Thermal conductivity of epoxy resin–aluminium (0 to 50%) composites

It is necessary in some electrical applications for a material to be a good electrical insulator, also to have a high thermal conductivity to dissipate heat, and also to have adequate mechanical strength. Technical data shows that Al powder in epoxy resins increases the thermal conductivity [1, 2]. We report here the results of a study on the thermal conductivity of an epoxy resin containing 0 to 50 vol % Al powder.

Araldite MY750 and hardener HT972 resin was used, with CIBA Al powder which was granular with a range of sizes and a maximum diameter of about 75 μm. After the Al was mixed in the resin the system was degassed for 15 min at 10^{-3} mm Hg, then cured 4 h at 80° C and post-cured 3 h at 180° C at atmospheric pressure. Microscopic examination showed the Al to be well dispersed. Specimens were polished flat to a silicon carbide 600 grit paper, checked for being parallel and the thickness measured with a micrometer. A standard Lees' disc apparatus was used to measure the thermal conductivity. Surface finish (final grit size, without and with silver paste to provide a contact surface) and contact pressure (the clamping forces holding the heater, discs, and specimens together) had relatively little effect on the thermal conductivity, but the effect of specimen thickness was significant, probably due to assuming that the emissivities of the Cu disc and the specimen were the same. The effect of contact pressure and specimen thickness are shown in Table I, which also illustrates the good reproductibility. Test conditions were standardised with a medium grit surface finish, a medium contact pressure, and a specimen thickness of 1.52 to 1.78 mm. It was estimated that the errors in the method was about 10%.

TABLE I The effect of contact pressure and specimen thickness on the thermal conductivity ($\mathrm{W\,m^{-1}\,K^{-1}}$)

Pressure	Specimen thickness (mm)		
	1.14	2.36	3.23
high*	0.20	0.25	0.29
low*	0.21	0.26	0.28

* These are the maximum and minimum pressures possible with the clamp holding the specimen in the apparatus.

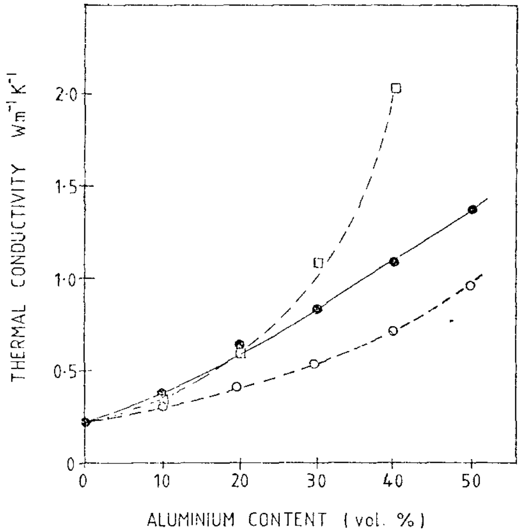

Figure 1 The thermal conductivity of epoxy resin containing 0 to 50 vol % aluminium: ● present results; ○ Maxwell–Eucken relation; □ semi-empirical relation (see text).

The results are shown in the Fig. 1. Each point is an average of 2 or 3 results. Also shown are the calculated results of two models for the thermal conductivity of a two phase system [3], the Maxwell–Eucken relationship and a semi-empirical relationship

$$\lambda^n = V_1\lambda_1^n + (1 - V_1)\lambda_2^n$$

where λ is the thermal conductivity of a composite in which particles of Al (thermal conductivity λ_1 and volume fraction V_1) are embedded in a continuous phase of epoxy resin (thermal conductivity λ_2), with a value of $n = -0.1$ taken from the data. The Maxwell–Euken model is for a uniform size of spheres dispersed in the matrix, and the increased conductivity observed is probably due to the range of sizes of Al used. However, overall, the Maxwell–Eucken relationship was closer to the experimental results than the semi-empirical relationship. Typical thermal conductivities for cast epoxy resin are 0.19 to 0.21 $\mathrm{W\,m^{-1}\,K^{-1}}$ [4] compared to the present 0.20 to 0.29 $\mathrm{W\,m^{-1}\,K^{-1}}$ (see Table I). Air has a much lower thermal conductivity of 0.026 $\mathrm{W\,m^{-1}\,K^{-1}}$ [5]. Cast epoxy resins always contain a significant amount of dissolved air, and it appears probable that the higher conductivity of the present data is due to elimination of part of the dissolved air by vacuum degassing.

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Divalent chromium in alkaline earth silicate systems

Only a few Cr^{2+}-containing oxides, e.g. Cr_2SiO_4 [1], and spinels e.g. $(Mg, Cr^{2+})Cr_2O_4$ [2], are known. Their preparation requires high temperatures and a strongly reducing atmosphere. Some other compounds could only be obtained at non-equilibrium conditions. From the rules for multicomponent system, the addition of acid SiO_2 and the oxides MgO, CaO, SrO and BaO with different basicity and radii of the metal ions seemed to be favourable for the preparation of Cr^{2+}-containing oxides. Cr^{2+} should be more basic than Cr^{3+}, and should have an ion radius greater than Cr^{3+}, which might be advantageous for the substitution of the alkaline earth atoms. In alkaline earth oxide–silica–chromium oxide systems the higher oxidation states of chromium are stable at high CaO, SrO and BaO contents, and low temperatures. Lower oxidation states of chromium therefore could be expected at low content of alkaline earth oxide and high temperatures. The temperature for the occurrence of liquids however decreases in the order $MgO > CaO > SrO > BaO$ especially at a low content of alkaline earth oxide and chromium oxide [4].

Mixtures of reagent grade MeO (Me = Mg, Ca, Sr, Ba), Cr_2O_3 and SiO_2 (from silicic acid) were thoroughly ground under acetone and pre-reacted in air for about 1 h at 1100° C. Small portions of the powder samples were put in fused silica crucibles, equilibrated at high temperatures in vertical molybdenum wound tube furnaces and quenched in water after about 20 min. A short time for equilibration seemed to be essential, because of reaction with the silica crucible and also of the fast volatilization of CrO, which both would change the composition. The strongly reducing atmosphere was attained by a slow current of H_2 which was saturated with H_2O vapour in a temperature controlled water bath.

Cr^{2+} could be identified by the blue colour of the quenched samples depending on the composition, temperature and oxygen partial pressure [3]. It could be most easily obtained in quenched liquids at the conditions listed in Table I.

TABLE I

System	Temperature (° C)	$\log P(O_2)$/atm	Approximate composition (mol %)		
			MeO	"CrO"	SiO_2
$MgO–Cr_2O_3–SiO_2$	1530	−12	42	4	54
$CaO–Cr_2O_3–SiO_2$	1405	−13	36	4	60
$SrO–Cr_2O_3–SiO_2$	1390	−13	31	5	64
$BaO–Cr_2O_3–SiO_2$	1350	−13.5	25	5	70