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A Review of Thermal Control Materials for Metallic Junctions

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Theme

THE use of thermal control materials, or interstitial materials, appears to be one of the most promising methods for the control of heat transfer in the metallic joints of spacecraft structures and electronic equipment. The thermal conductance of a metallic joint, including a thermal control material, provides a measure for rating the effectiveness of the material for thermal control. In order to make a direct comparison between the contact conductance of thermal control materials determined in previous experimental investigations of joint conductance, a dimensionless parameter incorporating the thermal conductance has been formulated. This dimensionless parameter is applied to the results of previous investigations to illustrate the relative effectiveness of a range of thermal control materials.

Contents

In order to evaluate the merits of thermal control materials for spacecraft applications, some measure of their relative effectiveness is needed. Since it is not possible theoretically to predict the thermal conductance (or effectiveness for thermal control) of each material, this value must be determined experimentally. Most experimental conductance data for interstitial materials are presented relative to the conductance of the same metallic junction without a material filler. Hence, both of these conductance values were used in the development of a new dimensionless parameter for comparison of the effectiveness of the thermal control materials. The uncompressed or initial thermal control material thickness and a surface parameter, or equivalent gap thickness, for the metallic junction were also incorporated in this parameter.

Definition of a surface parameter or an equivalent gap thickness for metallic junctions has been one of the major problems in analyzing thermal contact conductance data. One measure of the equivalent gap thickness which has met with some success, has been reported by Fletcher and Gyorog.[1] This parameter was defined in terms of the normally measured rms roughness (*RD*) and flatness deviation (*FD*) for the rough surface (*rs*) and smooth surface (*ss*) and may be written as

$$\delta_0 = 20.45 + 8.06 \times 10^{-2}d - 1.58 \times 10^{-5}d^2 + 1.36 \times 10^{-9}d^3 - \cdots$$

where

$$d = (FD + 2RD)_{rs} - \tfrac{1}{2}(FD + 2RD)_{ss}$$

This equivalent gap thickness provides a relative measure of the metallic junction surface condition of the test specimens used in the reviewed investigations.

The dimensionless conductance (η), then, is defined as the ratio of the thermal control material (tcm) conductance and uncompressed thickness (t) and the metallic junction (mj) conductance and equivalent gap thickness (δ_0). This dimensionless conductance may be written as

$$\eta = (h_c t)_{tcm}/(h_c \delta_0)_{mj} = k_{\mathrm{eff}}/h_c \delta_0$$

where k_{eff} is an effective thermal conductivity for the thermal control material.

The dimensionless conductance approaches zero as the effective thermal conductivity of the material becomes small, and becomes zero when the effective conductivity is zero. A dimensionless conductance of zero implies that there is an infinite resistance to heat transfer. Low values of the dimensionless conductance, then, are representative of good thermal isolation materials. When the contact conductance of a joint becomes large with respect to the bare metallic junction conductance, the dimensionless conductance becomes large. Large values of dimensionless conductance, then, are representative of good thermal enhancement materials.

Thermal control materials may be divided into several different classes, depending upon their physical and chemical composition. For purposes of this analysis, major classifications were selected as: 1) Synthetics and processed natural sheets (including mylar, teflon, rubber, mica, etc.); 2) Ceramic sheets and powders (such as magnesia, zirconia, beryllia, etc.); 3) Metallic foils and screens (such as stainless steel, lead, indium, etc.); 4) Greases and oils (including silicone grease, impregnated greases, petroleum products, etc.).

Most of these materials are suitable for some form of thermal control; however, their mechanical the thermophysical properties restrict their application. The low conductance interstitial materials generally are representative of categories 1 and 2, and high conductance materials generally are representative of categories 3 and 4. It should be pointed out, however, that there are exceptions in every category.

The previously defined dimensionless conductance enables a realistic comparison of the effectiveness of these materials. The use of this dimensionless conductance to compare published data for selected thermal control materials[2–7] is shown in Fig. 1. Because the actual thicknesses of grease and oil interstitial films under load are extremely difficult to measure, these materials have not been included in the comparison.

Decreasing dimensionless conductance in Fig. 1 implies increasing effectiveness for thermal isolation applications in structures. It may be noted that as the apparent contact pressure is increased from 100–300 psi, the variation between materials diminishes. If the apparent contact pressure were increased to an even higher value, the differences in effectiveness of the various materials would become negligible.

The conductance values for the materials shown in Fig. 1 were measured at a mean junction temperature of approximately 200°F. Some materials have also been tested at low temperatures (−120°F) to ascertain the effect of temperature on their thermal isolation characteristics.[5] The dimensionless conductance decreased with decreasing temperature in all cases. This effect, generally due to the temperature dependence of the interstitial material properties, indicates that the effectiveness of the material for thermal isolation increases as temperature decreases.

The dimensionless conductance has resulted in a general rating of these materials as follows: $\eta = 1$–10, excellent thermal isolation qualities, weak to moderate compressive strength, light weight, reasonably durable; $\eta = 10$–100,

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Index categories: Spacecraft Temperature Control Systems; Heat Conduction.

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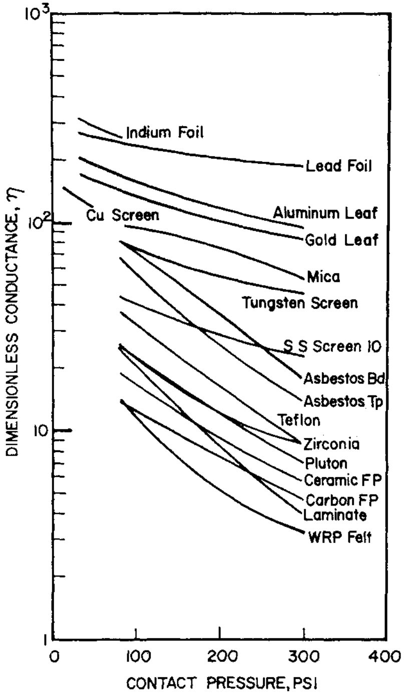

Fig. 1 Comparison of dimensionless conductance for selected thermal control materials in aluminium joints in a vacuum environment (Data from Refs. 2-7).

medium thermal isolation qualities, good compressive strength, medium to heavy weight, excellent durability; $\eta = 100$–1000, good thermal enhancement qualities, good compressive strength, medium to heavy weight, reasonably durable. Although a majority of the materials reviewed do fit these classifications, there are exceptions to these rating categories.

Additional investigations of the thermal conductance of other joint fillers such as conducting polymers, densified quartz, multilayer insulations, and new heat transfer cements would make possible an even more thorough evaluation of the relative merits of interstitial materials for thermal control applications. Yet even with the limited data currently available, the advantages of the thermal contact conductance phenomena, with and without interstitial materials, should be considered in the analysis and design of thermal control systems.

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