Thermal properties of micron size Ag-added PDMS composites: A fuel cell perspective

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Abstract. We consider polydimethylsiloxane (PDMS) as a prospective structural material candidate for a Fuel Cell fabrication. In this perspective, our work focuses on the tailorability and optimization of thermal properties of PDMS with micro/nano fillers such as silver particles. Thermal conductivity and thermal stability of micron size silver particle added PDMS composites (µAg-PDMS) were studied. The Ag filler fraction was varied in the range of 50 to 77 wt%. The thermal conductivity was measured using 'Cut-bar' technique in the temperature range 50 to 150 °C. We found that in general silver addition in PDMS improved the thermal conductivity and in particular the µAg-PDMS composite with 77 wt% silver filler showed a remarkable enhancement of almost 10 times as compared to the pure PDMS. This is very good for heat management and quick uniform distribution of heat generated in a fuel cell. Further we studied the thermal stability using TGA. We found that our µAg-PDMS composites are highly stable with only less than 1% weight loss. This feature is very good for a fuel cell fabrication using these µAg-PDMS composites.

1. Introduction

Electrical energy for powering small devices is widely expanding and, more focus is on developing advanced micro fuel cells. Developing fuel cells for potable communication system faces a new set of difficult engineering challenges including miniaturizing reactant delivery system and fabricating conductive polymers to be used in bipolar plates for fuel cell stacks. Traditionally, metals were used to fabricate bipolar plates. Many problems emerged when applying metals, as a result electrical conductive polymers were more preferred. Electrically conducting polymers are mostly used in fuel cells as flow field plates, i.e. bipolar plates and flow field plates; the characteristics of the polymer

makes them more preferred than metals. Thus miniaturization of the microscopic flow fields in fuel cells can help to achieve higher energy density which is crucial for the long lasting of micro fuel cells.

Most research on conducting polymers is focused on the electrical conductivity [1-4]. However, one has to consider the thermal properties of the polymer composite as well, especially in a fuel cell application as heat is a byproduct of the fuel cell operation. When conductive filler like carbon black, carbon nanotubes or metal particles are incorporated in the polymer matrix, not only the electrical but also the thermal conductivity is improved. The polymer used in the fabrication process is called polydimethylsiloxane (PDMS), which has advantageous properties such as high flexibility, chemical resistance, biocompatible making it popular in micro manufacturing [5]. Improved thermal conductivity will allow removing excess heat and therefore is very important for heat management as well as uniform distribution of heat generated in a fuel cell. Unmodified PDMS has a poor thermal conductivity (0.17 $Wm^{-1}K^{-1}$). In this perspective, our work focuses on the tailorability and optimization of thermal properties of PDMS with micro fillers. Previous work has been reported on the thermal properties of PDMS-Carbon Black composite [6,7]. In this paper, thermal stability and conductivity of PDMS- Silver composite has been studied. PDMS composite samples with 50wt% to 77wt% silver loadings were prepared.

2. Materials and experimental methods

2.1. Materials

PDMS (Sylgard 184 Silicone Elastomer) is supplied by Dow Corning as two-part liquid component kits comprised of a base and a curing agent. The two parts mix with a ratio of 10: 1, when the two liquids are mixed thoroughly, the mixture cures at 60°C to form a flexible elastomer. Silver powder (327085, silver powder, 2-3.5 μm, ≥99.9% trace metals basis) was supplied by Sigma Aldrich, it has a particle diameter of 2-3.5 μm

2.2. Test specimen fabrication

The silver particles and PDMS polymer blend is firstly ultrasonicated for 30min, then an in-house designed mechanical mixer was used to mix the blends for 24 h to obtain homogeneous dispersion, the crosslinker was added last. A vacuum degassicator was used to remove the bubbles caused by the mixing process. The blend was casted in the mould and oven-baked for 8 h at 60°C to cure properly. Samples with silver loading of 50wt% to 77wt% were prepared. A disk-shaped mould with diameter of 25 mm and thickness of 1 mm was designed for the specific requirement of the thermal conductivity measurement.

2.3. Characterisation

A widely used Cut-Bar technique (ASTM E 1225-87 methodology) was used for thermal conductivity measurement for samples with varied silver loading, as well as thermal conductivity dependence on temperature with the temperature range of 50–150°C. Thermal Gravimetric Analysis (TGA) for thermal stability/degradation was performed using a TA Instrument TGA Q500 under air atmosphere. The heating rate was 10°C/min and the flow rate for oxygen and nitrogen are 5 and 30 ml/min, respectively. All experiments were conducted in the temperature range 30–800°C.

3. Results and discussion

3.1. Thermal conductivity

Thermal conductivity (k) of the test specimens is measured using a cut-bar test facility under steady-state conditions. The system is assumed to have attained steady-state conditions when all the temperature sensors (thermocouples) indicate a constant value with a variation of less than 0.5 °C. Variation of thermal conductivity as a function of mean bulk temperature is determined. Complete details of experimental procedure are described elsewhere [8] . Figure 2 shows the variation of thermal conductivity k as a function temperature for PDMS composites filled with silver with different filler fraction ranging from 50 wt% to 77 wt%. The measurements of the thermal conductivity are made in the temperature range of 50–150°C.

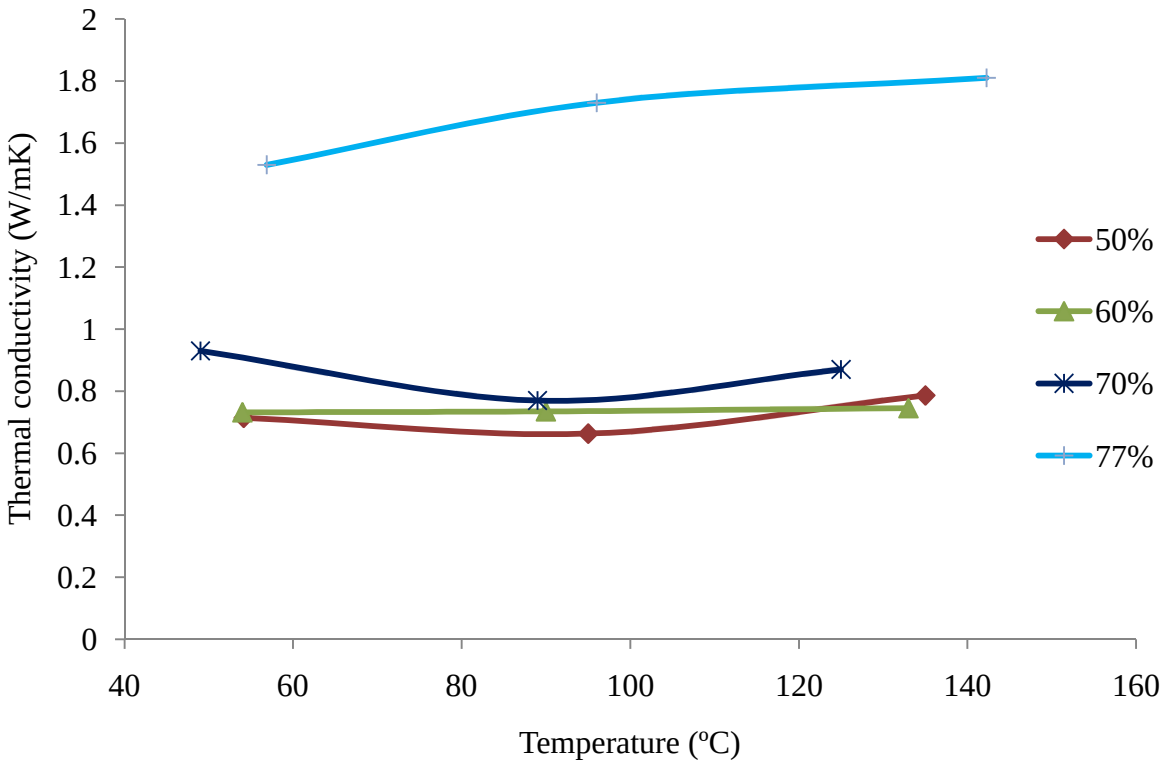

Figure 1 Thermal conductivity VS temperrature for silver filled PDMS composites.

Results have shown a general trend for all samples that thermal conductivities remain relatively stable with minor variations upon increasing temperature. PDMS is a polymer with low thermal conductivity of 0.17 $Wm^{-1}K^{-1}$[9]. However, for PDMS composite with silver fillers incorporated (77wt% sample), a remarkable enhancement of almost 10 times was noted. At lower silver loadings (50, 60 and 70wt %) samples showed similar thermal conductivity, no significant difference was found. When silver loading of 77wt% is achieved, thermal conductivity is twice of 50wt% sample (0.71 $Wm^{-1}K^{-1}$) and one and half times of 70wt% sample (0.93 $Wm^{-1}K^{-1}$). This could be attributed to the increase in the conductive pathway and network density (obtaining the percolation threshold) at 77wt% of filled silver particles [10]. Similarly, Cong et al reported improvement of thermal conductivity with silver addition in PDMS [2]. However, we cannot compare their results with ours as their measurements were as a function of volume concentration.

3.2. Thermal stability (TGA)

To maintain thermally stability is important for materials to be used in a fuel cell application at various operating temperatures. Therefore, the thermal degradation of silver filled PDMS composite is investigated by TGA. Figure 2 illustrates the results of TGA analyses.

From figure 2, results have shown that all four samples remained a high weight percentage until 220°C with only less than 1% weight loss. Above this temperature, samples start to degrade with a higher rate. Samples with higher silver filler loading showed better thermal stability, the weight remaining of samples matches the increasing order of filler concentration. Apparent weight loss occurred between 430 and 500°C and then all samples appeared to be stable up to 800°C. 77wt% silver loading sample had 81% weight remaining while 57% for 50wt% silver loading sample at 800°C, this also indicates that silver is very stable at this temperature range and weight loss for these composite are mainly due to the PDMS polymer matrix. This kind of thermal stability of the material is very good for fuel cell fabrication as normally the fuel cell has optimum performance at operational temperatures around 100 - 200 °C depending on the types of fuel cell.

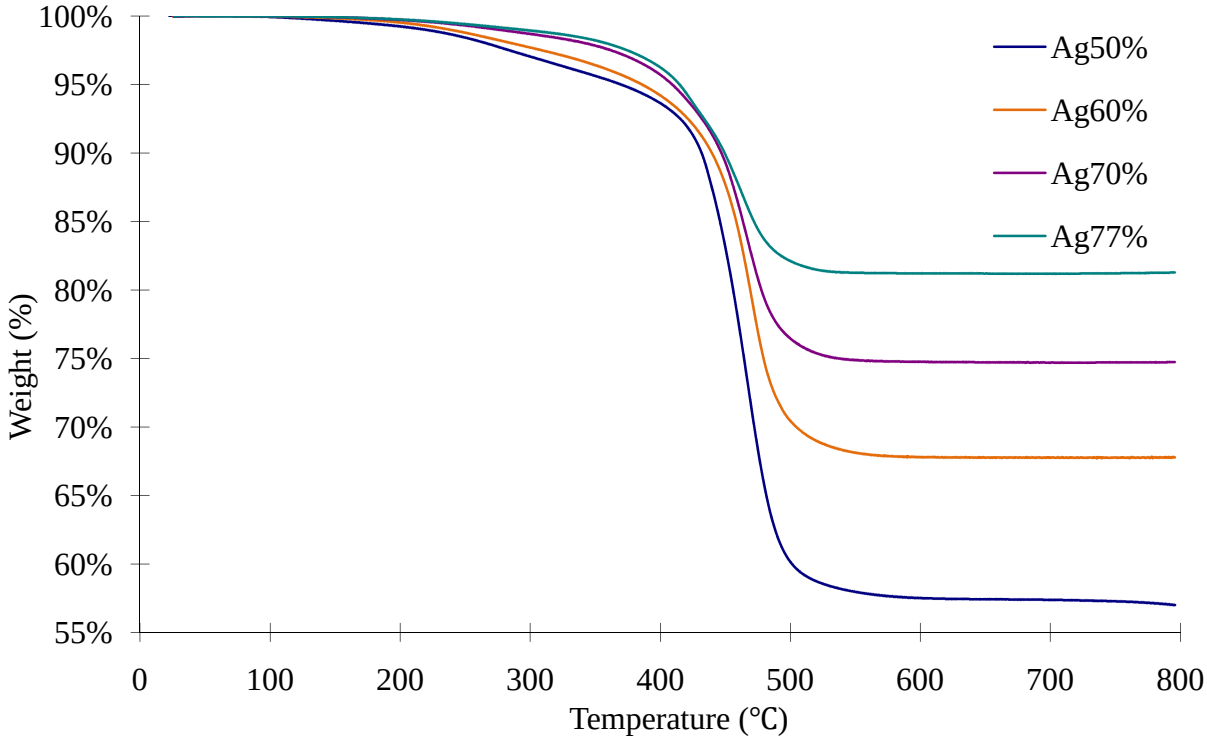

Figure 2 Thermal conductivity vs temperature for silver filled PDMS composites.

4. Conclusion

Thermal conductivity measurements were carried out on silver filled PDMS composites as functions of temperature as well as filler fractions. When compared with pure PDMS polymer, thermal conductivity of sample with 77wt% silver loading was noticed with an order of magnitude improvement as compared to that of pure PDMS. Furthermore, the composites blends have also shown synergistic improvement in thermal stability. The presence of silver filler in the PDMS polymer has resulted in retardment of the thermal decomposition of the composite. A study of these composites with utilisation in the fuel cell bipolar plate is still at the research and development stage. Further tasks include the study of the electrical and mechanical properties of the composites.

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