Carbon Fiber Reinforced polyimide for Space Applications

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Introduction

Space technology has become one of the high technology fields that influence the modern society. The continuous development and application of space technology require materials that have better performance than conventional materials. Recently, amorphous asymmetric aromatic polyimide (TriA-PI) has been synthesized from a-BPDA, ODA and PEPA. It demonstrated excellent properties and can have long-term stability in the space environment. However, this is not feasible for large-scale applications because of higher cost of a-BPDA and processing difficulties. So, there is need to find some suitable material for this purpose which fulfill the required criteria of space applications.

Results and Discussion

In our research work, we used a mixture of dianhydrides i.e. i-BPDA and s-BPDA in monomer feed. Our studies show that when i-BPDA percentage was 40-80% in dianhydride mixture, resulted polyimide demonstrated excellent thermal and mechanical properties. It also showed good solubility in various organic solvents. Soluble nature of polyimide improved its thermoplastic processing.

Phenylacetylene terminated i-BPDA/s-BPDA type thermosetting polyimide prepolymer before cross-linking, showed lower melt viscosity, a wide processing window and also low-cost preparation. Cross-linked resin also demonstrated excellent mechanical properties, thermal properties and aging resistance. Its performance is similar to the TriA-PI. The use of low-cost s-BPDA and i-BPDA reduced the overall cost which makes it possible for large-scale application. Therefore, we controlled raw material ratio in the synthesis process. According to calculations, we prepared the dianhydride monomer by mixing the s-BPDA, i-BPDA and a-BPDA in 40% , 40% and 20% ratio respectively.

In order to study the overall performance of polymers, we used a hybrid monomer, ODA and PEPA to synthesize phenylethynyl-terminated polyimide oligomers. The molar ratio of reaction monomers was BPDA:ODA:PEPA=4:5:2, molecular weight of polyimide oligomers is about 2500. The processing of prepolymer and curing properties was studied deeply. The results show that the prepolymer has low processing temperature range, wide processing window for melt molding process [Figure. 1]. Cross-linked resin has high glass transition temperature and thermal weight loss temperature. It is an excellent thermosetting resin with heat resistance properties [Figure. 2].

To further expand the scope and utility of phenylethynyl terminated polyimide, we applied this as high performance resin matrix composite material. We used the poly(amic acid) (PAA) solution and carbon fiber to prepare fiber-reinforced composites by molding successfully. The results indicated that the material has good mechanical properties, high modulus, high strength and high elongation at break. The aging properties of the composites demonstrate that the weight loss was not significant after aging. However mechanical properties have deteriorated a little bit after aging. This can be attributed to the release of small molecules and decomposition of carbon fiber epoxy-based sizing agents. But still, mechanical properties of material were good enough for application. Morphological studies revealed that the surface of the composite material did not change significantly after aging. Resin and fiber maintained good adhesion [Figure. 3].

Atomic oxygen (AO) simulation and analysis was applied to evaluate application of this material in Low Earth Orbital (LEO). The results of AO simulation showed that negligible weight change and mechanical properties remain stable after AO simulation. The weight loss was on the range of 0.05%-1.6%. Morphological studies after AO simulation indicate insignificant erosion on the surface and few small cracks in fiber-reinforced resin [Figure. 4]. AO simulation showed strong adhesion between fibers and resin in composite.

Conclusions

A simple procedure was employed to prepare carbon fiber reinforced polyimide for space applications.. Cross-linked resin demonstrated excellent heat resistance properties and mechanical property. This composite material also exhibited anti-aging properties. Results indicates that this material can be a good candidate for long-term space applications.

References

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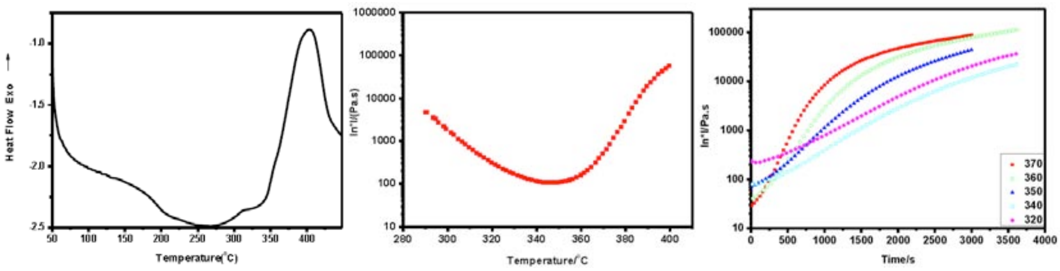
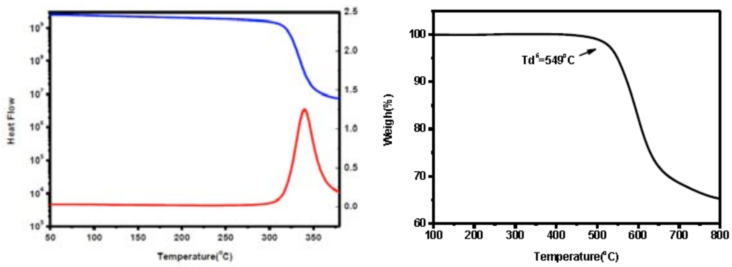


(a) **(b)** **(c)**

Figure 1. (a) DSC curves of the polyimide oligomer; (b), (c) The rheology curve of a polyimide oligomer



(a) **(b)**

Figure 2. (a) DMA curves of cured polyimide; (b) TGA curves of cured polyimide


(a) **(b)**

Figure 3. SEM images of the composite materials after aging

Figure 4. (a) Image of the composite material after radiation
(b) SEM images of the composite materials after radiation