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Performance Testing of Thermal Interface Filler Materials in a Bolted Aluminum Interface Under Thermal/Vacuum Conditions

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TABLE OF CONTENTS

1. INTRODUCTION 1

2. MATERIALS TESTED 2

3. TEST APPARATUS 3

4. TEST PROCEDURES 5

5. RESULTS 6

6. CONCLUSIONS 9

LIST OF FIGURES

1. Test apparatus mounted to coldplate 3

2. Test apparatus with MLI 4

3. Vacuum chamber, data acquisition, and cooling cart 4

LIST OF TABLES

1. Thermal filler materials tested 2

2. CHO-THERM-like materials at 10 in-lb 6

3. CHO-THERM-like materials at 25 in-lb 6

4. All other materials at 10 in-lb 7

5. All other materials at 25 in-lb 7

6. Vel-Therm at 10, 25, and 40 in-lb 8

NOMENCLATURE

A	contact area
d	bolt diameter
f	friction factor
N	number of bolts
P	contact pressure
T	bolt torque
ΔT	change in temperature

TECHNICAL MEMORANDUM

PERFORMANCE TESTING OF THERMAL INTERFACE FILLER MATERIALS IN A BOLTED ALUMINUM INTERFACE UNDER THERMAL/VACCUM CONDITIONS

1. INTRODUCTION

A thermal interface material is one of the many tools often used as part of the thermal control scheme for space-based applications. For example, these materials are placed between an avionics box and a coldplate in order to improve the conduction heat transfer so that proper temperatures can be maintained. Interface materials are usually compliant and act to fill the microscopic gaps on a surface so that the area of the heat transfer path is maximized. Any flat surface has hills and valleys in it that are not visible to the naked eye. If two surfaces are placed in contact with each other, only the peaks of the hills will actually contact and create a heat transfer path, thus, greatly reducing the effective amount of energy that can transfer between the two surfaces. Under atmospheric conditions, the gases present greatly aid in heat transfer. Interface materials are not usually required in this case and, in fact, can act as insulators. However, in the vacuum of space, there are no atmospheric gases to aid in heat transfer, and these interface materials are of great benefit.

Historically, at Marshall Space Flight Center, CHO-THERM® 1671 has primarily been used for applications where an interface material was deemed necessary. However, in recent years, numerous alternatives have come on the market. It was decided that a number of these materials should be tested against each other to see if there were better performing alternatives. The tests were done strictly to compare the thermal performance of the materials relative to each other under repeatable conditions and do not take into consideration other design issues, such as off-gassing, electrical conduction, or isolation, etc. The purpose of this Technical Memorandum is to detail the materials tested, test apparatus, procedures, and results of these tests.

2. MATERIALS TESTED

Twenty different materials tested are listed in table 1 with their respective test number, manufacturer, series, model, thickness, and thermal resistance (provided by the manufacturer). They can be broken down into the following categories: CHO-THERM and similar (tests 1–5), graphite (tests 6–10), foil (test 11), sandwich (tests 13–16), phase-change material (PCM) (tests 17–20), and other (test 12).

Table 1. Thermal filler materials tested.

Test No.	Manufacturer	Series	Model	Type	Thickness (in)	Vendor-Specified Resistance (°C in^2/W)
0	–	–	–	Bare (no filler)	–	–
1	Chomerics	CHO-THERM	1671	Silicone w/Boron Nitride	0.015	0.23
2	Chomerics	CHO-THERM	T500	Similar to CHO-THERM 1671	0.01	0.19
3	Thermagon	T-pli	220	Similar to CHO-THERM 1671	0.02	0.21
4	Thermagon	T-pli	205	Similar to CHO-THERM 1671	0.005	0.11
5	Bergquist	Sil-pad	K–10	Similar to CHO-THERM 1671	0.006	0.41
6	Graftech	eGraf	705	Graphite	0.005	0.03
7	Graftech	eGraf	1210	Graphite	0.01	0.03
8	Graftech	eGraf	1220	Graphite	0.02	0.07
9	Thermagon	T-gon	805	Graphite	0.005	0.07
10	Thermagon	T-gon	820	Graphite	0.02	0.17
11	Indium Corp.	Indium foil	–	Foil	0.015	0.007
12	Energy Sciences Laboratory Inc.	Vel-Therm	A20B–G251	Other	0.02	–
13	Bergquist	Q-pad	II	Sandwich	0.006	0.22
14	Bergquist	Q-pad	3	Sandwich	0.005	0.35
15	AOS Thermal Compounds	Micro-faze	A6	Sandwich	0.006	0.02
16	AOS Thermal Compounds	Micro-faze	K	Sandwich	0.006	0.03
17	Thermagon	T-pcm	HP105	PCM	0.005	0.015
18	Thermagon	T-mate	2910C	PCM	0.01	0.09
19	Thermagon	T-mate	2920	PCM	0.02	0.27
20	Bergquist	Hi-flow	625	PCM	0.005	0.71

3. TEST APPARATUS

The test fixture consisted of three 6-in square aluminum plates bolted to a liquid-cooled coldplate mounted in a small vacuum chamber. The filler material to be tested was placed between the two plates nearest the coldplate. Each of these plates included four imbedded resistance temperature devices (Minco® part No. S7798PD) that were connected to an Agilent Technologies® 34970A data acquisition unit for monitoring and recording temperature data. A Minco Kapton®-insulated thermo-foil heater resided in the interface between the two outermost plates. The heater was wired to a calibrated Agilent 6675A power supply to provide the constant voltage current across the 15.8-Ω heater. The test fixture was mounted to the coldplate with six No. 10 machine screws, which also provided the contact pressure across the interface filler. The coldplate was cooled via a Neslab® CFT–150 chiller utilizing a water-ethylene-glycol coolant mixture.

The contact pressure imposed on the interface material by this setup can be calculated by equation (1):

$$P = \frac{T \times N}{f \times d \times A} \,, \tag{1}$$

where P = contact pressure (psi), T = bolt torque (in-lb), N = number of bolts, f = friction factor (0.2 for unlubricated bolts), d = bolt diameter (in), and A = contact area (in^2).

Based on this equation, the contact pressure for the 10, 25, and 40 in-lb cases is 44, 110, and 176 psi, respectively. The setup is depicted in figure 1.

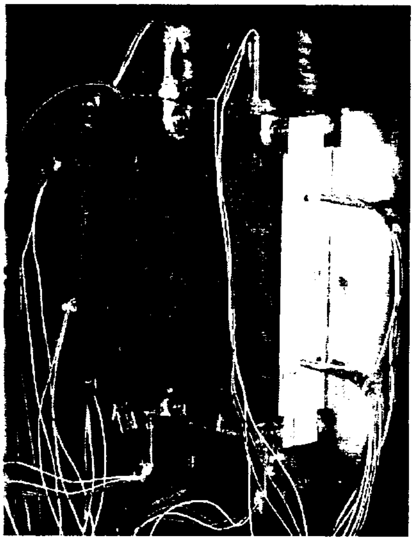

Figure 1. Test apparatus mounted to coldplate.

Following initial checkout tests, interface material was placed between the test apparatus and the coldplate to improve the heat transfer to the coldplate. Thermal interface material was also placed between the two outermost aluminum plates along with the heater to help fill surface irregularities and provide more uniform contact between the heater and the plates. Once the test fixture was assembled and mounted to the coldplate, a multilayer insulation (MLI) blanket was placed over it to reduce radiation heat transfer from the test fixture to the chamber walls. Photographs of the assembled test apparatus are shown in figures 2 and 3.

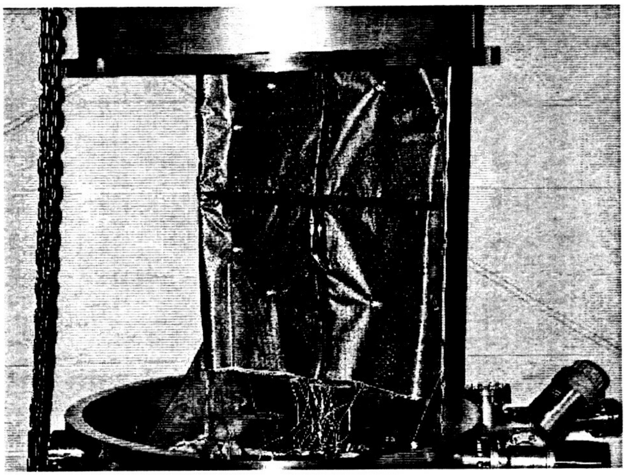

Figure 2. Test apparatus with MLI.

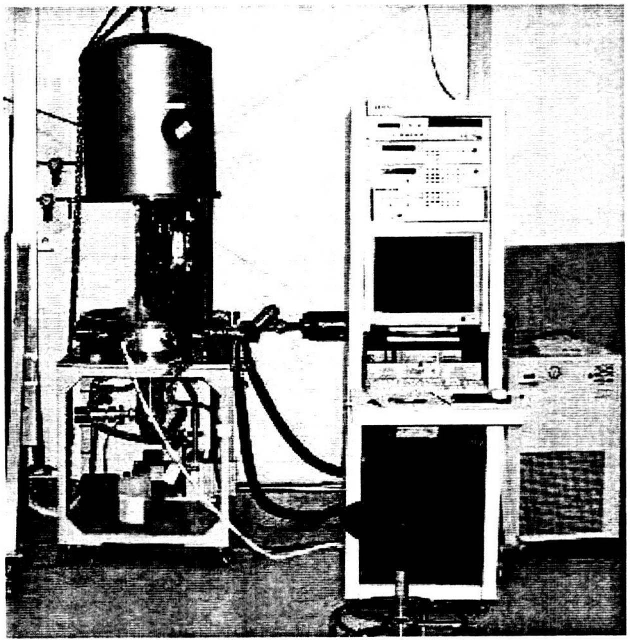

Figure 3. Vacuum chamber, data acquisition, and cooling cart.

4. TEST PROCEDURES

The approach used in testing was to measure the average temperatures of the two plates on either side of the interface material and use the ΔT across the interface as a comparison of performance of the materials. A constant (±1 °F) bottom plate temperature was maintained between each test, and the input voltage applied to the heater was maintained for each test. By using this method, testing was much simpler than trying to account for all energy losses or gains within the system, and it still gave valid results for comparison purposes.

Prior to any testing, the entire assembly was placed in the vacuum chamber and baked out for 2 hr at a temperature above 176 °F. After this was complete, the chamber was repressurized, and the bolts were retorqued. All testing was done at less than 1×10^{-4} torr.

A baseline test—no interface material (bare)—plus a test of each material was performed at torque values of 10 and 25 in-lb. A 40 in-lb test was also done on Vel-Therm®.

The bottom plate temperature and heater voltage were set for each materials test from those established in the baseline test. The settings used were arbitrary, but with the goal of an ≈90 °F ΔT. The settings ended up being ≈80 °F for the bottom plate and 70 V for the heater voltage, or ≈300 W of power.

During the early stages of testing, one of the CHO-THERM-like materials (T-pli 220) proved to perform far better than expected and only produced a ΔT of ≈6 °F. Based on this result and the fact that a number of the materials that had yet to be tested had far lower vendor-supplied resistance values, it was decided that a higher power level was needed to provide better resolution in the results. Consequently, two subsets of results were obtained. Results from the first subset consisted of the baseline (bare) test and all the CHO-THERM-like materials tested using the previously mentioned settings. The second subset of results were from retesting CHO-THERM 1671 and T-pli 220 at a higher input power and applying those settings to the remaining materials. The settings for the second subset were a bottom plate temperature of ≈86 °F and an input voltage of 95 V, or ≈570 W of power.

5. RESULTS

The results for the CHO-THERM-like materials are shown in tables 2 (10 in-lb) and 3 (25 in-lb) in order from least to highest ΔT. It can be seen from the tables that additional torque provides better results, which is expected. It also shows that none of these particular materials are more sensitive to torque; i.e., the order of the results does not change between the two tables.

Table 2. CHO-THERM-like materials at 10 in-lb.

Test No.	Material	Torque (in-lb)	Top Average (°F)	Bottom Average (°F)	ΔT (°F)
3	T-pli 220	10	84.7	78.6	6.1
4	T-pli 205	10	91.3	78.8	12.5
5	Sil-pad K-10	10	101.4	79.6	21.8
1	CHO-THERM 1671	10	112.6	79.3	33.3
2	CHO-THERM T500	10	117.0	80.4	36.6
0	Bare	10	166.8	79.6	87.2

Table 3. CHO-THERM-like materials at 25 in-lb.

Test No.	Material	Torque (in-lb)	Top Average (°F)	Bottom Average (°F)	ΔT (°F)
3	T-pli 220	25	84.7	79.8	4.9
4	T-pli 205	25	88.4	79.6	8.8
5	Sil-pad K-10	25	96.3	78.7	17.6
1	CHO-THERM 1671	25	105.4	79.0	26.4
2	CHO-THERM T500	25	106.7	78.5	28.2
0	Bare	25	143.6	79.9	63.7

Tables 4 (10 in-lb) and 5 (25 in-lb) show the results for the rest of the materials tested at the higher power levels. The same general trends can be seen for these materials. Two pairs of materials do swap places with the higher torque value but the ΔTs show that they are very close together in both cases.

Table 4. All other materials at 10 in-lb.

Test No.	Material	Torque (in-lb)	Top Average (°F)	Bottom Average (°F)	ΔT (°F)
17	T-pcm HP105	10	96.9	90.2	6.7
12	Vel-Therm	10	93.3	86.3	7.0
3–V	T-pli 220	10	95.3	85.6	9.7
20	Hi-flow 625	10	97.2	84.1	13.1
19	T-mate 2920	10	100.3	84.5	15.8
8	eGraf 1220	10	106.4	85.7	20.7
13	Q-pad II	10	108.0	86.7	21.3
7	eGraf 1210	10	108.6	85.9	22.7
18	T-mate 2910C	10	108.5	85.6	22.9
11	Indium	10	117.2	86.4	30.8
10	T-gon 820	10	118.5	85.8	32.7
15	Micro-faze A6	10	119.0	85.8	33.2
9	T-gon 805	10	120.7	86.4	34.3
6	eGraf 705	10	119.5	84.7	34.8
14	Q-pad 3	10	121.9	87.0	34.9
16	Micro-faze K6	10	138.2	83.7	54.5
1–V	CHO-THERM 1671	10	140.6	85.7	54.9

Table 5. All other materials at 25 in-lb.

Test No.	Material	Torque (in-lb)	Top Average (°F)	Bottom Average (°F)	ΔT (°F)
17	T-pcm HP105	25	91.9	85.4	6.5
12	Vel-Therm	25	91.1	84.4	6.7
3–V	T-pli 220	25	93.3	85.5	7.8
20	Hi-flow 625	25	99.0	86.0	13.0
19	T-mate 2920	25	101.5	85.9	15.6
13	Q-pad II	25	103.1	85.6	17.5
8	eGraf 1220	25	103.0	85.3	17.7
7	eGraf 1210	25	106.3	86.1	20.2
18	T-mate 2910C	25	106.5	85.4	21.1
11	Indium	25	107.0	85.1	21.9
10	T-gon 820	25	109.1	85.1	24.0
15	Micro-faze A6	25	109.9	85.4	24.5
9	T-gon 805	25	112.6	86.5	26.1
14	Q-pad 3	25	114.6	86.1	28.5
6	eGraf 705	25	115.8	86.4	29.4
16	Micro-faze K6	25	125.1	86.9	38.2
1–V	CHO-THERM 1671	25	128.9	86.7	42.2

Table 6 shows the results for Vel-Therm for all three torque cases. It was expected that with higher torque, the Vel-Therm would not perform as well. This is because the material consists of carbon fibers, which tend to get crushed at higher torque values, and the fibers are not effective at moving energy when this happens. As can be seen from the table, it does perform slightly better at 25 in-lb, but it loses performance at the 40-in-lb level.

Table 6. Vel-Therm at 10, 25, and 40 in-lb.

Test No.	Material	Torque (in-lb)	Top Average (°F)	Bottom Average (°F)	ΔT (°F)
12	Vel-Therm	10	93.3	86.3	7.0
12	Vel-Therm	25	91.1	84.4	6.7
12	Vel-Therm	40	91.5	84.2	7.3

6. CONCLUSIONS

The results show that there are many materials currently available that perform quite well. Cost is not a big consideration between any of them with the exception of Indium® and Vel-Therm, which are much more expensive than the others. There are many design considerations that come into play when trying to choose a suitable candidate, but these data should help with the thermal performance aspect of that decision. From a mainly thermal perspective, the following conclusions can be made:

- CHO-THERM 1671 is much better than a bare interface but it is one of the poorest performers in the group tested.

- There is little correlation between the manufacturer's thermal resistance data and the results from these tests, indicating that there is more to interface performance than just material properties.

- Graphites tended to improve with thickness. This was unexpected but may be pressure related if the graphite fillers are not as compliant as the silicone-based fillers.

- Indium was disappointing for the price. It may need higher pressures to conform to minor surface irregularities.

- There was little difference in the top two performers except price: Vel-Therm, $1000 and HP105, $16. The extra $984 buys a somewhat easier removal process; also, note that since HP105 is a PCM, it may have off-gassing problems.

- T-pli 220 had the best combination of thermal performance, price, and ease of use. Performance is consistent with the top two, but it is a CHO-THERM 1671-like filler. The only category where it does not outperform 1671 is in ease of reuse, which, at $38 a sheet, should not be an issue.

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13. ABSTRACT *(Maximum 200 words)*

A thermal interface material is one of the many tools often used as part of the thermal control scheme for space-based applications. Historically, at Marshall Space Flight Center, CHO-THERM 1671 has primarily been used for applications where an interface material was deemed necessary. However, numerous alternatives have come on the market in recent years. It was decided that a number of these materials should be tested against each other to see if there were better performing alternatives. The tests were done strictly to compare the thermal performance of the materials relative to each other under repeatable conditions and do not take into consideration other design issues, such as off-gassing, electrical conduction, isolation, etc. The purpose of this Technical Memorandum is to detail the materials tested, test apparatus, procedures, and results of these tests. The results show that there are a number of better performing alternatives now available.

14. SUBJECT TERMS thermal interface material, filler, and testing; thermal filler; thermal gasket; thermal grease; heat transfer; avionics cooling; bolted interface thermal conduction; vacuum thermal interface

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