# IMPROVEMENT OF TEMPERTURE RESISTANCE OF Al-Mg/$Al_2O_{3P}$ COMPOSITE BY COATING WITH ANTIMONY TRIOXIDE FILM

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**Abstract**

Aluminum matrix composites $AMC_S$ with 10 wt % $Al_2O_3$ particles with average size (3.86 µm) were fabricated by stir casting method, then the composite produced coated with Antimony Trioxide ($Sb_2O_3$) by hot dipping coating process. Thermal conductivity of composite materials with and without coating was estimated by applying Fourier equation to investigate its behavior under different temperature conditions. Results revealed that coating with antimony trioxide decreased the thermal conductivity (k) of composite material. The thermal conductivity of the master composite material was (207 W/m°C) at (80 °C) and (182 W/m°C) of the coated composite material at same temperature.

**Keywords: Aluminum Matrix Composite, Antimony Trioxide, Thermal Conductivity, Temperature Resistance.**

# تحسين مقاومة درجة الحرارة للمواد المتراكبة (Al-Mg/$Al_2O_{3P}$) بطلائها بطبقة من اوكسيد الانتيمون الثلاثي

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**الخلاصة**

صنعت المواد المتراكبة المعدنية ذات أساس الألمنيوم $AMC_S$ من جزيئات اوكسيد الألمنيوم($Al_2O_3$) بنسبة(10 wt %) ومتوسط حجم حبيبي(3.86 µm) باعتماد طريقة السباكة بالمزج(Stir casting) , بعدها تم طلاء المادة المتراكبة الناتجة باوكسيد الانتيمون الثلاثي باعتماد طريقة التغطيس الحار(Hot dipping) , حسبت الموصلية الحرارية(Thermal conductivity, k) باعتماد معادلة فورير, فأظهرت النتائج بان طبقة الطلاء باوكسيد الانتيمون تعمل على تقليل الموصلية الحرارية للمادة المتراكبة حيث كانت قيمة الموصلية الحرارية للمادة المتراكبة الأساس هي ( 207 W/m˚C) عند درجة حرارة (80°C) بينما قيمتها للمادة المتراكبة المطلية هي (182 W/m˚C ) عند نفس الدرجة الحرارية.

## Introduction

High-performance thermal materials, which are at various stages of development, fall into five main categories: monolithic carbonaceous materials, metal matrix composites (MMCs), carbon/carbon composites (CCCs), ceramic matrix composites (CMCs) and polymer matrix composites (PMCs) (3 ،8 ،10).

A metal matrix composite ($MMC_S$) is a material with at least two constituent parts, one being a metal, the other material may be a different metal or another material, such as a ceramic or organic compound. When at least three materials are present, it is called a hybrid composite.

MMCs are made by dispersing a reinforcing material into a metal matrix, the matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, the matrix is usually a lighter metal (low density metals, and lower coefficient of thermal expansion), such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. The reinforcement material is embedded into the matrix, used to change materials properties such as wear resistance, friction coefficient, or thermal conductivity (Surappa, 2003).

One of the common methods of manufacturing of MMC materials is Stir casting; discontinuous reinforcement is stirred into molten metal, which is allowed to solidify (liquid state methods) (Surappa, 2003).

Dip coating techniques can be described as a process where the substrate to be coated is immersed in a liquid and then withdrawn with a well-defined withdrawal speed under controlled temperature and atmospheric conditions. The coating thickness is mainly defined by the withdrawal speed, the solid content and the viscosity of the liquid. If the withdrawal speed is chosen such that the sheer rates keep the system in the Newtonian regime, The thickness of coating depend on thickness of the piece, and temperature of the piece at the moment of dipping, the coating thickness slightly varied from 150 µm to 400 µm(Schmidt, 2000).

The interesting part of dip coating processes is that by choosing an appropriate viscosity. The schematics of a dip coating process are shown in **Figure 1**.

The famous application of antimony trioxide is a flame retardant for wide range of plastics, rubbers, papers, and textiles (Alexander, 2007، Heinrich,2000), it is white, granule structure, high efficiency, less toxicity and environmental clean, also it is consider odorless white crystalline powders, stable under ordinary conditions, and slightly stable in water (www.antimony-cn.com.). **Table (1)** shows some of the properties of antimony trioxide (from the product).

Heinrich, H. and Stefan, P.(Heinrich,2000) tried to improve the thermal properties of FRP composite by using a sodium silicate and vermicular film coating as a flame retardant materials., but Ali (Ali, 2003) studied the effects of adding (10, 20, 30 wt %) of a flame retardant materials (Antimony Trioxide) on thermal properties (thermal conductivity, heat capacity, and flame resistance) of glass fiber reinforced polyester composite materials and he concluded the thermal conductivity results were (1.41 W/m.˚C),and (1.136 W/m.°C) at (55°C) for with and without (30% $Sb_2O_3$) addition respectively. Despite the availability of some studies(2،5 ،6 ،7) for improving the thermal properties of composite materials, but all of these studies were applied on polymer matrix composites, while the present study aims to study the effect of the coating film of $Sb_2O_3$ on some of thermo physical properties of aluminum metal matrix composite as a trial to improve it's ability to withstand various temperature to be suitable for using in application of automotive engine parts.

**Experimental Details:**

**1. Preparation of the Composite Materials:**

The initial metal alloy (Al-3Mg) was prepared by melt a (500g) of aluminum foils (purity 99.99%) with a (3wt% of magnesium) according to center of vortex and mixing for (3-5 min) by (Heidolph Mixer type/Germany) with speed 420 rpm, after the initial alloy was prepared directly it dispersed (by stir casting route) with aluminum oxide particles ($Al_2O_3$) with average particle size (3.86 μm) and (10 wt%) at mushy state (Eutectic Point) at 645°C, and then it cast into cylinder ingots of (25 mm diameter and 30 mm in length) at mild steel molds.

**2. Preparation of the Testing Specimens**:

In this study a film of antimony trioxide ($Sb_2O_3$) would coated on surface of aluminum matrix composite by hot dip process under certain conditions of temperature for the sake of improving the thermal properties of composites, cylindrical specimens whose dimensions were (25 mm in diameter and 30 mm in length) were obtained to be as a sample for coating process, these samples were clean out, polished, and immersed by (20%HCL solution) for five minutes (it's weight 37.0008 grams),and then it heated for 300 °C (by careful control of thermal balance external heating of the molten metal may even be eliminated), and finally it immersed directly in the hot antimony molten bath (750 °C) for a minute, and it has been leaving inside the oven even it cool down and oxidation process was done. After three or four stages preparative treatment, some slight film would remain after oxidation (with weight 37.8014 grams); the thickness of ($Sb_2O_3$) film was measured using the difference between densities, as shown in equation (1) below (George, 2002):

$$\rho = M / V \qquad (1)$$

ρ: density of the part ($g/mm^3$).

M: Mass of the cylinder (g)
V: volume of the part ($mm^3$).

**3. Thermo physical Testing:**

Some of the thermo physical properties (density, thermal conductivity, and thermal resistivity) of aluminum matrix composite before and after coating with antimony trioxide film were measured to investigate the effect of coating on thermal properties of ($AMC_S$): density of $MMC_S$ material can be determined by simple using the relationship between volume and mass or by (Archimedean density), the equation (1) above.

Thermal conductivity can be measured by comparative method with steady state longitudinal heat flow in a temperature, the comparative instrument measures that flow based upon the known thermal properties of standard reference materials, thermal conductivity test specimen is sandwiched between two identical reference samples; this stack is placed between two heating elements controlled at different temperature. **Figure 2** shows the thermal conductivity measurement device.

Thermal conductivity coefficient (K) can be calculated from the expression below (Fourier Low) (George,2002):

$$K= \frac{.Q}{A.} \cdot \frac{\Delta T}{L} \quad \ldots\ldots \quad (2)$$

K: Thermal conductivity coefficient (W/m.°C).
Q: Heating power of the heater (KW).
ΔT/L: Temperature gradient across the stack measured by thermocouple.
L: Length of the specimen (cm).
ΔT: Temperature difference between heater and heat sink (°C).
A: Cross section area of the specimen ($cm^2$).

Thermal Resistivity coefficient (1/K) of $MMC_S$ measures during taking the thermal conductivity reverse.

**Results and Discussion:**

An antimony trioxide film with a thickness (313 µm) was coated on aluminum matrix composite ($AMC_S$) by using hot dip coating process to improve the thermal behavior, some of thermo physical properties (density, thermal conductivity, and thermal resistivity) of (Al-Mg/10$Al_2O_3$) were measured ,the density of (Al-Mg/10$Al_2O_3$) was (2.5125 g/$cm^3$), and the density of antimony powder was (6.684 g/$cm^3$), while the density of composite material with coating by antimony trioxide was (2.5403g/$cm^3$).
**Figures 3** and **4** show the relationship between various temperature (80-110°C), and values of thermal conductivity (k) of $AMC_S$ before and after coating by $Sb_2O_3$ film, the thermal conductivity of the master composite material would increase when values of temperature are increased, where the conductivity of $AMC_S$ was ( 207 W/m.°C) at (80 °C) and it became (234 W/m.°C) at 110 °C, while the

effective of $Sb_2O_3$ coating was decreased the thermal conductivity of composite to (182 W/m.°C) and to (228 W/m.°C) at 80 °C and 110°C respectively, because the antimony trioxide (as a flame retardant) does as a trapping of the entire temperature.

**Figures 5** and **6** show the relationship between the temperature and thermal resistivity (1/k); we can see the decreasing of the thermal resistivity of $AMC_S$ with increasing of the temperature, and also the effective of $Sb_2O_3$ film was decreased the heat transmission.

**Conclusion:**

The results of coated of ($AMC_S$ / Al-Mg/$Al_2O_3$) by an antimony trioxide ($Sb_2O_3$) as a flame retardant material revealed, the coated film was improved the temperature resistance and reduced the thermal conductivity of ($AMC_S$).

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Table (1): Some Properties of Antimony Trioxide ([www.antimony-cn.com)

| Formula | Molecular Weight | Melting Temperature | Boiling Temperature | Specific gravity |
|---|---|---|---|---|
| $Sb_2O_3$ ($Sb_4O_6$) | 291.52 | 652 °C | 1570 °C | 5.2 g/mm$^3$ |

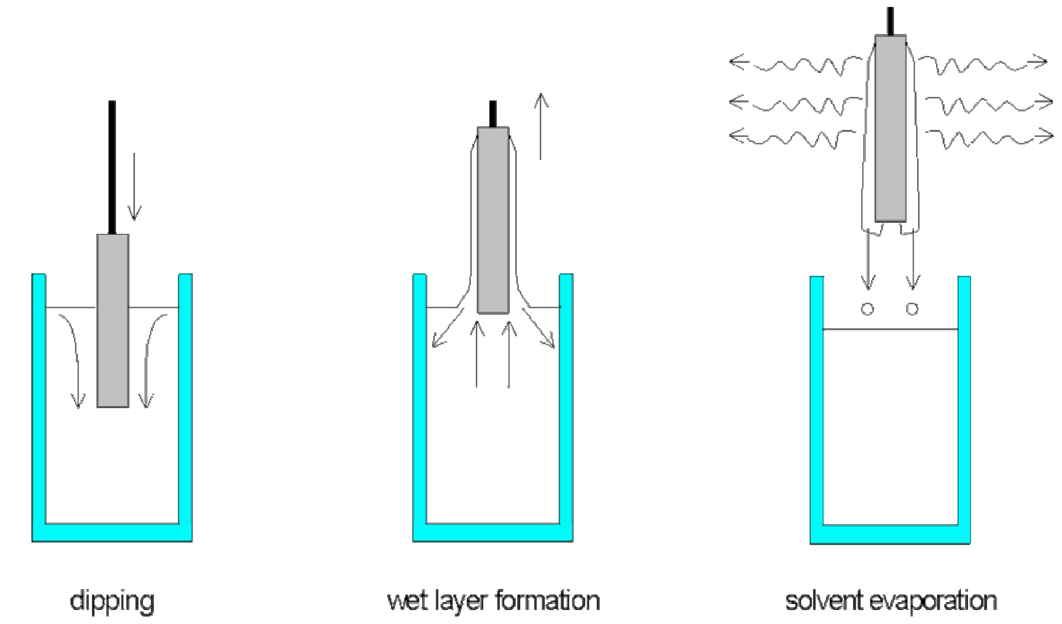


**Fig.(1) :Stages of the dip coating process: dipping of the substrate into the coating solution, wet layer formation by withdrawing the substrate and gelation of the layer by solvent evaporation (Schmidt,2000)**


**Fig 2: Thermal Conductivity Measurement Device**

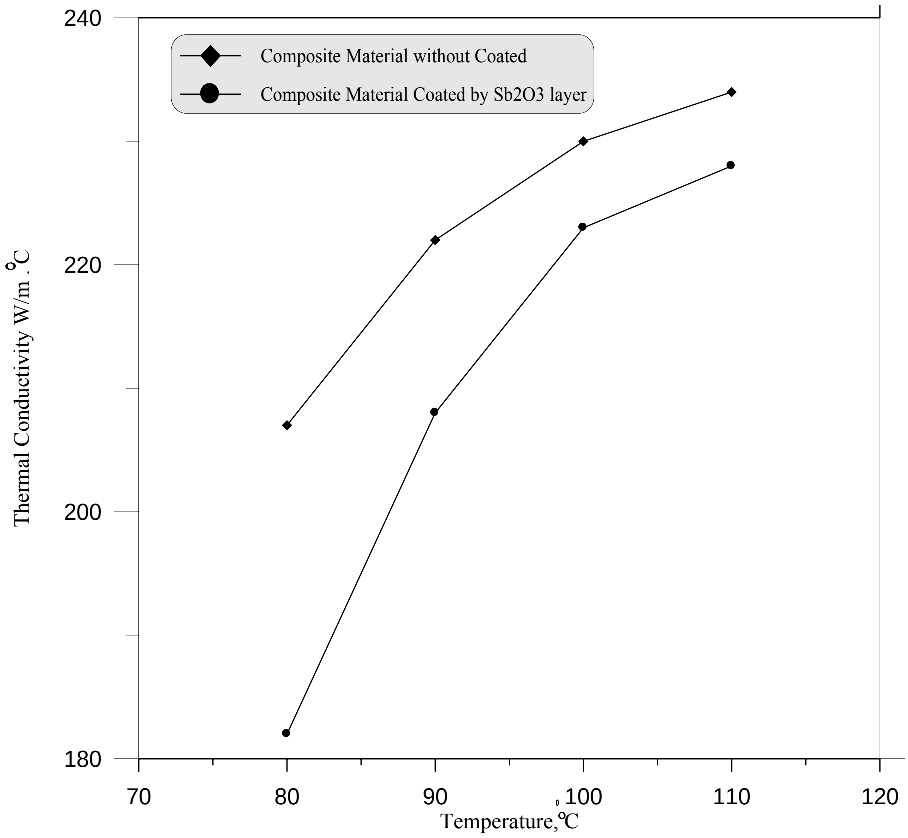


**Fig. (3): The relationship between the temperature and thermal conductivity (k) of AMC$_S$ with and without coating by $Sb_2O_3$**

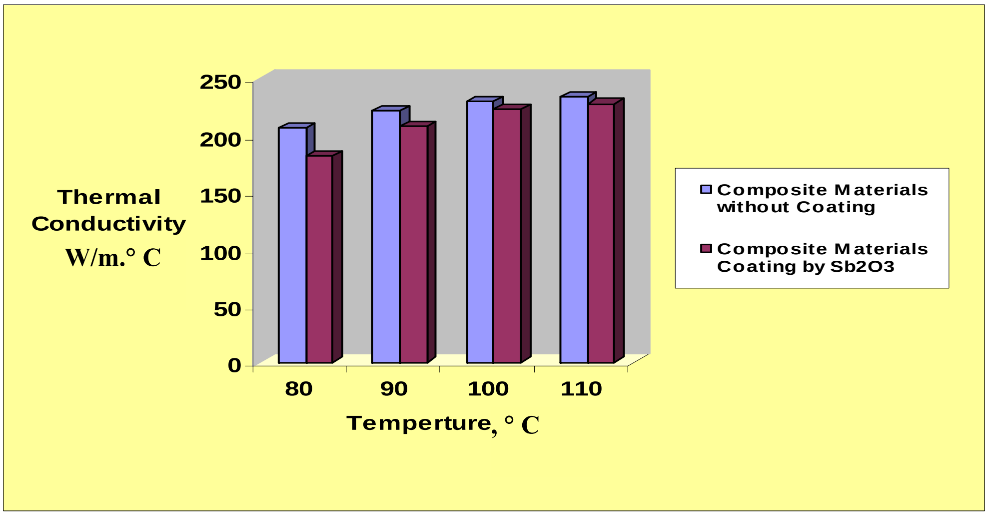


**Fig. (4): The relationship between the temperature and thermal conductivity (k) of AMC$_S$ with and without coating by $Sb_2O_3$**

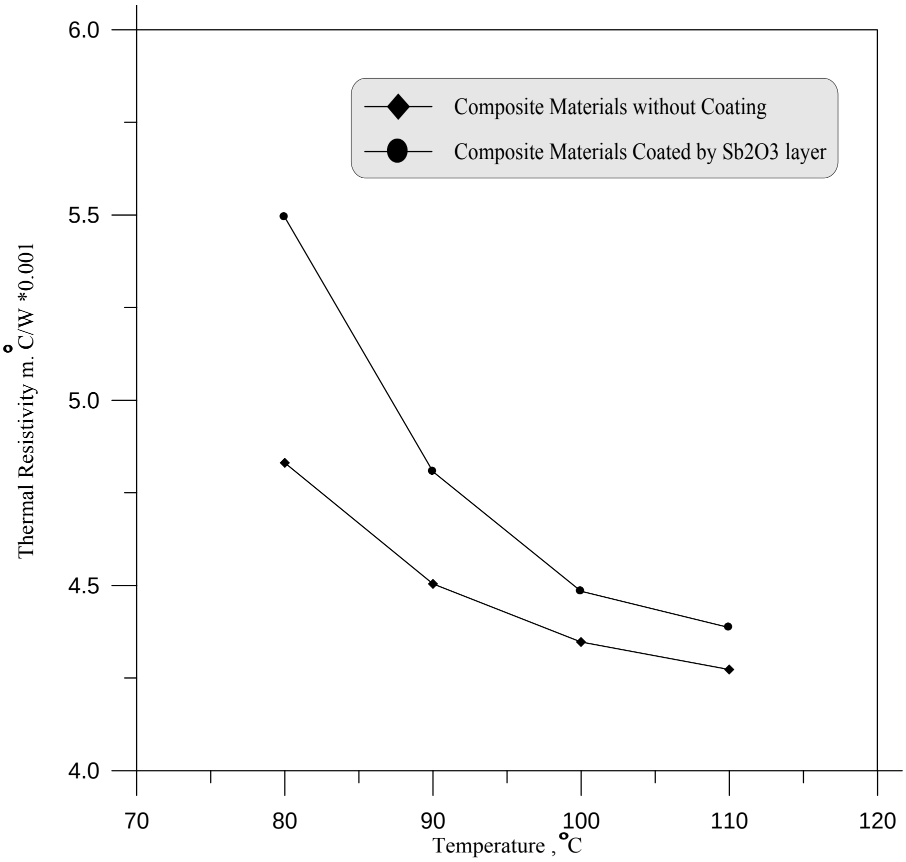


**Fig. (5): The relationship between the temperature and thermal resistivity (1/k) of $AMC_S$ with and without coating by $Sb_2O_3$**

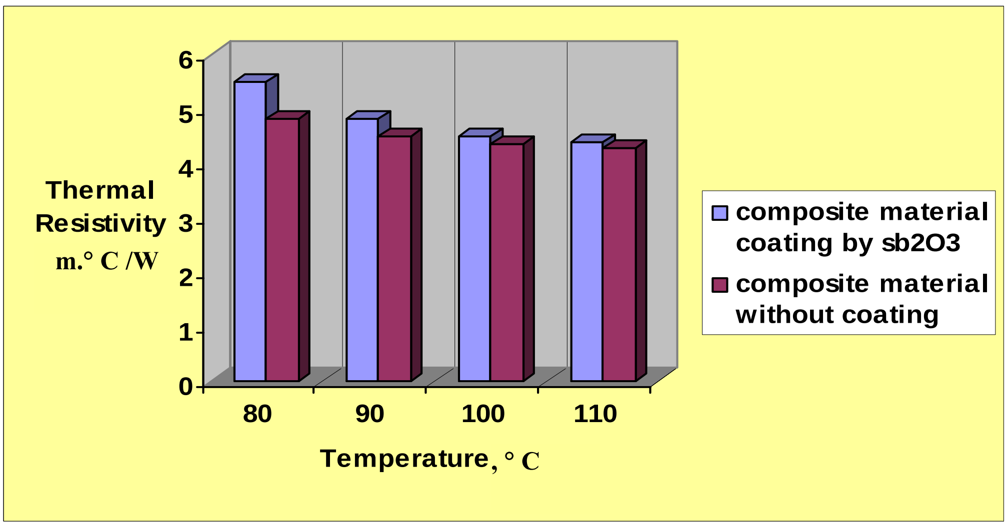


**Fig. (6): The relationship between the temperature and thermal resistivity (1/k) of AMCS with and without coating by $Sb2O_3$**