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# Supersonically sprayed thermal barrier layers using clay micro-particles

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ABSTRACT

Several clay minerals were supersonically sprayed onto flexible substrates to form highly thermally and electrically insulating materials which could be wrapped onto protected surfaces. Among these clay minerals, montmorillonite (Mt) revealed the best thermal insulating properties.



## 1. Introduction

Thermal barrier coatings (TBC) are widely used in gas turbines and power generators to increase their efficiency by thermally insulating metal components in the hot section (Evans et al., 2001). These coatings are advantageous because of their ability to endure at high thermal gradients. Lowering temperature of metal substrate prolongs the life of the component by protecting it against environmental attack, creep fracture, or fatigue. For turbines and high-temperature engine parts, only Ni-based super alloys can be used, and the temperature of hot gas in engines exceeded the melting point of these alloys (Schulz et al., 2003). Demand for TBC materials with better thermal insulation is growing. TBC are also used to insulate electric cables with metal cores such as copper shields with plastic jackets made of various polymers for electrical insulation. These jackets may melt because of heat or fire. Thus, a TBC is needed between the core and the plastic jacket, and also for the outer encapsulation, as reported by Woodland et al. (1967) and Elliott and Baltimore (1970).

There are two ways to improve thermal insulation: increasing the insulation layer thickness and/or searching for new materials with lower thermal conductivity and diffusivity.

A variety of materials have been investigated as potential candidates for TBC. Several ceramic coatings such as $Al_2O_3$, $TiO_2$, yttria-stabilized zirconia (YSZ), $ZrO_2$ have exhibited the best performance in terms of insulation and have been well studied. Selection of TBC materials depends on some requirements: (1) high melting point, (2) no phase change between room temperature and operation temperature, (3) low thermal conductivity and diffusivity, (4) chemical inertness, (5) similar thermal expansion as that of metallic substrate, (6) good adherence to the metallic substrate, and (7) low sintering rate of the porous microstructure (Cao et al., 2004).

Plasma spray is commonly used for depositing TBC, and mainly ceramics such as $Al_2O_3$, YSZ, and $ZrO_2$ have been reportedly deposited (Schulz et al., 2003; Curry et al., 2011). The cold spray technique is used for deposition of the above-mentioned ceramics (Lee et al., 2005) and thermally grown oxides for bond coatings (Li et al., 2010).

The cold spraying technique facilitates acceleration of coating particles up to supersonic speeds. This coating method is rapid and scalable, which will thereby enable large-scale roll-to-roll manufacturing, as shown in Fig. 1. The sprayed particles have high kinetic energy such that they flatten on impact and adhere strongly to the substrate(Kim et al., 2015). In this work, supersonic spray method has been used for deposition of thermal barrier coatings from clays and clay minerals such as bentonite, kaolinite, and montmorillonite. Clays and clay minerals show good thermal insulation (Cetin et al., 2014; Pelot et al., 2015) and low thermal conductivity and diffusivity (Table 1). Clays and clay minerals are attractive coating materials because of their abundance in nature and low toxicity. Clays and clay minerals have been compounded in nanocomposites with some polymers using the

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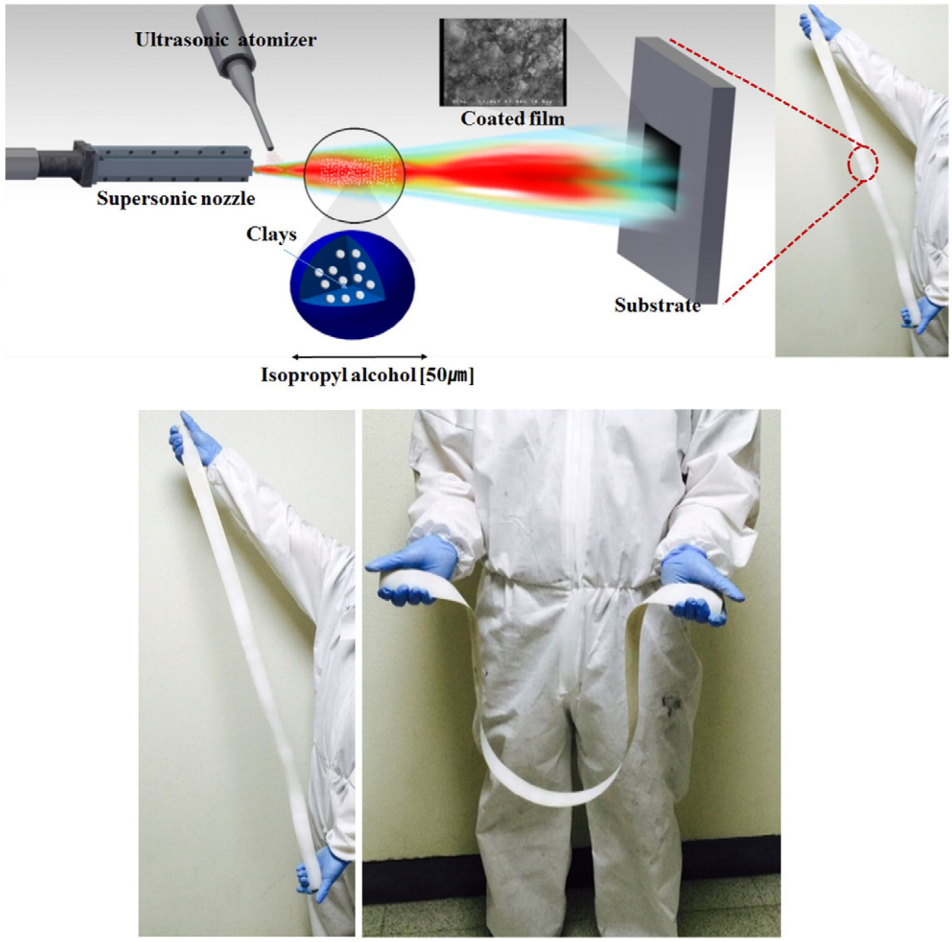


**Fig. 1.** Supersonic spray schematic (top), and large-scale flexible insulating tape coated with montmorillonite that can wrap around multiple copper cables as a thermal barrier/protection layer.

sol–gel (Meera et al., 2012) and layer-by-layer (Lin et al., 2008) methods. However, to the best of our knowledge, clays and clay minerals have never been spray-deposited as a thermal barrier coating, even though spraying of clays and clay minerals holds great potential for preparation of commercially viable thermal and electrical insulation films.

## 2. Experimental

Films of clay such as bentonite and clay minerals like kaolinite, and montmorillonite, have been fabricated using supersonic spray. All the mineral particles were purchased from Sigma Aldrich and were used as is. The basic setup of a supersonic spray consists of a gas tank, syringe pump, nozzle, and x–y motor stage. The details of the setup were published elsewhere (Kim et al., 2014). Each mineral particles (3 g) were mixed separately with 1.8 g of nylon and 30 mL isopropyl alcohol (IPA) to prepare colloidal sols. The sols were supplied with a flow rate of 3 mL/min and fed into a supersonic air jet issued at a pressure of 4 bar. The sols were atomized and formed sprays, which were deposited onto a substrate located at a distance of 90 mm from the nozzle.

To evaluate the thermal insulation properties of the deposited films, a test was performed as depicted in the schematic shown in Fig. 2. A Cu plate was positioned onto a pre-heated hotplate kept at a fixed temperature of 300 °C. In the first experiment, temperature was measured with a thermocouple at the back side of the Cu plate as a function of time (Fig. 2a). In the following set of experiments (Fig. 2b), a Cu plate was coated with an insulation layer (IL) using clays and clay minerals and the temperature was measured above the Cu plate placed on top of these clays and clay minerals after the entire sandwich was positioned onto a pre-heated hotplate kept at a fixed temperature.

The difference in the temperature of the heater and the Cu plate above the coating was measured using a chromel–alumel thermocouple (Type K). An infrared camera (FLIR system, Inc. FLIR-E63900) was utilized for visualizing the temperature field. In addition, the coatings were characterized using scanning electron microscopy (SEM, Hitachi S-5000) at 10 kV to reveal their structural morphology.

**Table 1**
Thermal conductivity and thermal diffusivity of kaolinite, bentonite, and montmorillonite.

| Material | Thermal conductivity [W/m-K] | Thermal diffusivity [$m^2$/s] |
|---|---|---|
| Kaolinite (Brigaud and Vasseur, 1989) | 2.6 | $1.01 \times 10^{-6}$ |
| Bentonite (Plotze et al., 2007) | 1.3 | $5.71 \times 10^{-7}$ |
| Montmorillonite (Blitz, 2011) | 0.48 | $2.51 \times 10^{-7}$ |

## 3. Results and discussion

The SEM image in Fig. 3 demonstrates the morphology of different clays and clay minerals particles: kaolinite in panel (a), bentonite in panel (b), and montmorillonite in panel (c). These clays and clay minerals have particle sizes are in the range of a few microns.

It is desirable that fabricated films would be not only thermal but also electric insulators, so that metal cables are protected from electrical shortcuts. After the clays and clay minerals were deposited by