Investigations on thermal contact conductance between filled polymer composites and solids using micro thermography

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Background
When optimising cooling paths in electronic devices, thermal interface materials (TMs) are used to improve the thermal transfer between two solid surfaces. TMs are thermally conductive filled polymer composites. For a good thermal transfer between the solid surfaces not only a high thermal conductivity of the TM but also a high thermal contact conductance between TM and surface is required.

Heat has to pass three thermal resistances connected in serial, see Figure 1. While the bulk resistances can be measured easily, and have been investigated in several studies, thermal contact conductance of filled polymers and solid surfaces have not yet been investigated in detail and just a few experimental results are available.

Approach
Xian et al. [1] published an extensive summary of transient and steady state measurement methods for thermal contact conductance. However, all these studies are used for solid-solid contacts and not resolved spatially. In the presented study we use micro thermography to measure and study thermal contact conductance between filled polymers and solid surfaces on a microscale.

Method and Materials

Multi-layer samples
- Aluminium substrate and filled epoxy composite
- Variation of surface structure, filler size, shape and content
- Steady state thermal measurement
- Sample placed between heated and cooled aluminium bars, see Figure 2
- Measurement of temperature field on sample surface using IR camera
- Heat flow determination with reference temperature measurements in lower aluminium bar
- Calibration of heat flow determination with well known reference sample, see Figure 3

Results
Sample 1: Epoxy unfilled
- Evaluation and Results
- Comparison of results with other methods (thermal conductivity) shows a good agreement
- Additional micro scale simulation approach for further studies
- Particle shapes and surface structure digitised
- Calculation of steady state heat flow through cube-shaped representative volume with \( T = \text{const.} \) boundaries in \( z \)-direction
- Evaluation of continuous thermal insulation along \( z \)-axis
- Good opportunity for investigations on micro scale heat paths, see Figure 9
- Further insights due to even finer local resolution
- Boundary effects in particle arrangement become visible, see Figure 10

Evaluation and Results
- Averaging of temperature field along \( z \)-axis
- Calculation of continuous thermal insulation using temperature data and heat flow, see Figure 4
- Localisation of contacting zones using microscopy images
- Separation of bulk and contact zones
- Linear regression in bulk zone
- Extrapolation to virtual contact \( z \)-levels \( \lambda_{1,2} \) and \( \lambda_{2,3} \)
- Evaluation of contact insulation and contact conductance with \( k_c = \left( \frac{R_{c,2,3} \lambda_{1,3}}{R_{c,1,2} \lambda_{2,3}} \right) \)

Evaluation and Numerical Simulation
- Comparison of measured thermal conductivity
- ASTM D5470: Steady state cylinder method
- ASTM E1461-13: Laser flash analysis (Thermal diffusivity and heat capacity, TC calculated)
- Various samples with different filler materials, sizes and contents
- Overall good agreement, see Figure 8

Conclusion and Outlook
- Smooth transition from substrate to TIM with unfilled epoxy, see Figure 5
- Significant contact resistance with filled epoxy, see Figure 6
- Linear course in bulk section in both cases
- Great variations in contact insulation along \( z \)-axis with filled epoxy, see Figure 7
- Variations caused by random filler and surface structures

Validation and Numerical Simulation
- Additional micro scale simulation approach for further studies
- Particle shapes and surface structure digitised
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References

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