APPLICATION OF POLYMERIC NANO COMPOSITES AT LOW EARTH ORBIT AND GEOSYNCHRONOUS EARTH ORBIT

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ABSTRACT

Use of different polymer or polymeric composites for structural application at space and shielding of electronic instruments under electromagnetic radiation at Low Earth Orbit (LEO: 150 to 3000 km from Earth surface) has shown high potential during past few decades. It is to be noted that even interplanetary space mission especially at Geosynchronous Earth Orbit (GEO: 36000 km away from earth surface) both unmanned and manned missions also searching light weight-high strength vis-à-vis thermally stable and radiation resistance polymer and polymeric composites. Therefore, technology is still evolving to developing polymer and polymer based composites which could be useful as structural materials for spacecraft as well as shielding material when spacecraft is subject to intense radiation at GEO. At GEO, the major primary cosmic radiations of concern are positively charged atomic nuclei, protons, helium nuclei, gamma rays and some heavier nuclei. Many of these are extremely energetic and highly penetrating to be stopped by the modest thicknesses of polymeric material used in LEO spacecraft. Therefore, for space mission at GEO, application of aluminium based composite is still prominent. Therefore, in this investigation attention is given to find an appropriate polymer which could be stable and will exhibit all the desired properties of aluminium with much lighter in weight, and therefore, will be an alternative to replacing aluminium. One such space durable polymer is polybenzimidazole (PBI) having service temperature ranges from -260 C to + 500 C and also having excellent properties to resist high energy radiation and fire. Therefore, this paper highlights polymeric nano composite based on PBI resin with dispersion of appropriate nano particles such as Single Walled carbon Nano Tube (SWNT) and carbon nano fibre and its proper fabrication by space durable nano adhesive and that could be an alternative solution for materials under space radiation at longer mission under GEO. In this context, the thermomechanical properties of the polymer and polymeric nano composites are carried out by Differential Thermal Analysiss (DTA), Thermo Gravimetric Analysis (TGA) and mechanical testing under tensile load, and it is observed that there is an improvement in thermomechanical properties of the polymer. Further, in order to understand the influence of space radiation on the polymer and polymeric composites, the polymers are getting exposed to high energy radiation and are analysed for potential application to space at GEO.

1. INTRODUCTION

In recent times, all noted space agencies in the world have emphasized to developing materials which can withstand high energetic space radiation related to Low Earth Orbit (LEO) and Geosynchronous Earth Orbit (GEO). In this context, although polymers are extensively used as construction materials in spacecraft due to their high strength-to-weight ratio and relatively better mechanical, thermal, electrical and thermo-optical properties, however, there are certain limitations to using polymers when subjected to space radiation at LEO or GEO [1]. Typical polymers are silicones, epoxies, polyurethanes, polyesters, bismaleimides, polyamides, fluorocarbons, polyimides, etc. When one consider about space radiation, the main hazards of the natural LEO and

GEO environment includes (i) external – energetic electrons, photons, protons, alpha particles, neutrinos, neutrons, and all naturally occurring isotopes, (ii) internal – neutrons, gamma rays, and beta particles and (iii) braking radiation – Braking radiation (x- and γ-rays) is generally more penetrating than the incident particles that lead to damage of materials. Therefore, in order to select polymeric materials for spacecraft, the influence of each individual constituent of the space environment, as well as their cumulative effects, should be considered [2].

In this context, the present study highlights the difference between the environment at Low Earth orbit (LEO) and Geosynchronous Earth Orbit (GEO) and rationale to dispersing nanoparticulates in polymer matrix composite and finally to developing high performance polymeric nano composite which could be useful for structural application at LEO and GEO.

2. SPACE RADIATION

The ionizing particles are considerably different from plasma based charged particles on their lower densities ($<1\ cm^{-3}$) and higher energies (~MeV). The main sources of energetic particles (ionizing radiation) in space are

(a) electrons and protons trapped in the Van Allen radiation belts

(b) galactic or cosmic ray protons and heavy ions (from outside the solar system)

(c) protons and heavy ions from solar flares

(d) heavy ions trapped in the magnetosphere

The trapped heavy ions have insufficient energy to generate the ionization required to cause single-event effects (SEEs) and can not make a significant contribution to total ionizing dose (TID). In addition, electrons are not known to cause SEEs. The energetic particles causing single-event upset include galactic cosmic rays, cosmic solar particles (which are heavily influenced by solar flares), and trapped protons in the radiation belts.

2.1 LOW EARTH ORBIT (LEO) ENVIRONMENT

The Low Earth Orbit (LEO) is somewhat complex and dynamic environment. The constituents of natural orbital environment vary with time zone, position, season and solar activity [3]. The local satellite environment, especially neutral particles and plasmas, are significantly different from the natural one. All these different constituents of the space environment play a crucial role in determining the system function, reliability and lifetime of spacecraft materials [4].

2.2 DIFFERENCE BETWEEN LOW EARTH ORBIT (LEO) AND GEOSYNCHRONOUS EARTH ORBIT (GEO)

Low earth orbit is about 200 - 3000 km from Earth surface in altitude. Below 200 km, orbits rapidly degrade, causing surface impact, and above 3000 km or even less, the Earth's radiation belts damage electronic equipment, necessitating special shielding. The region from 3000 km altitude to GEO (app 36,000 km) is known as Medium Earth Orbit (MEO). By comparison, the Moon orbits the Earth at an altitude of approximately

384,399 km putting GEO at about 10% of the way to the Moon. Low earth orbit is only about 1% of the way to the Moon.

2.3 SOLAR PARTICLE EVENTS AND VAN ALLEN BELTS

The Sun gives off a regular "Solar Wind" and a few times a year a "Solar Particle Event" (SPE). Some of the particles from the Sun get trapped and collected by the Earth's magnetic field. Inside this area the particles build up to higher concentrations than in open space. There is an inner concentration of protons and an outer concentration of electrons. Each circles the Earth like a doughnut or belt. This area is known as the ‘Van Allen Belts’. Below about 1000 km the trace atmosphere reduces the radiation levels. However, from the Van Allen Belts to GEO, exhibits severe radiation. Therefore, to protecting spacecraft even below GEO require more shielding which may not be at LEO.

2.4 DEVELOPMENT OF SHIELDING MATERIALS AND RADIATION PASSING THROUGH THE VAN ALLEN BELTS

The data generated by Space Environment Information System reveals that one trip from LEO to GEO and back on a single orbit is: 800 km perigee and a 36000 km apogee. Since this passes through the Van Allen belts, therefore the radiation problem is significant. In these cases, generally aluminium is used as shielding materials for spacecraft. However, it is well known that density of aluminum is about 2.7 gm/cm^3, and therefore, shielding of 20 cm thick, requires 54 grams/sq-cm or 540 kg/sq-meter. Therefore, it is necessary to find alternative of aluminium and which could be polymer if the polymer having desired properties of aluminum with much lower density. Moreover, the advantage of polymer-like materials is that they produce far less "secondary radiation" than heavier materials like aluminum. Secondary radiation comes from the shielding material itself. When particles of space radiation smash into atoms within the shield, they trigger tiny nuclear reactions.

3. RESULTS AND DISCUSSION

In this investigation, attention is given to developing high performance polymeric nanocomposite, i.e., space durable polymer based nanocomposite. The polybenzimidazole systems is extremely useful for matrix resins for high performance fibre-reinforced composite materials because of its highest heat and radiation resistance due to abundance of hydrogen groups in the polymer chain with density 1.3 grams/cc, resulting in one of the best polymer for space applications. It is interesting to observe that any basic polymer even high performance polymer when subject to high energy radiation, the radiation rays penetrates from one side to another side, certain filler can restrict this penetration up to certain extent, however, appropriate nano filler can restrict the penetration of electromagnetic radiation as such as shown in Figure 1 as graphical diagram.

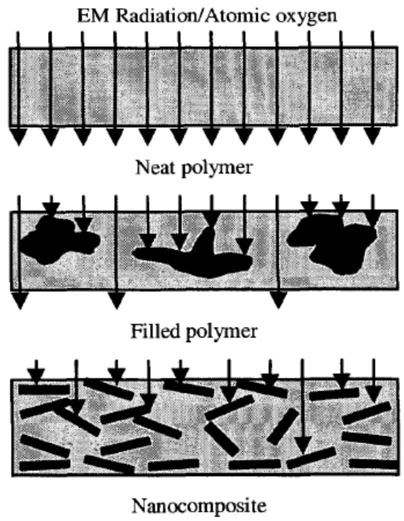

Figure 1: High energy radiation on basic polymer, traditional filled polymer and nano particle dispersed polymer.

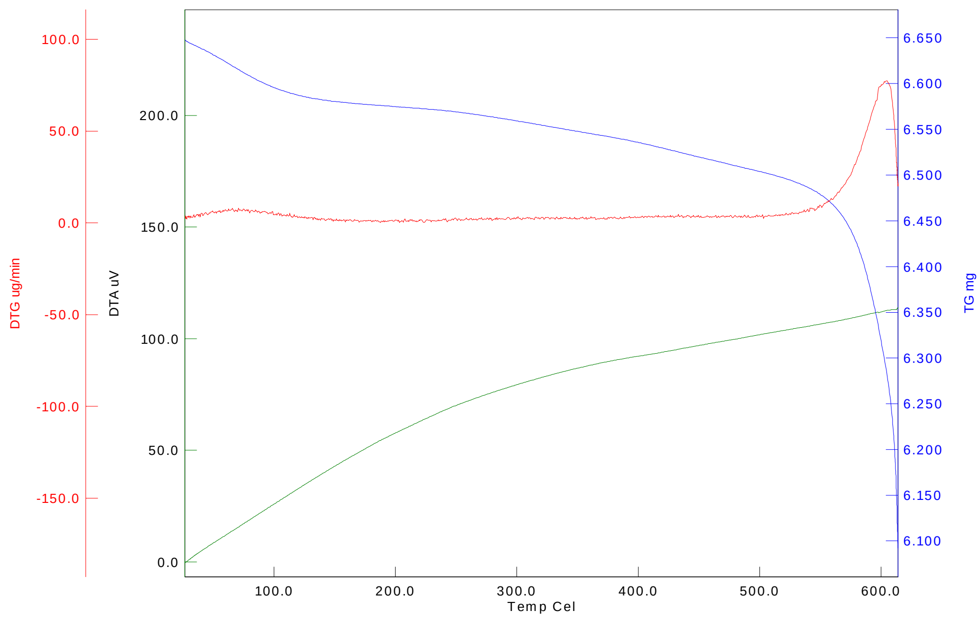

Figure 2: Thermal properties of polybenzimidazole, characterized by TGA and DTA.

Thermal properties under thermo gravimetric analysis (TGA) and differential thermal analysis (DTA) of the PBI is shown in figure 2. The figure reveals that PBI is clearly useful up to +500 ^{0}C and therefore, this polymer can act as thermally stable polymer when subject to space radiation at LEO as well as GEO. The ultimate tensile strength of basic PBI is 160 MPa, and it is interesting to observe that when the PBI based polymeric nano composites are exposed to mixed field radiation in a SLOWPOKE-2 Nuclear Reactor with a dose rate of 37 kGy/hr for 6 hours, when the reactor is at steady state half power operation of 10 kW (thermal) the mechanical properties of the composite improve considerably as shown in Fig. 3.

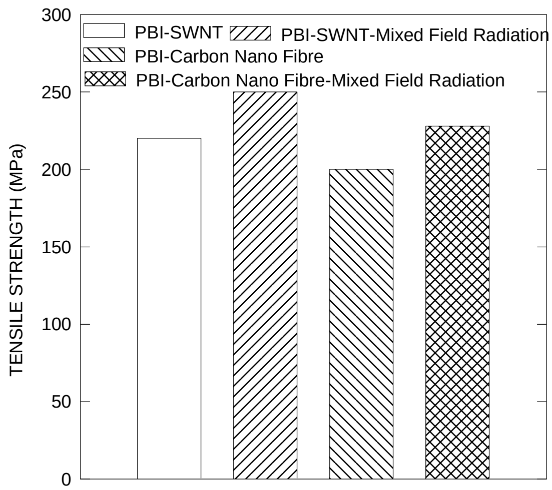

Figure 3: Mechanical properties of PBI based nano composite when exposed to mixed field radiation.

The present investigation concludes that the polybenzimidazole systems could be highly useful for matrix resins for high performance fibre-reinforced composite materials because of its highest resistance to heat as well as excellent mechanical properties. Therefore, this could be an alternative material to replacing aluminium for long duration mission at LEO and GEO.

4. CONCLUSIONS

(i) PBI based polymeric nano composite may serve an alternative to aluminium for an effective materials for structural application to space as well as materials for space radiation shielding.

(ii) Dispersion of SWNT and carbon nano fibre into the polymer matrix resin improves mechanical properties of the composite.

(iii) When the polymeric nano composites are exposed to mixed field radiation, there is a further increase in mechanical properties of the composite.

ACKNOWLEDGMENTS

The financial support provided by the Delft University of Technology, The Netherlands for carrying out this work is gratefully acknowledged and the authors also express their thanks to Royal Military College of Canada for the use of the SLOWPOKE-2 Nuclear Reactor.

REFERENCES

1- R. H. Bradley, *Key Engineering Materials*, 99-100, 37-42 (1995).

2- C. Chen, and D. Curliss, *Nanotechnology*, 14 (6), 643-648 (2003).

3- L.A. Teichman, B.A. Stein, compilers, NASA/SDIO Space Environmental Effects on Materials Workshop, June 28–July 1, Hampton Virginia, NASA CP 3035 (1988).

4- E.M. Silverman, NASA Contractor Report 4661, Part 1, Hampton, Virginia, (1995).