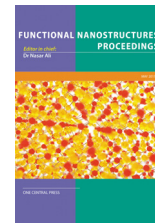


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# Preparation and analysis of paraffin-based phase change material using aluminum nitride as the reinforcing agent

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## ABSTRACT

Ceramic powder in form of aluminum nitride (AlN) was employed to improve the thermal properties of paraffin, known as one of the most significant materials for thermal energy storage. This was attempted considering the superior thermal properties and chemical inertness of AlN. Reinforcing powder was carefully mixed with paraffin in a controlled environment to ensure the well-dispersed AlN particles within the phase change matrix. Results of thermal characterization of the final composite phase change material (PCM) are presented in this study. Differential scanning calorimetry (DSC) was performed to thoroughly portray the thermophysical changes of the fabricated composite PCM as a function of temperature.

## I. INTRODUCTION

Energy can be stored in different forms via variety of methods. Among these, storage of energy utilizing the latent heat thermal storage (LHTS) and phase-change is of interest owing to its simplicity, efficiency, and abundance of such forms of wasted energy in large quantities. Several characteristics of paraffin wax including suitable melting point, large latent heat (i.e. 145-240 kJ/kg), chemical stability with regular degradation level, process-adaptability, low cost, and low environmental effects, present this material as a promising phase-change material (PCM) for LHTS. However, engineers still face a significant challenge dealing with paraffin, specifically its intrinsic low thermal conductivity (i.e. below 0.4 W/m·K). To tackle such difficulty and further improve the desired responses in energy storage such as melting/solidification onset temperatures, durability, and chemical inertness, additives have been used to produce a paraffin-based composite PCM [1-7].

Due to their substantially high melting point, chemical stability and durability, and significant high temperature tolerability, ceramics could also be used as efficient media for energy storage. Nabeel S Dhaidan et al. [8] used CuO for paraffin reinforcement and experimentally and numerically investigated the melting behavior of the resultant composite PCM. Ho and Gao [9] were able to improve the dynamic viscosity (at 30 °C) of paraffin by 28%, using 10 wt.% of Al<sub>2</sub>O<sub>3</sub> as the filler. They also concluded that this improvement was about four times greater than that of thermal conductivity using same mass fraction of alumina. Tun-Ping Teng and Chao-Chieh [10] experimentally studied the effect of different ceramic additives (Al<sub>2</sub>O<sub>3</sub>, TiO<sub>2</sub>, SiO<sub>2</sub>, ZnO) on the LHTS performance of paraffin wax. They concluded that TiO<sub>2</sub> exhibits a better enhancement in thermal energy storage performance as it increases the thermal conduction and solidification onset temperature while reducing the melting onset temperature of paraffin. In the present study, new series of ceramic fillers were employed to enhance the thermal energy storage behavior of paraffin. Because of their low density, low thermal expansion, considerably high thermal conductivity, superior thermal shock resistance, and relatively low cost, aluminum nitride (AlN) and silicon carbide (SiC) were selected as the target ceramic fillers. Moreover, production of AlN-SiC hybrid via time-efficient high-energy ball milling was also practiced to unveil the effect of biceramic blend as well as singular fillers. Variety of characterization methods were carried out to thoroughly investigate the fillers and thermal features of the final composite PCMs.

## II. EXPERIMENTAL DESCRIPTION

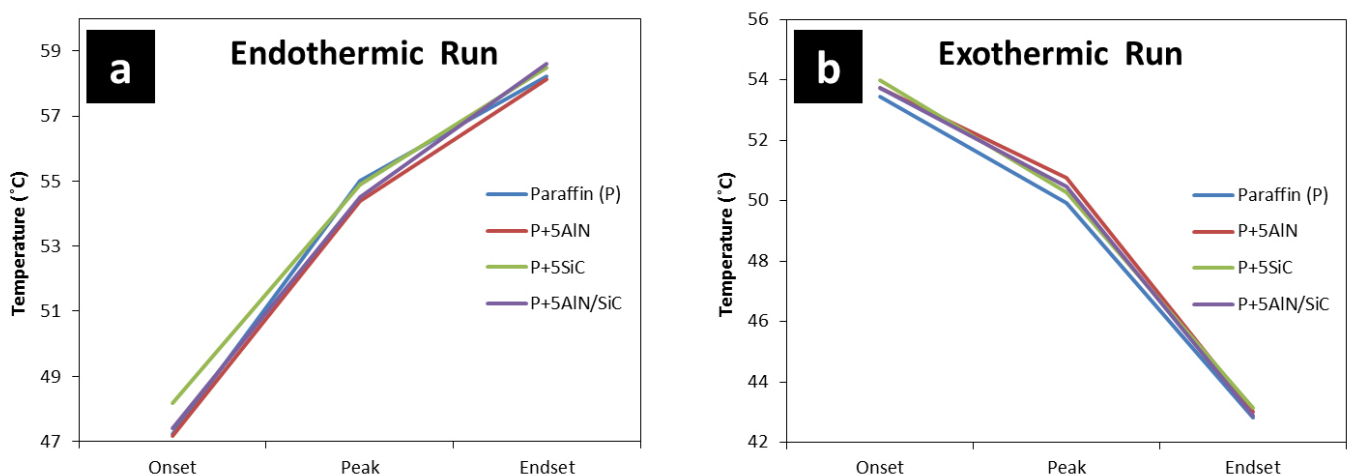
**Preparation of AlN-SiC hybrid.** Mechanical alloying method via vibratory mini ball mill (Pulverisette 23, Fritsch International) was used in order to enhance the particle bonding in the hybrid. Also, it likely facilitates the production of a uniformly distributed particle size within the AlN-SiC mixture, where pristine AlN and SiC particles are 6 and 67.8  $\mu\text{m}$  in diameter, respectively. Accordingly, treated hybrid powder is expected to enhance the thermal energy storage capacity of paraffin while maintaining the intrinsic low electrical conductivity of the matrix as it could be potentially used as phase-change thermal energy storage medium.

Different variables have been considered to optimize the integration and uniformity of final AlN-SiC hybrid. 15, 30, 50 Hz were chosen as the studied milling frequency, where the milling time and ball-to-powder mass ratio (BPR) vary from 15 to 120 min and 4:1 to 20:1, respectively. Mass fraction of each component in the hybrid ceramic was kept constant at 50 wt.%. Grinding ball (15 mm in diameter) and the milling vial (10 ml) were both made of zirconia (95%  $\text{ZrO}_2$ ).

**Composite PCM preparation.** Uniformly mixing of the composed biceramic hybrid with the liquefied paraffin is the next step in the PCM fabrication. A rather simple, but effective, method was used employing an ultrasonic generator (Sonosmasher, ULSSO HITECH Co., Ltd.) to increase the dispersion of the solid particles within the melted paraffin wax, while reducing the amount of trapped bubbles and gaseous impurities in the mixture. During the sonication process, mixture was regularly monitored to ensure the minimum deposition of the powder by controlling the input power of the ultrasonic generator (10-30%). Temperature of the hot plate was kept at 100 °C and mass fraction ratio of the filler to the whole composite PCM is 5 wt.% for all the cases.

## III. RESULTS AND DISCUSSION

**DSC thermograms of fabricated PCMs.** As seen in Figure 1 obtained by DSC analysis, addition of fillers delay the starting temperature of the phase transition in both heating and cooling runs. Among these, pristine SiC due to its higher melting point ( $\sim 2730$  °C) exhibits a longer hold-up in phase-change onset temperatures. This can be attributed to the lower thermal conductivity of the bulk composite PCM reinforced with SiC (see Section 3.4) which postpones the heat distribution and subsequently transition of crystal structure. Also, the absence of useful porous networks in pristine SiC particles will result in poor integration with paraffin leading to less functionality as a stable and uniform PCM. This is evidenced by the lower phase-change differential temperature and latent heat of P+5SiC at the endothermic run. Use of the AlN coarse particles as the reinforcing agent indicates a slightly higher latent heat compared with that of P+5SiC in heating run that can be attributed to better dispersion of the particles within the paraffin and higher level of integration with matrix due to a better porous structure. Both pristine powders, however, decrease the intrinsic higher latent heat of paraffin which is the opposite of what is desired from a material for a reliable LHTS. Comparing the values of latent heat, paraffin reinforced with milled hybrid AlN/SiC presents a slightly greater latent heat than all the cases including pure paraffin. This is due to the combination of a better macro-porous structure in the particles, which was improved by the mechanical alloying method, and higher volume fraction of well-dispersed ceramic particles for energy storage.



**Figure 1** DSC results for transition temperatures of the PCMs.

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