

Experimental Evaluation of Thermal Resistance of Composites

G.V.Krishna Reddy, Chikkanna, B.Uma Maheswar Gowd

Abstract: In this paper thermal contact resistance is measured for different kinds of composite materials. The gaps at contact surface between two highly conducting materials are filled with the interstitial material. The interfacial gap is maintained by applying pressure on the surface by using shim, until certain thickness has been obtained. Shims of multiple sizes are used obtain different sizes of the gaps. Samples of the interface materials like Silicone grease, Eupec grease, Unial grease, graphite foil, silicone foil, aluminum foils, etc were tested. Also these samples with different material compositions were experimented. The measured thermal resistance values are compared with the theoretical values of thermal resistance for all the materials tested. In other words, the thermal conductivities published by their respective manufacturers are validated. It is found that thermal resistance is least for foils compared to grease or grease filled with powder. Also of all the foils tested, aluminum yielded the best results as far as the thermal resistance is concerned.

Keywords: Thermal interfacial materials, grease, aluminum foils, thermal contact resistance, thermal conductivity, electronics cooling.

I. INTRODUCTION

The size reduction of electronic components and the advances made in that area have increased the heat flux dissipation drastically. In the last two decades, packages have been shrunk to a hundredth of their initial size. Today, heat fluxes in computer chips are of the magnitude 100 W/cm². Metal oxide semiconductors controlled thyristors generate heat fluxes in the range 100±300 W/cm² [1] already. The junction temperature of each electronic component must be kept below 100±1108C for better performance and reliability. In order to enhance the heat removal to a maximum extent, the thermal contact component/cooler must be increased. The most commonly used method for maximizing the thermal contact conductance consists of filling the interfacial gap with thermal grease, during the assembling phase [2].

Recently, some interstitial materials are developed, like metallic, non-metallic or phase change material (PCM)-coated foils. The purpose of the present experimental study is to compare the performance of various interstitial materials. The variation of thermal contact resistance (R) depends up on the interface geometry, the thermal and mechanical properties of the contacting materials and the interstitial fluid [3]. The surface characteristics such as flatness, waviness and roughness have a major impact on the thermal contact resistance decreases with the increase in surface flatness. In contrast, thermal contact resistance decreases with decrease in waviness and roughness [4-8]. The thermal contact resistance is usually is parted into two parts/ One with a macroscopic resistance that varies with the waviness and flatness, and other is a microscopic resistance varying with the roughness. Another important parameter that controls the thermal resistance is the hardness which affects the deformation amplitude of the surface under a load. Softer the material, lesser the thermal contact resistance. Under a given load, the asperity deformation is greater for a soft material than for a hard one. Hence, the effective contact surface area is larger and the thermal contact resistance lower. As pressure increases a greater asperity deformation happens and the thermal contact resistance reduces. Usually at lower pressures, deformations are elastic and the macroscopic resistance dominates over the microscopic one, whereas at high pressures, deformations are plastic and the inverse phenomenon occurs [4, 9-11]. Another important parameter is the interface pressure distribution over the entire surface of the joint. The heat fluxes are not uniform if there are bolted joints. In such cases, the thermal contact resistance is minimal under the bolt head and steeply increases away from the bolt centerline [12, 13].

There is some research work focused on the heat flux variation with stress undergone by the contacting materials on the thermal contact resistance [14]. It proved that repeated loading unloading cycles produce a plastic deformation of the surface, so that the contact is flattened and progressively improved. The thermal contact resistance becomes stable after a certain number of cycles. Even when the load is independent of time, the material plastic flow causes a thermal contact resistance variation during the initial days after the assembly [14, 15]. The thermo physical properties of the contacting materials also play an important role on the thermal contact resistance.

Revised Manuscript Received on 30 June 2012.

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High values of thermal conductivity and thermal expansion coefficient can have a favorable effect on the resistance. As thermal conductivity and thermal expansion coefficient vary with the temperature, the thermal contact resistance depends on the temperature at the interface [14].

Introducing a thin layer of oil or grease between the surfaces [2,16-19] is the most popular to reduce the thermal contact resistance. The optimum thickness of the interstitial material depends on the thermal conductivity of the grease, which can be further improved by adding metallic particles to the silicone greases. Properties of Oil and grease may be altered when they are subjected to high temperatures for a long duration because they have a tendency to migrate and vaporize out of the contact area, all the faster as the interface temperature is higher [19]. As the interstitial layer thickness becomes not uniform, the thermal contact resistance increases. Another method to improve the thermal conductance consists of introducing a thin metallic or non-metallic foil between the contact surfaces [2, 4, 16, 17, 20]. Due to the deformation of the foil under the pressure, the number of contact areas increase thereby decreasing the thermal contact resistance due to constriction of the heat flux lines. The load pressure should be an optimum one for maximum thermal contact conductance. Too low a pressure will lead to a bad contact and a too high a pressure will lead to a foil damage. Hence, the foils are recommended to be made of a soft material to conform exactly to the profile of the contacting surfaces. Thus, non-metallic foils are typically made of carbon or silicone and charged with metallic particles. Snaith et al. [16] proved that the best results can be obtained when copper; indium or lead foils are used at the interfaces. If the foil material is at the solid state for the operating conditions, migration and dry-out problems can be avoided. But, some foils are difficult to implement practically because of their fragility, their adhesiveness to crease and their bad adherence to the surfaces, leading sometimes to degradation of thermal conductance. One can use some special treatments to enhance the heat transfer between contacting surfaces like anodized coating [2,16,21] or chemical vapor deposition (CVD) [2,16,22,23]. The type of coating type depends on its hardness mainly. Thus, the CVD is the most effective, but costly treatment because the microscopic resistance dominates over the macroscopic one. As for the other processes are concerned, there is an optimum coating thickness for given maximum thermal contact conductance. A high load application may possibly lead to degradation of conductance due to the coating cracking. The main disadvantage of this method is its difficulties in practicality and cost, since CVD is performed in a vacuum environment.

II. APPLICATIONS

A. Thermal interface in high performance devices / semiconductor packages such as Thermal interface materials (TIM1) applications, in MPUs & CPUs:

- High thermal conductivity (1.5 to 5.0 W/m K)
- Low thermal resistance
- Low separation
- Minimal ionic impurities

- Wide operating temperatures
- Structural adhesion
- Thin bond lines
- Low modulus & stress

B. Thermal interface between high performance devices, & heat dissipation devices in TIM2 applications

- High thermal conductivity (1.5 to 5.0 W/m K)
- Low thermal resistance
- Low separation
- Minimal ionic impurities
- Wide operating temperatures
- Structural adhesion
- Thin bond lines
- Low modulus & stress

C. General heat dissipation in board assemblies and various electronic sensors

- Moderate thermal conductivity (1.0 to 2.0 W/m K)
- Wide operating temperatures
- Low thermal resistance
- Structural adhesion

D. Thermal interface with heat dissipation devices in control units, medium-performance CPUs, etc.

- Moderate thermal conductivity (1.7 to 2.0 W/m K)
- Low thermal resistance
- Structural adhesion

E. Board level assembly and component sealing /fixing, Switching Power Supply component assembly / sealing

- Moderate thermal conductivity (0.83 to 1.3 W/m K)
- Low thermal resistance
- Low separation
- Room temperature cure
- Ease of use

F. Rubber and Gel potting encapsulation in power modules, converters, IGBT units

- Moderate thermal conductivity (0.83 to 1.6 W/m K)
- Low thermal resistance
- Low viscosity
- Flame retardancy
- Ease of use

III. THERMAL MANAGEMENT

Thermal Conductivity is a property of the material which describes the intrinsic ability of a material to conduct heat. Q indicates the rate of heat transfer when there is a temperature difference of T1-T2 between two points, separated by a distance of L.

Table 1: Interstitial materials and forms vs thermal conductivities.

Let k = thermal conductivity (W/m.K)
 Q = Rate of heat flow in W
 T = temperature
 d = distance between two points
 A = effective contact area through which the heat transfer happens

$$q = -kA \frac{dT}{dx}$$

$$q = kA \frac{T_1 - T_2}{x_2 - x_1}$$

$$q = kA \frac{T_1 - T_2}{d}$$

$$k = \frac{q}{A} \cdot \frac{d}{T_1 - T_2}$$

Thermal Resistance: Thermal Resistance is thermal property of a material and it indicates how it resists heat at a specific thickness. As shown below, thermal resistance is proportional to the thickness of the material, but it can be affected by gaps that occur between contact surfaces. These gaps create Contact Resistance, contributing to additional thermal resistance not represented in the above formula. Therefore, total thermal resistance in an application is represented by:

$$R_m = \frac{d}{kA}$$

$$q = \frac{T_1 - T_2}{R_m}$$

But, considering the total thermal resistance due to the contact resistance and the material resistance, the rate of heat flow can be expressed as

$$q = \frac{T_1 - T_2}{R_m + R_c}$$

As indicated in Fig. 1, the rate of heat flow can be expressed as

$$q = \frac{T_1 - T_2}{R_1 + R_2 + R_3}$$

IV. EXPERIMENTAL RESULTS

Experimentations were carried to find out the thermal contact resistance for different varieties of interstitial materials and form. A copper and aluminum plate of size 125mm x 125mm x 4mm are taken for experimentation. The copper plate is connected to heat source and maintained at a constant temperature of 200C. Whereas, the aluminum plate is maintained at a constant temperature of 100C. The interstitial materials are placed between the copper and aluminum plates. The thickness of the interstitial material at the interface is maintained by applying pressure and using standard shim to maintain a definite thickness.

Table 1 shows the types different interstitial materials and forms used along with their thermal conductivities.

Interstitial Material and Form	Thermal Conductivity in W/mK
G 641 Silicone grease Type I	0.83
G 641 Silicone grease Type II	1.7
G 641 Silicone grease Type III	2
G 641 Silicone grease Type IV	3
G 641 Silicone grease Type V	5
DC 340 (Dow Corning) Silicone grease with metallic oxide powder	0.42
P 12 (Wacker) Silicone grease with metal powder	0.81
Silicone grease based on polydimethylsiloxanic oil, with metallic oxide powder	0.41
Eupec (Henton) Grease	0.81
Unial (Henton) Grease	0.83
CHO-Therm 1678 (Chomerics) Silicone foil with boron nitride	1.6
CHO-Therm 1674 (Chomerics) Silicone foil with aluminium oxide	1.7
Kerafol 86/30 (Keratherm) Polymeric foil, with alumine oxide, ®breglass and ceramic reinforced	2.1
Kerafol 86/50 (Keratherm) Silicone foil with boron nitride	2.9
Kerafol 90/20 (Keratherm) Graphite foil	4.5
Furon C675 Aluminium foil coated on both sides with acrylic adhesives	1.1
Furon C695 Graphite foil coated on one side with acrylic adhesives	4
Crayofoil 8846 (Orcus) PCM foil with 51 mm thick aluminium support	207
Crayotherm 8844 (Orcus) PCM foil with 51 mm thick polyamide support	0.63
Crayotherm 8845 (Orcus) PCM foil with 76 mm thick polyamide support	0.63
Thermafoil 8843 (Orcus) PCM foil with aluminium support	207
domestic aluminium foil	207

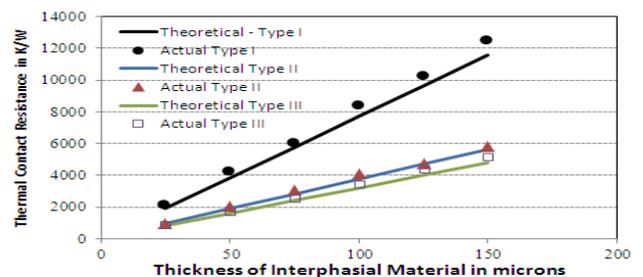


Fig. 1: Experimental Evaluation of Thermal Contact Resistance(1e⁻⁰⁶) of Type I, Type II and Type III



Fig.1. shows the experimental evaluation of the thermal contact resistance for three types of greases namely, G 641 Silicone grease Type I, Type II and Type III. The experimental results compare very well with the theoretical prediction.

The variation of the difference in the data is not too much and the difference can be attributed to the variations in the experimental set up versus the theoretical assumptions. The relation between the thermal contact resistance and the experimental values are linear in nature.

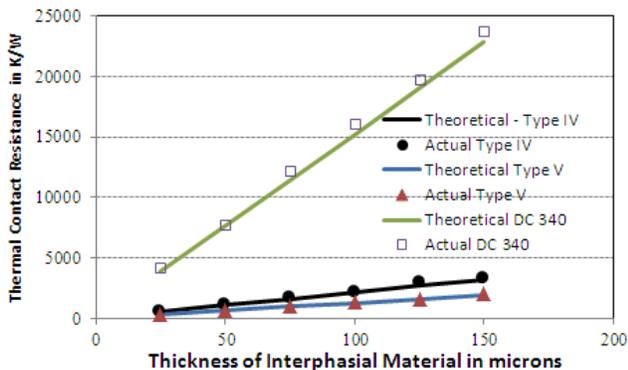


Fig. 2: Experimental Evaluation of Thermal Contact Resistance ($1e^{-06}$) of Type IV, Type V and DC 340

Fig.2. shows the experimental evaluation of the thermal contact resistance for three types of greases namely, G 641 Silicone grease Type IV, Type V and DC 340. The experimental results compare very well with the theoretical prediction. The relation between the thermal contact resistance and the experimental values are linear in nature. The contact resistance is least in the grease DC 340 among the three greases compared for the given conditions.

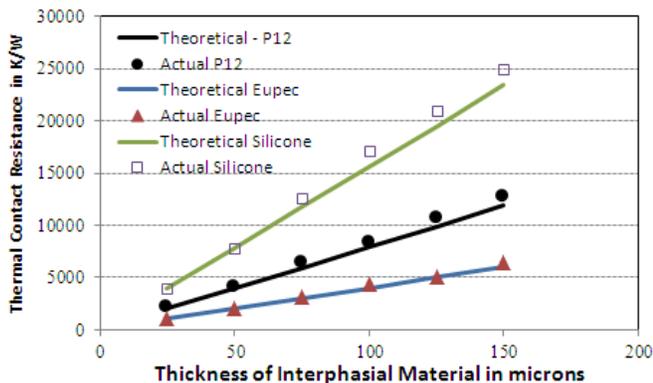


Fig. 3: Experimental Evaluation of Thermal Contact Resistance ($1e^{-06}$) of P12, Eupec and Silicone

Fig. 3. Shows the experimental evaluation of the thermal contact resistance for three types of greases namely, P12, Eupec and Silicone. Silicone grease is based on polydimethylsiloxanic oil, with metallic oxide powder, whereas P12 grease is with metal powder and Eupec is a normal grease. The experimental results compare very well with the theoretical prediction. The variation of the difference in the data is not too much and the difference can be attributed to the variations in the experimental set up versus the theoretical assumptions. The relation between the thermal contact resistance and the experimental values are linear in

nature. The thermal contact resistance is least for Eupec grease.

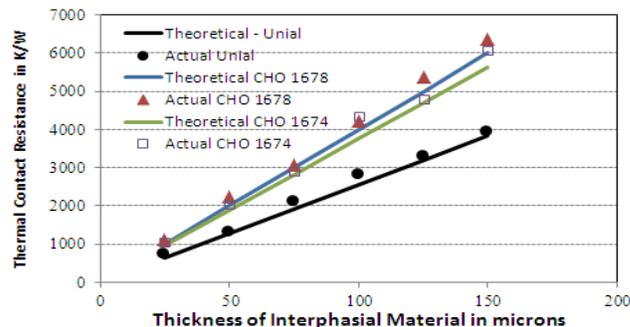


Fig. 4: Experimental Evaluation of Thermal Contact Resistance ($1e^{-06}$) of Unial, CHO 1678 and CHO 1674.

Fig.4. shows the experimental evaluation of the thermal contact resistance for three types of greases namely, Unial, CHO 1678 and CHO 1674. Unial is normal grease, CHO 1678 is with boron nitride and CHO 1674 is with aluminum oxide. The experimental results compare very well with the theoretical prediction. The thermal contact resistance characteristics of CHO 1674 and CHO 1678 are almost similar to each other.

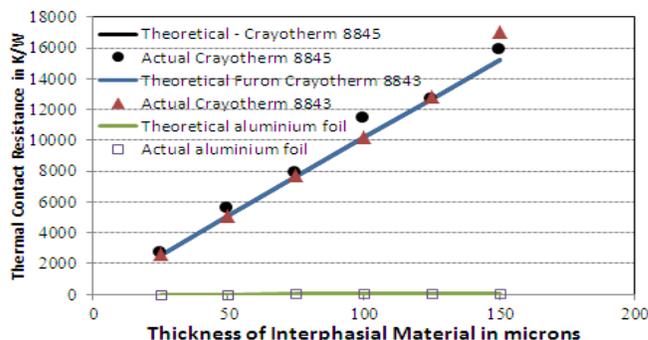


Fig. 5: Experimental Evaluation of Thermal Contact Resistance ($1e^{-06}$) of Crayotherm 8845, 8843 and Aluminium Foil.

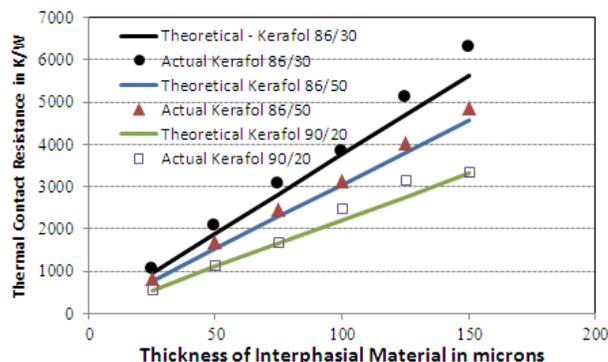


Fig. 6: Experimental Evaluation of Thermal Contact Resistance ($1e^{-06}$) of Kerafol 86/30, 86/50 and 90/20.



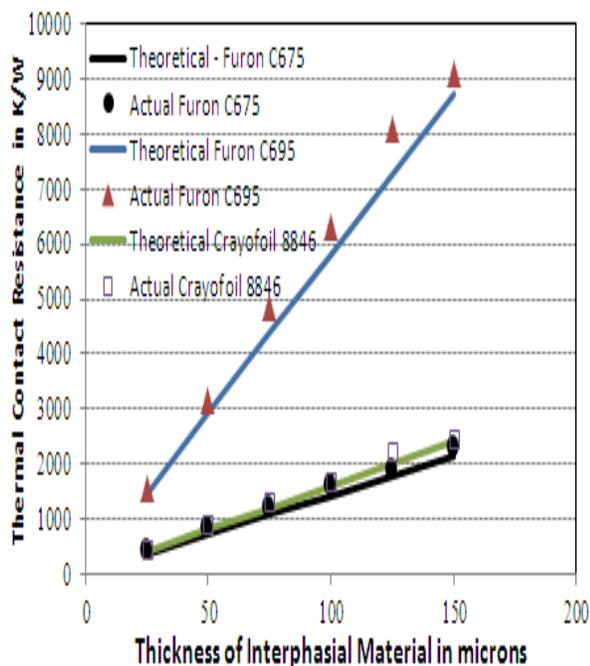


Fig. 7: Experimental Evaluation of Thermal Contact Resistance ($1e^{-06}$) of Furon C675, C695 and Crayofol 8846.

Fig's. 5, 6 and 7. shows the experimental evaluation of the thermal contact resistance for three types of greases namely, Crayotherm 8843, Crayotherm 8845, Crayotherm 8845, Furon 675, Furon 695, Kerafol 86/30, Kerafol 86/50, Kerafol 90/20 and aluminum foil.

V. CONCLUSION

In this work, the thermal conductivities of the materials used as interfacial materials are validated with the experimental data. The thermal contact resistance is calculated for thicknesses varying from 25 microns to 150 microns and it is compared with the measured thermal resistance. To calculate the thermal contact resistance for different thicknesses and establish the different thicknesses used for the calculations, shims of definite thicknesses were used and the gap is filled with the interfacial materials. Samples of the interface materials like Silicone grease, Eupec grease, Unial grease, graphite foil, silicone foil, aluminum foils, etc were tested. Also these samples with different material compositions were experimented. The measured thermal resistance values are compared with the theoretical values of thermal resistance for all the materials tested. In other words, the thermal conductivities published by their respective manufacturers are validated. It is found that thermal resistance is least for foils compared to grease or grease filled with powder. Also of all the foils tested, aluminum yielded the best results as far as the thermal resistance is concerned. The variation between the measured values of thermal resistance and the actual values are very minimal and the difference can be attributed to the variations in the experimental set up versus the theoretical assumptions.

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