjected to 24 hours of vibration as per ETSI EN 300 019-2-4 Section 3.5 Sinusoidal.
The temperature was maintained at 100°C.



Test setup

4.1.5 Results
4.1.5.1 Result Summary Table

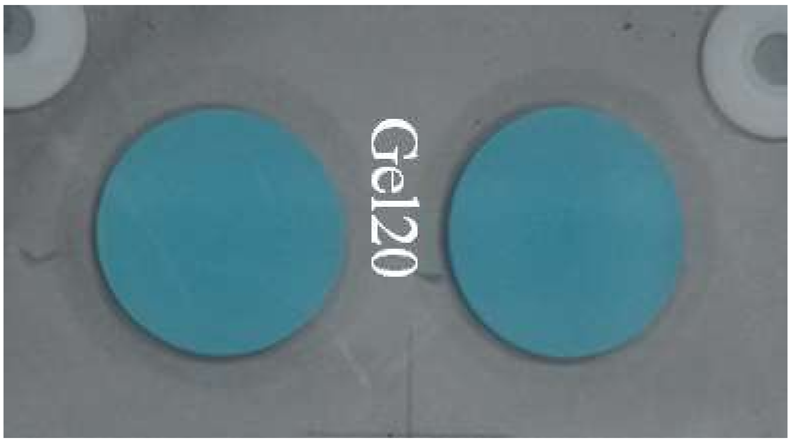
Sample	SpacerThickness (mm)	Thermal impedance (K-in.^2/W)		Change
		Initial	After	
GEL-20	0.5	0.53	0.52	-1.89%
	1.5	1.28	1.27	-0.78%
	2.5	2.36	2.35	-0.42%

Thermal Impedance Change

Samples	Sample Description	Gap(mm)	Slump Distance(mm)
C1	gel20	0.5	0
C2	gel20	1.5	0
C2	gel20	2.5	0

Linear Travel after Vibration (glass fixtures)

4.1.5.2 Specimens photos



Specimens after testing

4.1.5.3 Result Discussion

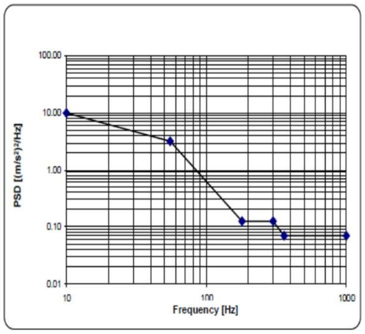
As shown in above tables, the thermal impedance of GEL 20 declined around 1percentage after vibration testing of ETSI, which meant GEL 20 thermal performance was better than that of original testing. The photos above indicated that after aging GEL 20 kept its shape and position very well. No sliding or cracking was observed in GEL 20 samples.

4.2. Vibration testing with GMW 3172 Automotive Method

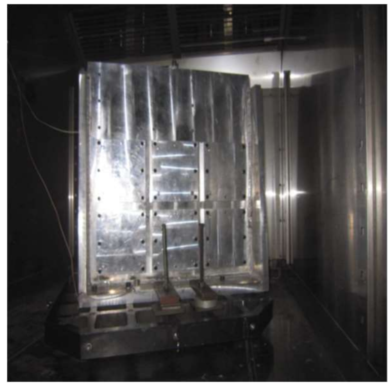
4.2.1 Testing method

The GMW3172 9.3.1.2 Random Vibration was designed for automotive application.
A random vibration test was performed strictly according to GMW 3172 to evaluate the stability of the gel materials under high acceleration and high temperate.
Random vibration is used to capture all vibration effects from piston/valve train (higher frequencies) and road-induced vibration (lower frequencies).

Sample preparation and test procedure are the same as ETSI method, expect the test parameters and profile as below.



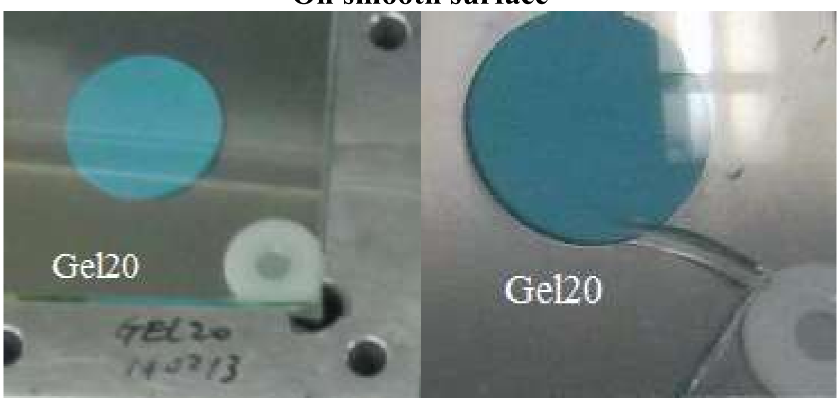
Effective Acceleration = 19.6 m/s^2 = 2.0 G_{RMS}



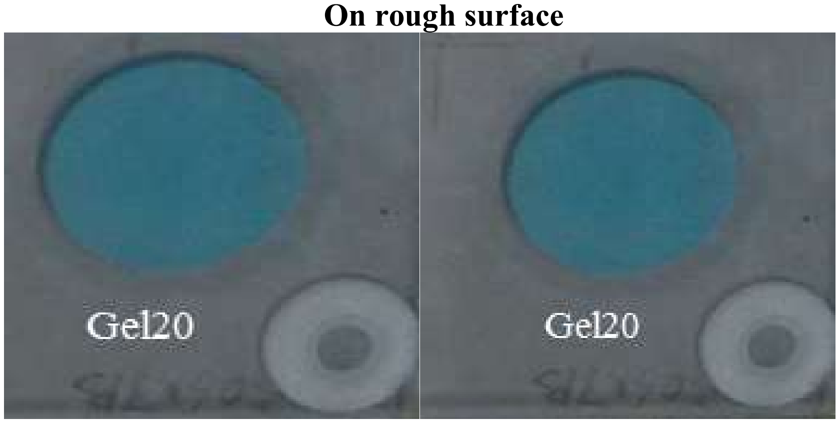
4.2.2 Testing results

Before aging **After aging**

On smooth surface



On rough surface



Thermal Impedance

Sample Description	Gap(mm)	Thermal Impedance Before Aging (K-in.^2/W)	Thermal Impedance After Aging (K-in.^2/W)	% Changes
Gel20	1.5	1.280	1.270	-0.78%
Gel20	2.5	2.360	2.290	-2.97

* The fixture with 0.5mm GEL 20 was broken after vibration testing

Thermal Impedance Changes

Samples	Sample Description	Gap(mm)	Slump Distance(mm)
G1	gel20	0.5	0
G2	gel20	1.5	0
G3	gel20	2.5	0

Linear Travel after Vibration (glass fixtures)

As shown in above tables, the thermal impedance of GEL 20 declined after vibration testing of GMW3172, which meant GEL 20 thermal performance was better than that of original testing. The photos above indicated that after aging GEL 20 kept its shape and position very well. No sliding or cracking was observed in GEL 20 samples. The results indicated that GEL 20 was suitable to be applied in automotive field.

5 .0 Outgassing Test

5.1 Purpose

The test was referring to ASTM E595, test condition was 125°C with vacuum for 24 hours.

This test method covers a screening technique to determine volatile content of materials when exposed to a vacuum environment.

5.2 Materials

5.2.1 Aluminum sample container

5.2.3 Vacuum oven with capability of 125°C at less than 7 x 10^{-3} Pa.

5.2.3 Micro balance with capability of +/- 1 µg

5.3 Test Procedure

5.3.1 Cut specimens to 25x25mm size and conditioning them in room temperature for 24 hours.

5.3.2 Weight sample containers for M1 in gram, put specimen into container and weight again for M2.

5.3.3 Put samples with container into vacuum oven for 24hours.

5.3.4 Weight samples with container after aging and record as M3

5.3.5 Calculate the Total Mass Loss as calculation below:

$$\textit{Total Mass Loss} = (M3\text{-}M2)/(M2\text{-}M1) \times 100\%$$

5.4Test results

Result Summary Table

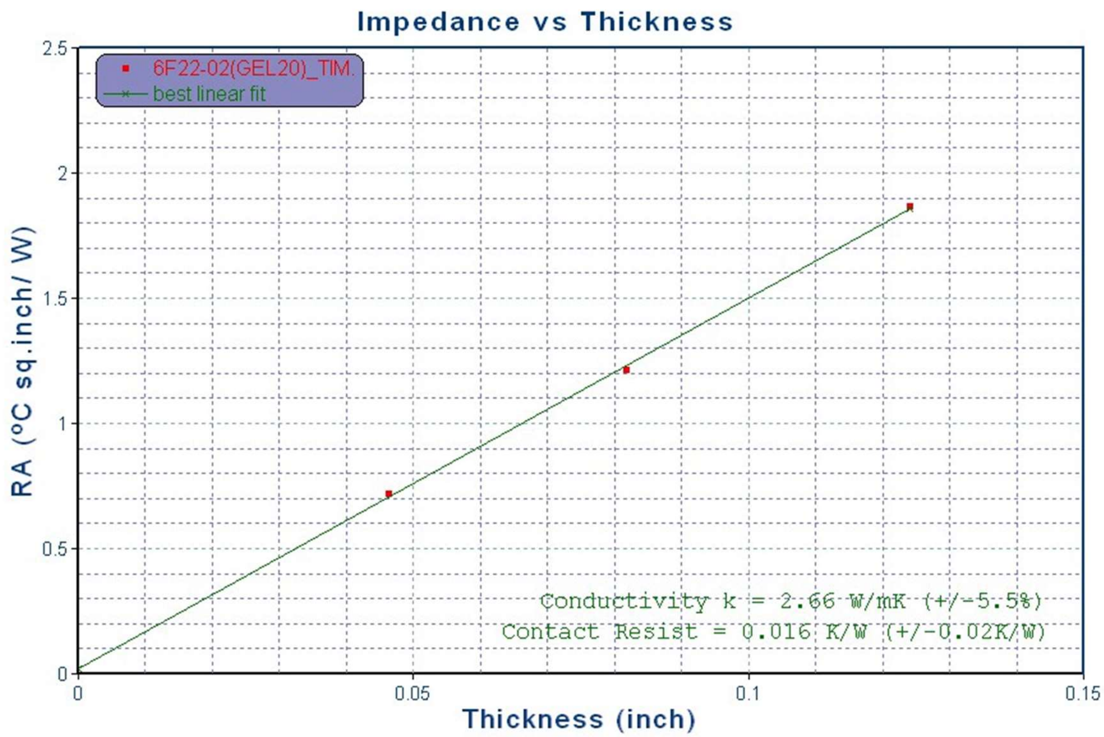
Gel20 Lot 131230	Pan Weight(g)	Total initial (g)	Total after (g)	Total Mass Loss
Sample 1	1.183	7.704	7.700	-0.06%
Sample 2	1.182	7.796	7.791	-0.08%
Sample 3	1.184	7.615	7.612	-0.05%
Average				-0.06%

5.4.2
Result Discussion
As shown in above tables, the Total mass loss of GEL 20 is lower than 0.1%, product applicable for most electronic applications.

6 Conclusion

GEL 20 demonstrates superior stable thermal performance and physical integrity after aging tests including 1000hrs at 125℃， 1000hrs at 85℃/85RH, 200hrs at 200℃， 1000 temperature cycles of thermal shock cycling from -40 to 85 °C. GEL 20 also demonstrates that its thermal conductivity is not impacted by steady-temperature thermal aging and vibration testing of telecom and automobile.

Footnote:
The user, through its own analysis and testing, is solely responsible for making the final selection of the system and components and assuring that all performance, endurance, maintenance, safety and warning requirements of the application are met. The user must analyze all aspects of the application, follow applicable industry standards, and follow the information concerning the product in the current product catalog and in any other materials provided from Parker or its subsidiaries or authorized distributors.



Appendix B: Thermal vs Different Thickness