T3Ster® Investigation of Thermal Effects of Surface Roughness on TIMs

By Toshiharu Morimura, Shin-Etsu Chemical Co., Ltd.

Shin-Etsu Chemical Co., Ltd. was founded 90 years ago in Japan and is the largest chemical company in the country, with the world's top share in polyvinyl chloride (PVC) and semiconductor silicon and the top domestic share for silicones. One of Shin-Etsu's main products is silicone which is used in a wide range of industrial fields, including electrical and electronic applications, automobiles, construction, cosmetics and chemicals.

About 40 years ago, Shin-Etsu decided to move into manufacturing TIMs (Thermal Interface Materials). TIMs help to move heat away from electronic components and are an integral part of electronic product design. The challenge with TIMs is usually associated with how effective the interface attachment is to the electronic components especially air gaps that may appear – the so-called "heat resistance" of such materials to heat flow from hot components to their cooling systems (Figure 1).

Silicone is a highly effective TIM because it is both soft and stable and it can be used over high and low temperature ranges. It is an artificial polymer compound that has an inorganic siloxane bond (Si-O) repeating as a main chain, along with various organic groups in its side chains (Figure 2). A spider diagram of its physical and chemical properties can be seen in figure 3 where it can be seen to be excellent in most of its properties and suitable as a base material for TIMs.

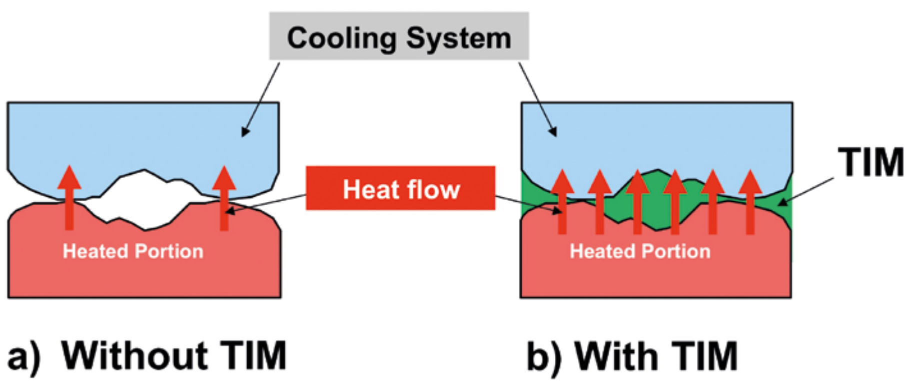
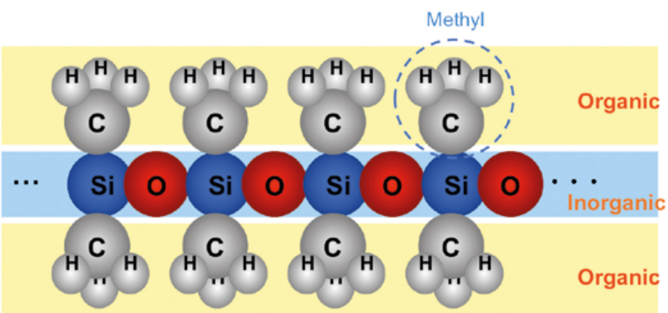
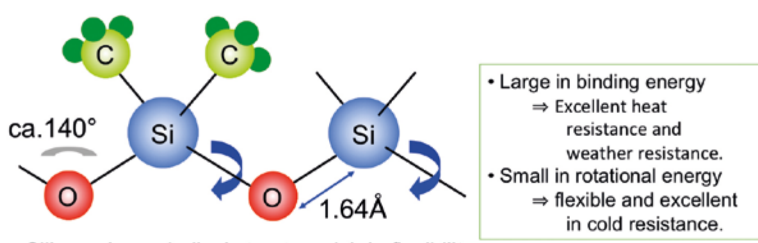


Figure 1. Principle of Operation of an electronics TIM



Structural schematic view of a polydimethyl silicone



Silicone has a helical structure rich in flexibility.

Bonding	Bond distance	Bond angle	Rotational energy	Binding energy
Siloxane bond (Si-O)	1.6Å	*ca.*140°	<0.8 kJ/mol	444kJ/mol
C-C bond C-C	1.54Å	*ca.*110°	15.1 kJ/mol	356kJ/mol

Figure 2. Molecular Composition of Silicone and the polymer's Physical Properties

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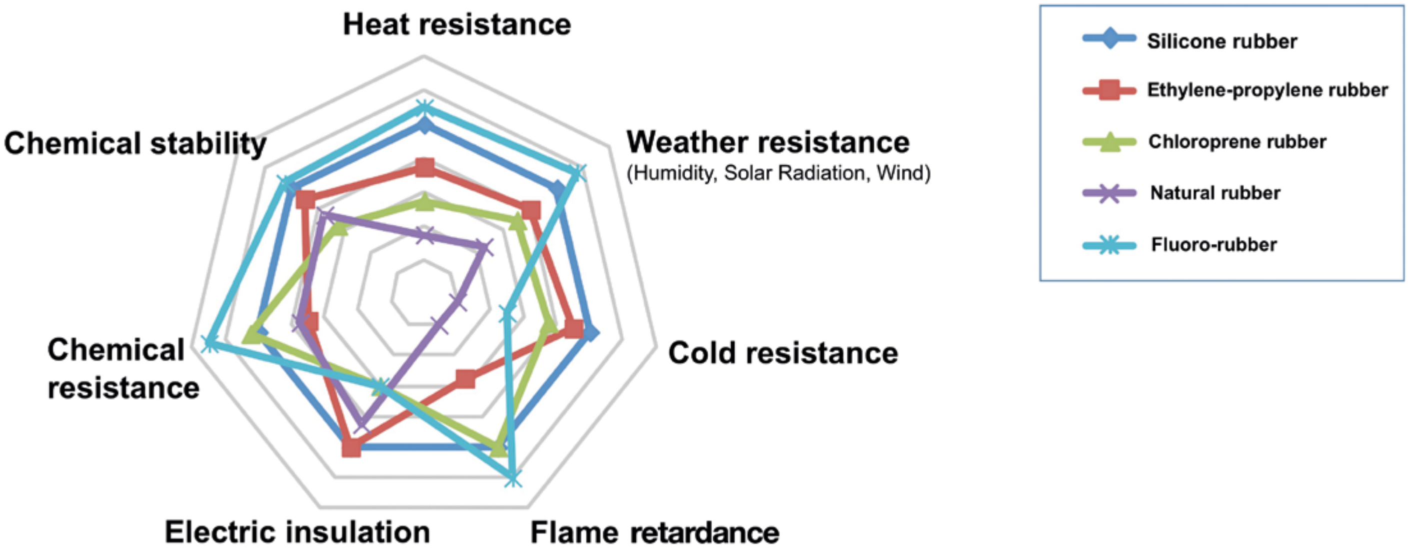


Figure 3. Physical & Chemical Properties of Silicone versus other Rubber Materials

Up to 2015, Shin-Etsu employed in-house test equipment to measure thermal resistance of their TIM products within their laboratories. However, they recently acquired a Mentor Graphics T3Ster transient thermal tester unit in order to capture complex transient thermal features during testing of their TIM products. A series of benchmark tests were devised to validate the MicReD T3Ster™ hardware for a range of TIM variables, some of which involved T3Ster being connected to in-house equipment:

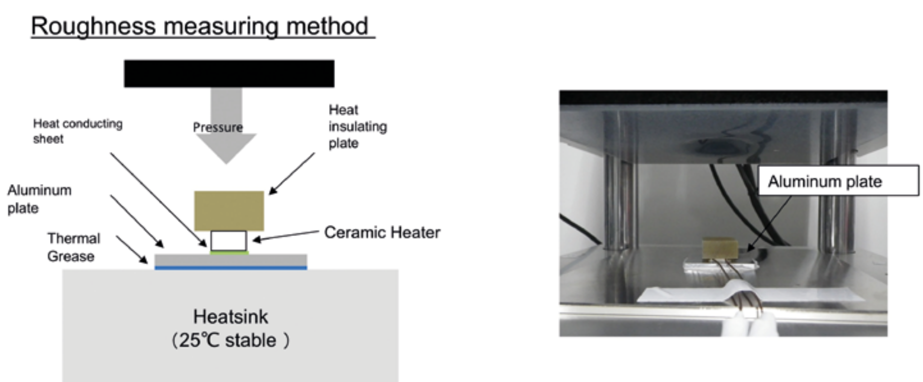
a) Thickness of TIM layers,

b) Hardness of TIM layers, and

c) Roughness of layers TIMs attach to.

The powerful T3Ster Master software from MicReD and its "Structure Function" approach to quantifying thermal resistance for TIMs was employed to good effect in assessing (a) and (b) first. For TIM hardness and thickness Shin-Etsu were able to confirm with T3Ster measurements that the heat releasing performance of silicone based rubbers depends on the pressure the TIM is under during normal operation. In addition, Low Hardness TIMs performed better for heat spreading than High Hardness TIMs, plus thin TIMs produced better heat release than thick TIMs. This article will deal with item (c) in detail, that is, roughness effects on thermal performance of TIMs using T3Ster thermal test methods.

To assess the impact of the roughness of an aluminum plate attached to a TIM (heat release sheet) between the plate and a



Pressure 【psi】						
50	75	100	125	150	175	200

Roughness of Aluminum plate			
As is	▽	▽▽	▽▽▽

・measure the temperature at each conditions.

Figure 4. Test Equipment used to assess the effects of aluminum plate roughness is contact with various hardness TIMs

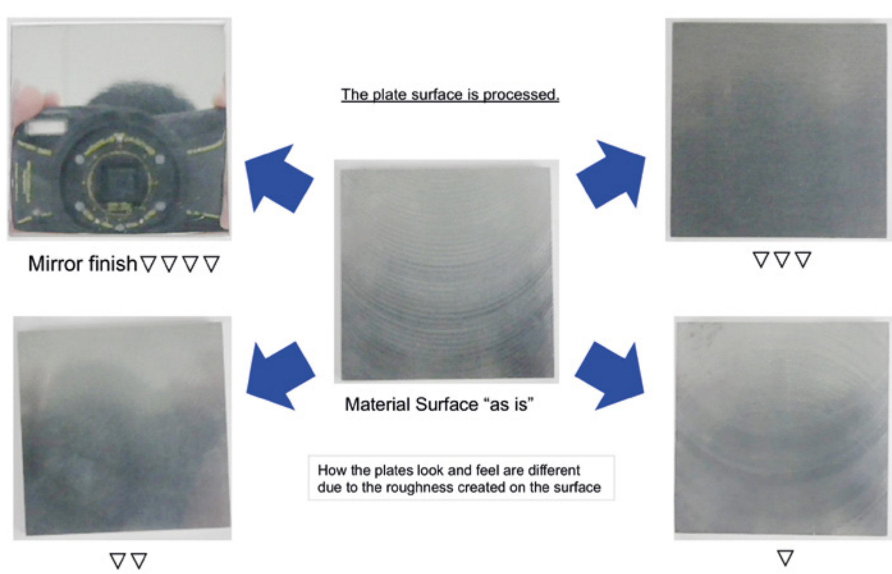
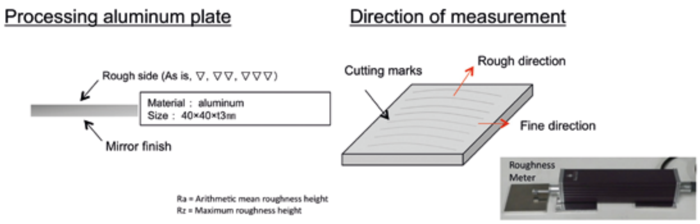


Figure 5. Photos of the five surface roughnesses of the aluminum plates used in the test



Rough process	Actual number [μm]			
	Ra (rough)	Rz (rough)	Ra (fine)	Rz (fine)
▽▽▽▽ (mirror finish)	0.039	0.272	0.026	0.186
▽▽▽ (sub-mirror finish)	0.256	1.549	0.126	0.664
▽▽ (regular finish)	0.741	2.664	0.126	0.649
▽ (rough finish)	1.842	9.391	0.653	3.246
as is	1.362	8.471	0.305	1.453

Figure 6. Details of the Aluminum Plate surface roughnesses and measurements taken

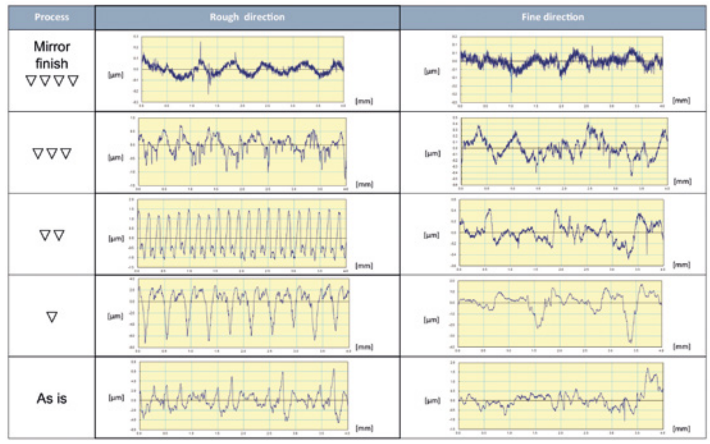


Figure 7. Details of the Aluminum Plate surface roughnesses in the rough and fine directions

ceramic heater, a test was devised (Figure 4) whereby identical plates had varying degrees of roughness etched onto them (Figure 5) and various pressures applied to the test unit while it was heated by a ceramic heater.

Shin-Etsu measured to submicron levels of accuracy the aluminum plate surfaces for four plate smoothness levels. Maximum roughness levels were found to be between 0.2 to 9 microns in height in the samples tested (Figure 6) and actual roughness cross-sections typically showed peaks and troughs illustrative of repeated surface roughness patterns (Figure 7).

Shin-Etsu chose two TIM products, TC-30TAG-8 and TC-100CAF-40 to be applied to the set of aluminum plates to evaluate the influence of roughness. Both materials had similar heat dissipation performance when there was no aluminum plate in position but TC-100CAF-40 had a low hardness (that is, it was relatively soft) and TC-30TAG-8 was of high hardness; see figure 8. There is clearly a small spread in temperature for the plates of different roughness with TC-100CAF-40 in place. However, figure 8 does show a significant difference in temperature due to the different aluminum roughnesses in touch with TC-30TAG-8: the high hardness TIM.

Figures 9 and 10 show the same aluminum plates measured in T3Ster for low and high hardness TIMs at both a high applied pressure (200psi) and a low pressure (75psi). The diagnostic T3Ster structure functions show not much influence due to the difference in roughness with the lower hardness TIM product probably due to less contact heat resistance. With the high hardness TIM product however, heat resistance is different according to the aluminum plate roughness due to the contact heat resistance being larger on the

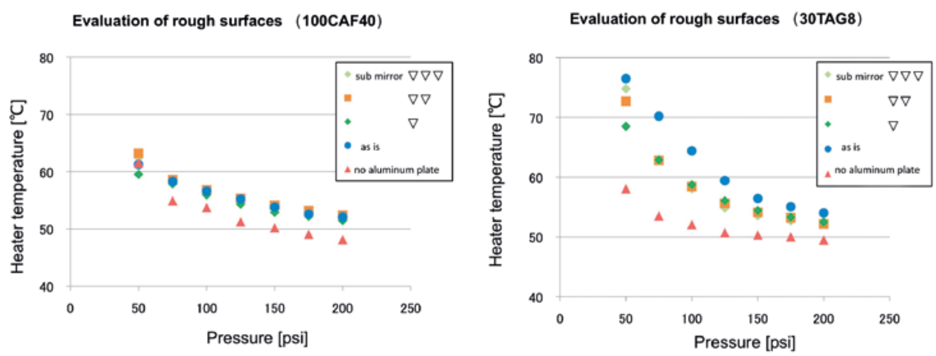


Figure 8. Evaluation of Surface Roughnesses for TC-100CAF-40 and TC-30TAG-8 TIM products heated and under various pressure loadings

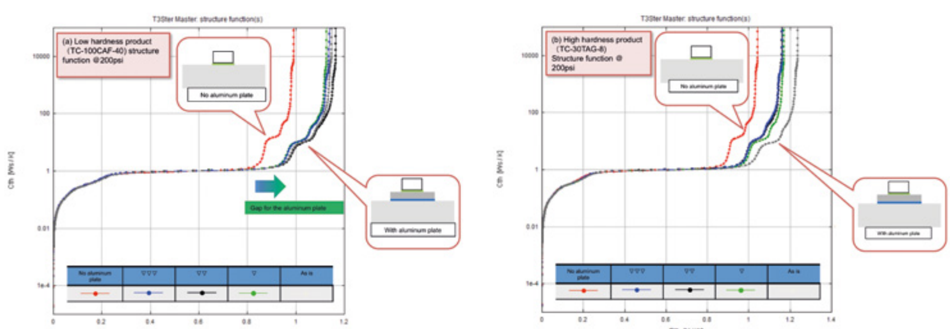


Figure 9. T3Ster Structure Function plots of Low Hardness TC-100CAF-40 and High Hardness TC-30TAG-8 TIM products on aluminum plates of different roughnesses for a 200psi loading

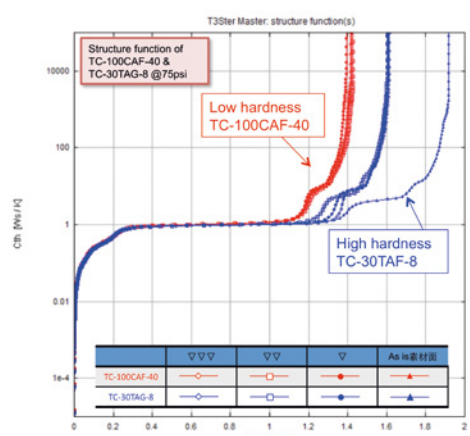


Figure 10. T3Ster Structure Function plots of Low Hardness TC-100CAF-40 and High Hardness TC-30TAG-8 TIM products on aluminum plates of different roughnesses for a 75psi loading

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material surface (Figure 9). When comparing the low pressure to high pressure tests, high and low hardness heat release sheets showed obvious differences in structure function (Figure 10) in "as is" condition.

One conclusion from this study is that figure 11 shows that the aluminum plate surface roughness depths (Ra, Rz) cannot be the sole determinant of a TIM's heat spreading performance; rather, the cross sectional roughness curve of the plate needs to be considered too. Figure 12 illustrates the underlying issues schematically where an off-the-shelf "as is" surface of a typical aluminum plate will have peaks that are erratic and with relatively large distances between them. Hence, with "as is" surface, the more air that enters the gap, the larger the contact heat resistance if compared with other smooth surfaces. Comparing a low hardness heat spreading TIM sheet with a high hardness heat spreading sheet, the low hardness TIM by virtue of its softness can fill the gap caused by the surface's roughness thereby reducing the overall contact thermal resistance. Not surprisingly, the same contact thermal resistance can be reduced by pressurizing a TIM by applying a high pressure (of, say, 200psi).

This experimental study clearly shows that with the help of a Mentor T3Ster™ transient thermal tester, Shin-Etsu are now able to supply their customers much more detailed thermal Data Sheets for their TIM products. This approach is much easier to do than was the case with previous in-house solutions and more automated. The company can assess hardness effects of TIMs much better than before plus T3Ster can give much more diagnostic information on the thermal layers under test in a dynamic manner. In effect, Shin-Etsu can now generate a much richer data set than a few years ago which allows it to produce better TIM products for its customers.

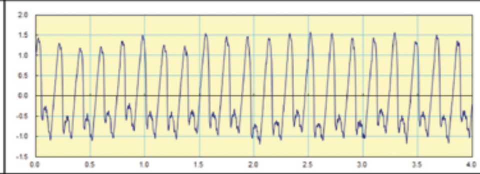
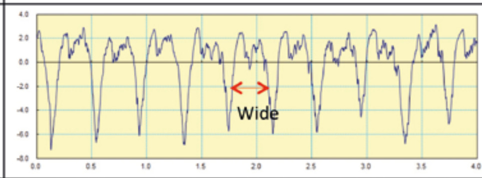
Rough process	Roughness curves	Influence of surface roughness	Characteristics of roughness curves
▽▽		little	· smaller distance · sharp peaks · cyclic nature
▽		little	· wider distance · cyclic nature
as is material surface		more	· wider in distance · no cyclic nature

Figure 11. Typical effects of Surface Roughness Cross sectional curves for rough to smooth plates

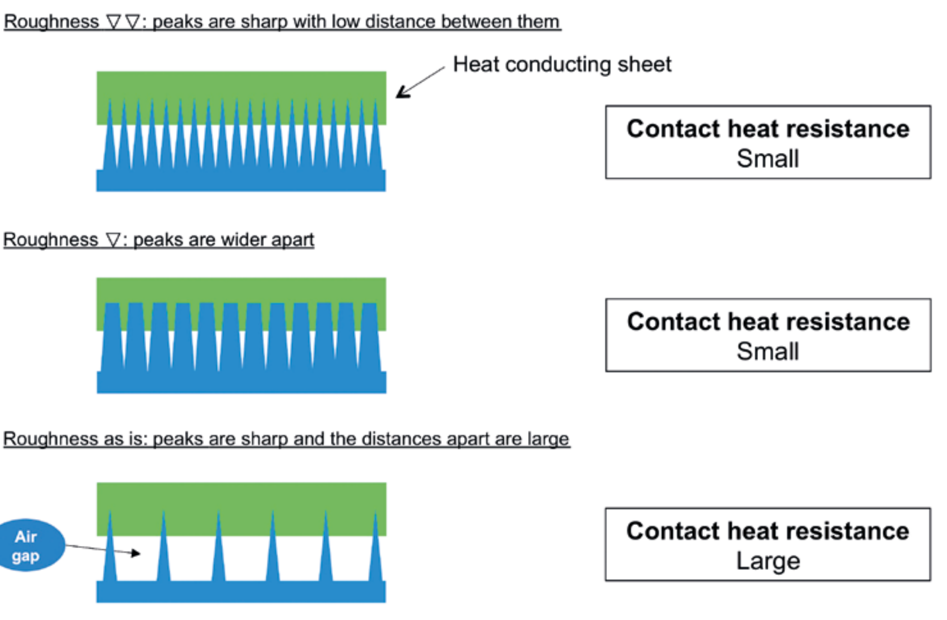


Figure 12. Schematic effects of Surface Roughness Cross sections on resultant surface contact heat resistances

About Shin-Etsu Chemical

Shin-Etsu Chemical Co., Ltd. is the largest chemical company in Japan. Shin-Etsu Chemical produces the key materials that modern industry demands. These business activities are divided into six segments: PVC/Chlor-Alkali Business, Semiconductor Silicon Business, Silicones Business, Electronics and Functional Materials Business, Specialty Chemicals Business and Diversified Business. In each of these fields, they have products with strong market share, with the world's top share in polyvinyl chloride (PVC) and semiconductor silicon and the top domestic share for silicones.

About Shin-Etsu Silicone

In 1953, Shin-Etsu Chemical became the first firm in Japan to venture into the silicones business. In the decades since, Shin-Etsu has created a diverse line of products designed to exploit the unique and useful properties of silicones. Today, their lineup includes over 5,000 products that meet user needs in a wide range of industrial fields, including electrical and electronic applications, automobiles, construction, cosmetics and chemicals.

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