

Development of High Thermal Conductivity Material for Heatspreader

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ABSTRACT

The DC-DC converter is key to developing small, lightweight power control units for Formula One hybrid systems. A new material consisting of a silver-impregnated diamond powder compact, was developed in order to enhance the heat dissipation performance of the DC-DC converter. The coefficient of thermal conductivity of the developed material is three times that of a conventional aluminum material. The use of the silver-diamond composite material in a heatspreader has reduced the temperature increase of the switching elements by 33%, offering a good prospect for the extension of continuous boost from 1.4 to 6.6 seconds, the maximum regulation figure.

1. Background and Aims

From 2009, the use of the Kinetic Energy Recovery System (KERS), a hybrid system for Formula One vehicles, is allowed by Formula One regulations. The KERS systems enable 60 kW of motor power and 400 kJ of regenerated energy to be used per lap to provide boost-up. Extension of the time for which continuous boost can be provided will help in overtaking on the straights, and will increase the degree of freedom in planning race strategies.

The KERS power control unit (PCU) consists of a DC-DC converter (VCU) that controls voltage, and an inverter that controls motor current. The heat load is highest on the switching elements in the VCU, which have a high operating frequency. The project discussed in this paper set out to enhance the heat dissipation performance of the VCU heatspreader in order to increase motor output to the regulation upper limit of 60 kW and enable 6.6 seconds of continuous boost (“full boost”).

2. Developed Technology

2.1. Study of Material

In order to enhance heat dissipation performance, the heatspreader material would be required to display a high coefficient of thermal conductivity and a coefficient of thermal expansion similar to that of the insulating plate of a circuit board. Aluminum nitride (AlN), a material with good thermal conductivity, is used for insulating

Table 1 Properties of materials for heatspreader

Material	Thermal conductivity W/mK	Coefficient of thermal expansion 10 ⁻⁶ /K	Density g/cm ³	Volume fraction of diamond %
Al6063	200	23.4	2.7	–
Ag-CD	630	5.5	6.0	62

plates. If the thermal expansion coefficient of the heatspreader was similar to that of AlN, the buffer used to relieve heat stress could be removed, and thermal resistance would be reduced (Fig. 1). As Table 1 shows, the production of a material from a composite of diamond and silver (Ag), both materials with high coefficients of thermal conductivity, enabled the achievement of a coefficient of thermal conductivity more than three times higher than the conventional material. In addition, the volume fraction of diamond, which has a coefficient of thermal expansion of $1.1 \times 10^{-6} \text{ K}^{-1}$, has been set at 62% in the composite material, giving it a coefficient of thermal expansion of $5.5 \times 10^{-6} \text{ K}^{-1}$, close to that of AlN (Fig. 2).

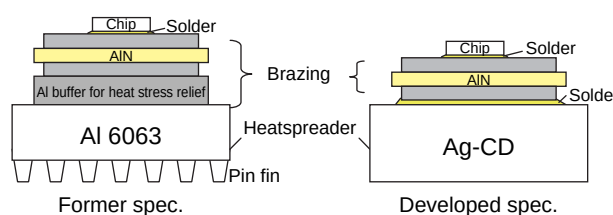


Fig. 1 Cross-section of power device

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2.2. Manufacturing Method for Material

A fine crystalline diamond powder with a mean grain diameter of 0.1 mm was used in order to enable maximal exploitation of the characteristics of diamond, which possesses a high coefficient of thermal conductivity. The diamond powder was pressurized inside the mold to increase the filling factor. The metal was impregnated into the material and a heat treatment was applied to prevent distortion, following which the compact was demolded. Figure 3 shows the microstructure of the Ag-CD material.

2.3. Development of Component

The diamond composite material displays a high level of hardness, making cutting and grinding extremely challenging. Water jet machining was used to drill the through holes used to fit the case and to cut the exterior, procedures which do not require high precision. Electric discharge machining was employed to produce the grooves used for the mounting of the thermocouple, the taper holes and the blind holes, for which precision is essential.

In addition to reducing the coefficient of thermal expansion of the heatspreader, specifications were employed for the potting resin, which gave it a low coefficient of thermal expansion of $10 \times 10^{-6} \text{ K}^{-1}$. No performance decline was observed following tests of thermal shock resistance in power cycle tests.

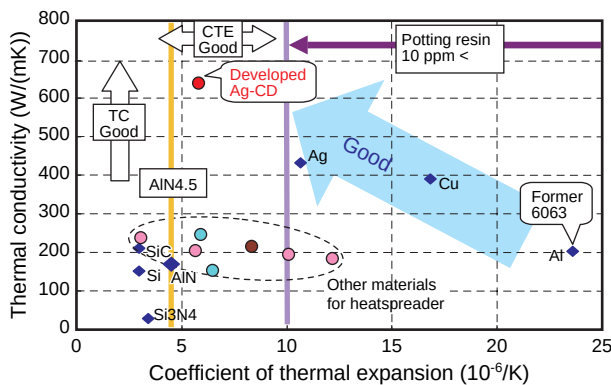


Fig. 2 Thermal conductivity and CTE of materials

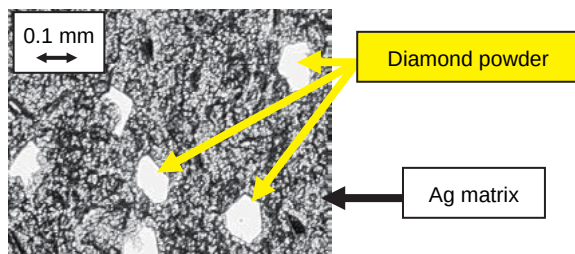


Fig. 3 Microstructure of Ag-CD material

4. Results

Heat dissipation performance was evaluated in thermal resistance tests of prototype power modules using heatspreaders manufactured from Al6063 and the Ag-CD material.

In a comparison using the same finless shape, the temperature increase of the switching elements was 35% lower in the power module using the Ag-CD heatspreader than in the module using the conventional Al6063 heatspreader. As Fig.4 shows, when the developed material was applied in the manufacture of a heatspreader that also incorporated a change in shape, the temperature increase of the switching elements was reduced by 33%. This indicates a solid potential for the extension of continuous boost time from 1.4 to 6.6 seconds per lap ("full boost") at a cooling water temperature of 80 °C or below, as assumed for an entire racing season.

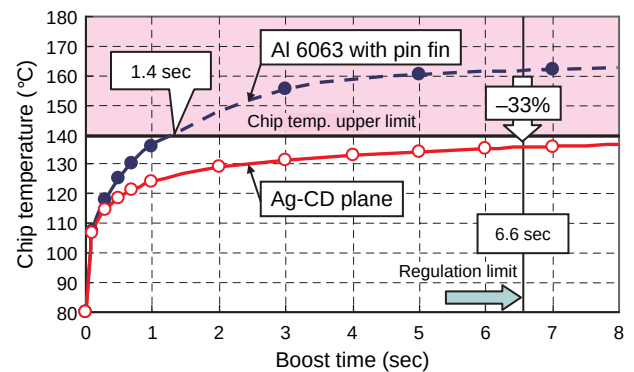


Fig. 4 Chip temperature after boost

5. Conclusion

An Ag-CD material displaying a higher coefficient of thermal conductivity and lower coefficient of thermal expansion than a conventional Al material was developed. The use of the developed Ag-CD material in the VCU heatspreader enhanced heat dissipation performance by 33%, offering good prospects for the ability to provide full boost for 6.6 seconds per lap for an entire racing season.

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