

Fabrication of Nanoengineered Radiation Shielding Multifunctional Polymeric Sandwich Composites

Nasim Abuali Galehdari, Venkat Mani, Ajit D. Kelkar

Abstract—Space Radiation has become one of the major factors in successful long duration space exploration. Exposure to space radiation not only can affect the health of astronauts but also can disrupt or damage materials and electronics. Hazards to materials include degradation of properties, such as, modulus, strength, or glass transition temperature. Electronics may experience single event effects, gate rupture, burnout of field effect transistors and noise. Presently aluminum is the major component in most of the space structures due to its lightweight and good structural properties. However, aluminum is ineffective at blocking space radiation. Therefore, most of the past research involved studying at polymers which contain large amounts of hydrogen. Again, these materials are not structural materials and would require large amounts of material to achieve the structural properties needed. One of the materials to alleviate this problem is polymeric composite materials, which has good structural properties and use polymers that contained large amounts of hydrogen. This paper presents steps involved in fabrication of multi-functional hybrid sandwich panels that can provide beneficial radiation shielding as well as structural strength. Multifunctional hybrid sandwich panels were manufactured using vacuum assisted resin transfer molding process and were subjected to radiation treatment. Study indicates that various nanoparticles including Boron Nano powder, Boron Carbide and Gadolinium nanoparticles can be successfully used to block the space radiation without sacrificing the structural integrity.

Keywords—Multi-functional, polymer composites, radiation shielding, sandwich composites.

I. INTRODUCTION

SPACE missions continue to increase in duration, a need to mitigate the exposure to space radiation has become more imperative. The space radiation consists mainly of electrons and protons, solar energetic particles (SEP), and galactic cosmic radiation (GCR) [1]-[4].

The most common component of space structures is aluminum. As aluminum is not effective at blocking space radiation heavy parasitic shielding is added to satisfy radiation, which result the current space craft to be relatively heavy and costly to transport into orbit. Therefore, development of a multifunctional radiation shielding light weight and high strength material is very important for the design of future space crafts.

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It has been known that hydrogen can provide the best shielding as it is effective at fragmenting heavy ions such as those found in GCR and stopping protons as seen in SEP [5]-[7]. Typically, polymers have high hydrogen content which make them good candidate for radiation shielding application. Zhong et al. reported the radiation shielding performance of nano-epoxy composite reinforced with ultra-high molecular weight polyethylene (UHMWPE) fibers. Their study indicated that UHMWPE/fiber nano-epoxy composite can be effectively used as the structural material for the future space applications [8].

Incorporation of nanotechnology offers unique solutions to a variety of technological problems. Particularly, material science has begun to incorporate and capitalize on the benefits of nanotechnology, improving or altering the properties of composites. Among several different available nanometers, ^{10}B -containing materials are known as excellent radiation (especially neutron and for thermal neutrons are around 4000 barns) absorbers and the composite filled with ^{10}B have the advantage of convenient and safety in construction, operation and reintegration [9]-[11]. Moreover, commercially available elemental gadolinium has the highest thermal neutron cross section of any known element (49,000 barns). N. M. Chikhradze et al. developed a multifunctional composite material system based on gadolinium, boron, and tungsten, which showed enhanced radiation absorption and also corrosion resistance [12]. The Diglycidyl Ether of Bisphenol F (EPON 862) and curing agent Diethyl Methyl Benzenediamine (DETD "W") resin system has been thoroughly studied and is useful in many industries, such as, marine, automotive and aerospace. Recently, there have been studies to infuse this resin system with nanofillers, such as, CNTs and Tetraethyl orthosilicate (TEOS) nanofibers [13]. There have been no studies infusing this resin system with Boron nanopowder, Boron carbide and Gadolinium. Therefore, in this research light weight hybrid sandwich panels incorporating three different particles (Boron nanopowder, Boron carbide and Gadolinium) were manufactured using Heat-Vacuum Assisted Resin Transfer Molding method (H-VARTM), which is a cost effective method for high volume production of sandwich structures. The proposed sandwich panels use a light weight core composed of epoxy resin and selective nanoparticles in conjunction with strong plain weave face sheets made out of UHMWPE fibers. UHMWPE has advanced mechanical properties and excellent physical properties, which are valuable for deep space missions.

The manufactured sandwich structures can be used as

possible future materials for the construction of effective radiation shielding structures. The proposed materials not only have radiation shielding properties but also excellent mechanical properties.

II. EXPERIMENTAL WORK

A. Materials

The epoxy resin used in this work was phenol formaldehyde polymer glycidyl ether called EPON Resin 862 and the curing agent was diethyl methyl benzodiamine EPIKURE W both were purchased from Miller Stephenson Chemical Co. Inc., Danbury, CT USA.

Three different particles were used including: Boron Nano powder (B, 99.5+%, 500nm, US research nanomaterial), Boron Carbide (0.7 Micron, Electro Abrasive LLC), Gadolinium nanoparticles (700nm, Skyspring Nanomaterials. Inc).

B. Fabrication of Core Sheet

Core sheets are manufactured using simple casting of resin into a mold with dimensions of 12" × 12" as shown in Fig. 1. Epoxy resin is mixed with the curing agent, in the pre-calculated percentage. Then particles are added to the mixture of resin and curing agent, and dispersed using reversible shear mixture and ultrasonic. When the chemicals are added to the resin and mixed, the resin mixture becomes aerated. Thus this mixture needs to be degassed before it is injected into the mold. If it were not degassed, it would tend to cause air pockets in the fabricated panel. Therefore, the mixture was placed in a vacuum chamber, which was at approximately 5 torr and was degassed for about 30 minutes at 80°C. Initially it could be seen that the resin begins to boil and the air was sucked out. Once there are no air bubbles in the resin mixture, it is ready to be casted into the mold setup.



Fig. 1 Set up for preparation of core sheet



Fig. 2 Core sheets with 3% Boron Nano powder

Following, the cure cycle based on Fig. 3 was performed to ensure the optimum mechanical strength of core sheet.

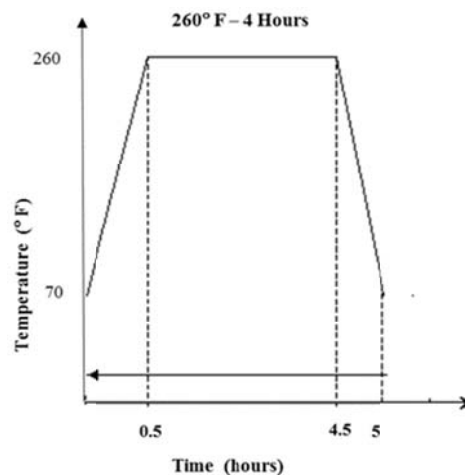


Fig. 3 Cure cycle for Epon 862

Total four core sheets were prepared. One is with neat resin and the rest three with three different types of particles. Table I shows the details regarding each core sheet.

TABLE I
CORE SHEET COMPOSITIONS

Core sheet	Resin/Curing agent (Mixing ratio)	Particle	Particle content (Weight %)
1	EPON 862/ Epikure W (1/0.264)	-----	-----
2	EPON 862/ Epikure W (1/0.264)	Boron Nano powder	3%
3	EPON 862/ Epikure W (1/0.264)	Boron Carbide	3%
4	EPON 862/ Epikure W (1/0.264)	Gadolinium nanoparticle	3%

C. Sandwich Panel Manufacturing

Multifunctional sandwich panels are manufactured using Heat-Vacuum Assisted Resin Transfer Molding method (H-VARTM) see Figs. 4 and 5. VARTM is a cost efficient, out of autoclave process for large volume production of high performance monolithic and sandwich panels. H-VARTM is an innovative method, which has been developed in our lab at North Carolina A&T State University [14]. The method includes forming a sandwich composite using a process similar to VARTM and subjecting majority of the components of VARTM to increase temperature, wherein the temperature is stabilized and maintained for a predetermined time prior to introducing a resin into the reinforcement fabric material. Therefore this method can improve the fiber volume fraction and/or the dimensional thickness of a composite panel.

The low cost H-VARTM process involves performing the following steps:

1. Mold preparation and fabric lay-up.
2. Sealing the mold and creating a vacuum.
3. Resin preparation and degassing.
4. Resin impregnation.
5. Cure cycle of fabricated panels.

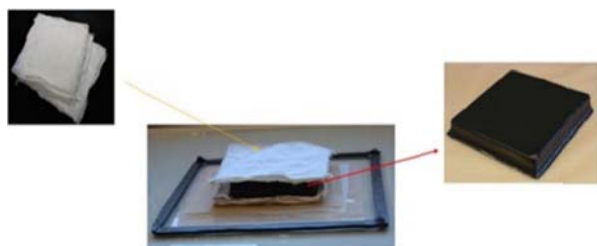


Fig. 4 Fabrication of sandwich panel

In each sandwich panel, core sheet is separated two face sheets and each face sheet consists of 6 layers of UHMWPE mats. Figs. 6 and 7 shows a typical H- VARTM set up.

In this process, first the heating pad is placed under glass mold to thoroughly cover the entire mold. A piece of fiberglass insulation is placed between the tabletop and the heating pad. Following that, a layer of release agent is applied to the surface for easy release of the composite panel. Next is the bottom release fabric or peel ply which leaves an impression on the part suitable for secondary adhesive bonding (like tabbing) without further surface preparation. Then the fabric which is woven roving High Molecular Weight PE is cut to dimensions of 12" x 12". Six plies of similar dimensions are cut for each face sheet and placed at the top and bottom of core sheet. Another peel ply is placed on the top of the stacked sequence of fabric. This allows for easy removal of the composite panel after fabrication from the vacuum bag. This is a porous release material which facilitates the resin flow through and leaves an impression on the part suitable for secondary bonding without further surface preparation. Then the distribution medium is laid on top of the top release fabric. A PE Spiral Wire Wrap tube is used as the resin distribution tube. This tube extends approximately 2" over the longest edge of the stacked layers. Another tube of similar dimensions is cut and is used as the vacuum line. These lines were laid above the distribution media at the two edges along the length of the stacked fabric lay-up. The resin line was closed at one end and connected to resin supply through the peristaltic pump at other end. The vacuum line was closed at one end and connected to a vacuum pump through the vacuum gage. It is standard practice to place the closed ends of these lines in opposite directions to each other.

Nylon bagging film is used as the vacuum bag. This film is placed over the mold area and sealed firmly using extruded sealing compound. After all these steps, the resin is degassed and injected into the mold at a very slow rate till the whole

panel is soaked into resin (see Figs. 6 and 7). Then the cure cycle performed on each composite panel to ensure that the composite attains its optimum mechanical properties.

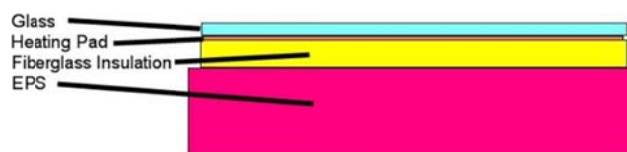


Fig. 5 Placement of heating pad and insulators [13]

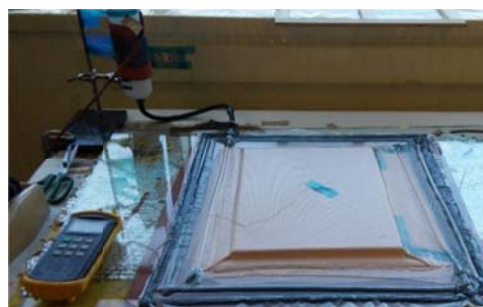


Fig. 6 H-VARTM Setup and resin infusion process

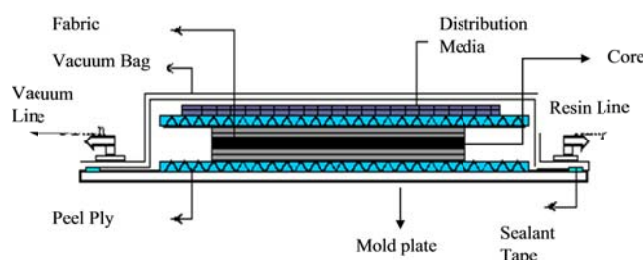


Fig. 7 Schematic of setup of VARTM process

III. RESULT AND DISCUSSION

To evaluate the effective radiation shielding and structural integrity of proposed hybrid structure, four sandwich panels were successfully fabricated (see Fig. 8) and characterized. The details of fabricated panels are provided in Table II. Three different panels with various nanoparticles were fabricated using H-VARTM process. The percentage loading of the nanoparticles was kept constant and was equal to 3% by weight. One panel was fabricated without any nanoparticles but was made of just neat resin.

TABLE II
COMPOSITION AND DIMENSIONS OF FABRICATED SANDWICH PANELS

Panel	Core sheet	Gram/cm ³	Thickness of face sheet (cm)	Thickness of core sheet (cm)	Final thickness of sandwich panel (cm)	Thickness of face sheet (inch)	Thickness of core sheet (inch)	Final thickness of sandwich panel (inch)
1	Neat resin	1.14	0.229	1.448	1.905	0.09	0.57	0.75
2	Resin with 3% Boron Nano powder	1.15	0.229	1.422	1.880	0.09	0.56	0.74
3	Resin with 3% Boron Carbide	1.15	0.254	1.397	1.905	0.1	0.55	0.75
4	Resin with 3% Gadolinium	1.13	0.254	1.442	1.930	0.1	0.56	0.76

Neutron radiation is produced by the interaction of GCRs and SPEs with matter. The GCR particles can interact with walls of space structure and the breakup of $Z > 1$ GCR particles releases neutrons along with deposition of large amount of energy into target nucleus. These secondary neutron radiations are known to be dangerous as can form radio genetic cancers [15]. In this case, to evaluate the radiation shielding performance of fabricated sandwich panels, neutron radiation testing was performed on sandwich panels and the results from neutron radiation tests indicated more than 99% shielding performance in all of the fabricated sandwich panels.



Fig. 8 Manufactured sandwich panels

IV. CONCLUSION

In this project, hybrid sandwich structures incorporating three different radiation shielding nanoparticles were fabricated to provide effective radiation shielding performance as well as structural strength. The Sandwich composites were successfully manufactured and radiation test were performed on both the sandwich panels and the core materials. The results from neutron radiation test showed more than 99% shielding performance in all fabricated sandwich panels. It is further recommended that these panels should be tested to ensure thermo-physical and structural integrity after radiation.

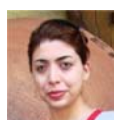
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