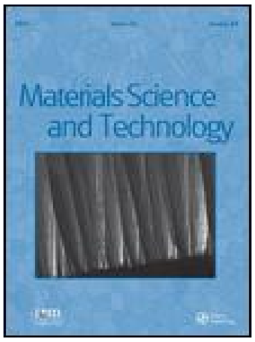

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Thermal contact at solder/substrate interfaces during solidification

S. Nyamannavar and K. N. Prabhu*

Heat flux transients at the solder/substrate interface during the solidification of Sn–37Pb and Sn–3·5Ag solder alloys against metallic substrates were estimated by the lumped heat capacitance model and the contact condition was assessed by scanning electronic microscopy (SEM). Copper substrates yielded maximum contact heat flux followed by brass and aluminium substrates. The SEM study in the solder/substrate interfacial region revealed the existence of a clear gap with the aluminium substrate. A conforming contact was obtained with copper and brass substrates.

Keywords: Solder/substrate interface, Solidification, Heat transfer

Introduction

In soldering, bonding is achieved by wetting of the solder alloy to the base metal and the process involves neither diffusion nor the melting of the base metal.[1] The conditions are similar to the solidification in conventional casting processes. Several researchers, utilising measured temperature in both casting and mould materials, have attempted to measure the interfacial heat flux for metal casting processes.[2–5] The effect of thermal contact heat transfer on the solidification of solder alloys was investigated by Titus *et al.*[6] The results indicated the significant effect of the substrate material on heat flux and metallurgical microstructures. An attempt has been made in the present work to design an experimental set-up to simulate the dip soldering process. The heat flux during solidification at the solder substrate/interface was estimated from the measured temperature history at the geometric centre of the substrate.

Experimental

In the present study, the liquid solder was allowed to solidify around the cylindrical metal probe instrumented with a K type mineral insulated sheathed thermocouple having a diameter of 1 mm. The temperature of the probe, during the solder solidification process, was measured by the thermocouple connected to a data logger (NI SCXI1000) at an acquisition rate of 100 samples per second. The thermocouple response time was found to be 0·1 s. The schematic sketch of the experimental set-up is shown in Fig. 1. The probe diameter was 10 mm and its height was 50 mm. The length of the probe was set at five times its diameter to ensure heat transfer in the radial direction.

Liquid metal was poured into the CO_2 sand mould (25 mm in diameter and 50 mm in height), preheated to about 433–546 K to avoid premature solidification of the solder after pouring. The cylindrical metal probe was coated with inorganic soldering flux (Alfa Aesar, USA) and dipped in liquid solder. The liquid metal was allowed to solidify around the probe. By use of the lumped heat capacitance method, the heat flux $q(t)$ at the surface of the probe was calculated as

$$q(t)=\rho C(R/2)\left(\frac{\mathrm{d}T}{\mathrm{d}t}\right)$$

where, ρ is the density of the probe material, C is the specific heat of the probe material, R is the radius of cylindrical probe, T is the instantaneous temperature of the probe and t is time. Thermal properties of the different probe materials used are given Table 1. Experiments were carried out for Sn-37Pb and Sn-3·5Ag solder alloys solidifying against aluminium, brass and copper probes.

The lumped capacitance model assumes a uniform temperature distribution throughout the body. The assumption is equivalent to saying that the interface resistance is large compared with internal conduction resistance. Such an analysis yields reasonable estimates within about 5% when Biot number defined as

$$Bi=\frac{h(V/A)}{k}<0{\cdot}1$$

is less than 0·1. [7], where h, V, A and k are the heat transfer coefficient at the solder probe interface, volume of the probe, interface area and thermal conductivity of the probe respectively. The Biot number corresponding to peak heat flux was estimated assuming the skin temperature of the solidified skin to be the eutectic temperatures of respective solder alloys. The estimated values of the Biot number for peak heat flux for all the conditions studied are less than the 0·1 (Table 2).

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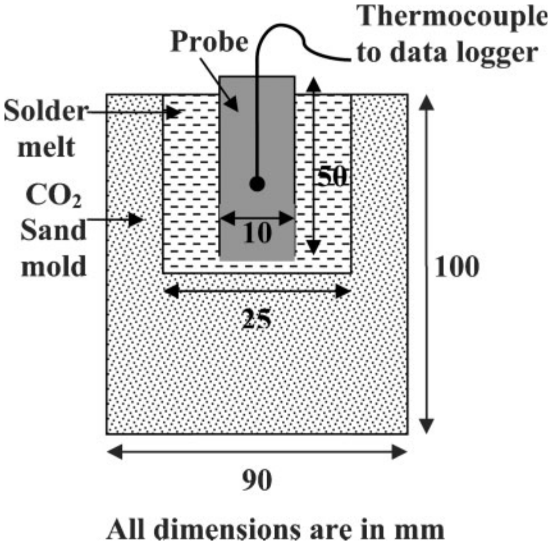


1 Schematic sketch of experimental set-up

Results and discussion

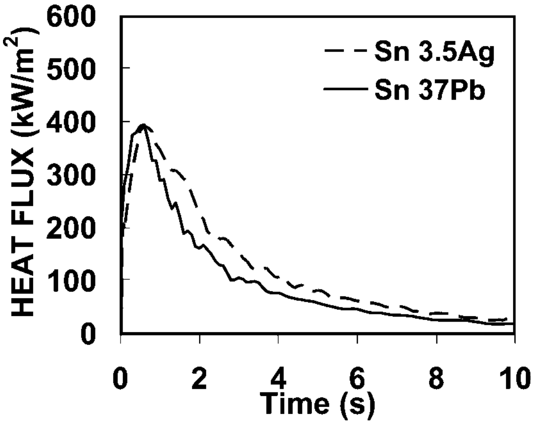
The estimated heat flux transients for both solders solidifying against aluminium, brass and copper are shown in Figs 2, 3 and 4 respectively. The interfacial heat flux rises rapidly, reaches a peak value and then decreases to low values. The initial rise in the heat flux is due to increased melt spread over the probe surface and good contact at the liquid metal/probe interface. With the onset of the solidification, the interface contact begins to change from liquid–solid contact to solid–solid contact, leading to a decrease in the thermal contact conductance. The decrease in the contact conductance coupled with the decreasing temperature difference between the liquid metal and the probe surface results in the decrease in the interfacial heat flux. The peak heat flux value is the highest for copper and the lowest for the aluminium substrate. Brass shows an intermediate peak heat flux value. This trend is observed for both Pb free and Pb based alloys. This is attributed to the better wetting behaviour of copper compared to aluminium and brass.

Micrographs (SEM) at the solder/substrate interface for various conditions studied are shown in Fig. 5. Both solders solidified with an interfacial gap against the aluminium substrate. The gap is much larger (~50 μm) for Al/Sn–3·5Ag solder interface (Fig. 5*d*) compared to the Al/Sn–37Pb interface (~10 μm) (Fig. 5*a*). The microstructure of the Sn–37Pb solder shows an intermixed structure consisting of Pb rich and Sn rich phases. The microstructure of Sn–3·5Ag consists of Ag_3Sn particles dispersed in the Sn rich matrix.

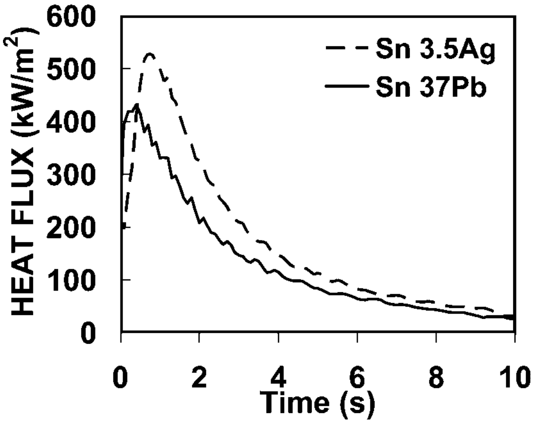
There is no significant difference in the peak heat flux value for Sn–3·5Ag and Sn–37Pb solder alloys solidifying against the aluminium substrate. The peak heat flux value of 527 kW $m^{-2}$for Sn–3·5Ag solidifying against

Table 1 Thermophysical properties of probe materials[8]

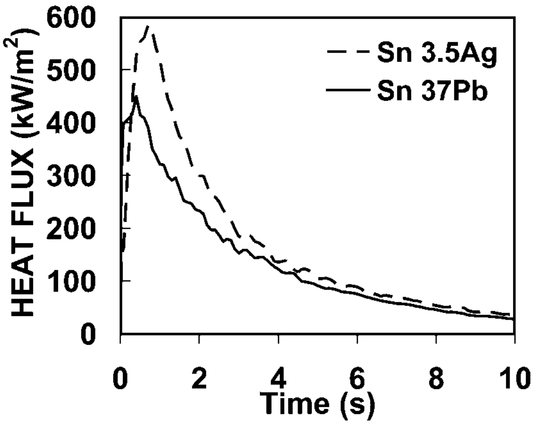
Probe material	Density, kg m^{-3}	Specific heat, J kg^{-1} K^{-1}	Thermal conductivity, W m^{-1} K^{-1}
Aluminium	2698	900	237
Brass	8400	390	127
Copper	8920	380	398



2 Evolution of interfacial heat flux for aluminium substrate and different solders



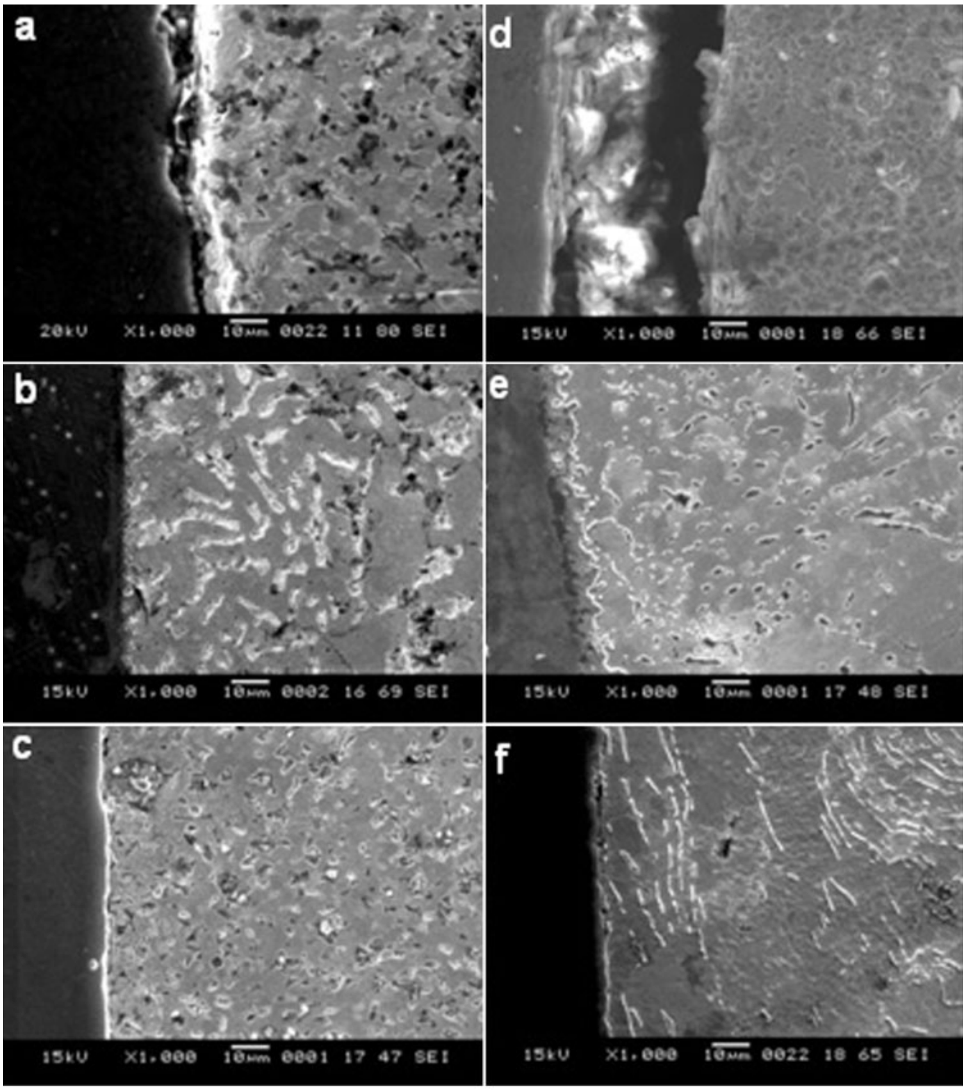
3 Evolution of interfacial heat flux for brass substrate and different solders



4 Evolution of interfacial heat flux for copper substrate and different solders

Table 2 Biot number at peak heat flux for various solder/substrate interfaces

	Substrate material		
Solder	Al	Brass	Cu
Sn–3·5Ag	0·03	0·06	0·02
Sn–37Pb	0·03	0·07	0·02



a Al/Sn–37Pb; *b* Brass/Sn–37Pb; *c* Cu/Sn–37Pb; *d* Al/Sn–3·5Ag; *e* Brass/Sn–3·5Ag; *f* Cu/Sn–3·5Ag

5 Micrographs of solder/substrate interfaces

brass is higher compared to the peak heat flux value of 431 kW m^{-2} for Sn–37Pb alloy. Similarly, the peak heat flux value of 584 kW m^{-2} for Sn–3·5Ag solidifying against the copper substrate is higher compared to the peak heat flux value of 449 kW m^{-2} for Sn–37Pb solder alloy. The temperature of the liquid solder that forms initial contact with the substrate surface is higher in the case of Sn-3·5Ag as compared to Sn-37Pb owing to its higher eutectic temperature. The temperature difference between the substrate and liquid during the initial 2–3 s is higher for Sn–3·5Ag alloy. However, this difference is not observed when an aluminium probe is used. This due to the fact that both solder materials poorly wet aluminium resulting in the formation of an interfacial gap during the solidification of the solder (Fig. 5*a*). The gap is much wider for the interface between aluminium and Sn–3·5Ag solder (Fig. 5*d*). The larger gap size indicates that the wettability of Sn–3·5Ag solder for the aluminium surface is poor and worse than the Pb based solder. With increase in the gap width, the thermal resistance across the solder/probe interface increases. Hence the magnitude of the peak heat flux value is similar although the temperature difference ($\sim$190 K) between the aluminium probe and the Sn–3·5Ag solder liquid is higher compared to the temperature difference between the aluminium probe and the Sn–37Pb solder liquid.

Conclusions

Contact heat transfer during the solidification of solders is significantly affected by the substrate material and solder alloy. For the non-wetting aluminium probe, there was no significant difference between the contact heat flux obtained with both solder materials. The SEM study revealed the presence of a clear gap at the solder/aluminium interface and a conforming contact solder/copper and solder/brass interfaces.

Acknowledgement

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References

1. H. H. Manko: 'Solders and soldering', 3rd edn, 1; 1992, New York, McGraw-Hill Book Co.

2. C. A. Muojekwu, I. V. Samerasekara and J. K. Brimacombe: *Metall. and Mat. Trans. B*, 1995, **26B**, 361–382.
3. K. Ho and R. D. Pehlke: *Metall. Trans. B*, 1985, **16B**, 585–596.
4. T. S. P. Kumar and K. N. Prabhu: *Metall. Trans. B*, 1991, **20B**, 717–727.
5. W. D. Griffiths: *Met. and Mat. Trans. B*, 1999, **30B**, 473–482.
6. T. Chellaih, G. Kumar and K. N. Prabhu: *Mat. Des.*, 2007, **28**, (3), 1006–1011.
7. J. P. Holman: 'Heat transfer', 9th edn; 2002, New Delhi, Tata McGraw-Hill.
8. D. R. Poirier and G. H. Geiger: 'Transport phenomena in materials processing'; 1994, Warrendale, TMS.