POLYMERIZATION OF COMPOSITE MATERIALS IN FREE SPACE ENVIRONMENT

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ABSTRACT

Light-initiated curing of composite in free space environment appears as one of the most promising processes to turn a foldable, inflatable prepreg into a rigid, load-bearing structure [1].

This paper presents activities aiming at the development of composite materials that complies with the strong requirements associated with in orbit curing, such as stability, flexibility and low outgassing in the uncured state, together with reactivity for rigidization and sufficient mechanical performances in the cured state.

The cationic polymerization of epoxy monomer was selected as polymerization process, and dedicated copolymers had to be synthesized to obtain a satisfying material. The obtained results allowed for the successful manufacturing, rigidization and testing of several breadboards.

1. INTRODUCTION

The development of original concepts such as inflatable and rigidizable structures for satellite equipments and spatial habitats is driving the need for new in-orbit rigidization technologies.

In-orbit polymerization of composite structures has many promising applications: in-orbit repair operations on orbital infrastructures, rigidization of inflatable structures or rigidization of parts of habitats (wall).

Currently, space appendages (such as solar array (Fig.1), aerobraking sails…) are identified as shortest term applications.

Fig.1. Solar array breadboard.

The biggest challenge is to carry out the rigidization of the foldable structure to get the requested mechanical performances. The polymerization of composite materials can be basically induced by thermal energy or by radiation (UV, visible or ionizing radiation). The curable systems can be accordingly formulated including monomers and prepolymers, hardeners (in the case of thermal curing) and / or initiation packages (photopolymerizable systems, for example).

Moreover, the chosen chemistry process has to satisfy the requirements for in-orbit rigidization [2]: low outgassing in uncured state, compatibility with manufacturing process and with boom deployment, reactivity, mechanical properties after curing and storage stability.

2. CHOICE FOR THE CHEMISTRY

Currently, radiation-initiated cross-linking polymerization seems to be one of the most promising in-orbit rigidization technologies.

The reaction is triggered on command with many radiations available (UV, visible…) (Fig.2). The polymerization is generally rapid, requires only one-component and the process offers very good storage stability.

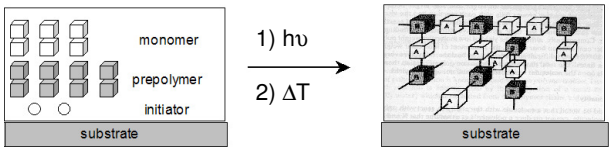
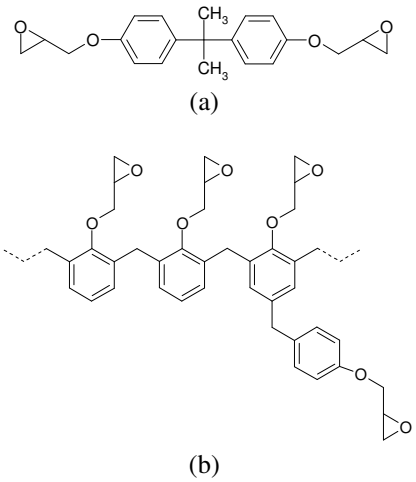


Fig. 2. On-command formation of a three-dimensional network.

Compared to the free radical polymerisation of acrylates, the cationic polymerization of epoxies offers several advantages, particularly because of a number of possibilities of activation of some initiators (Lewis or Bronsted acids, with various counterions). Whereas free radicals undergo recombination and are quenched by dioxygen, cationic active centers exhibit a living character, thus rendering easier the control of polymerization. Typically, some efficient cationic photoinitiators are the onium salts (diarylodonium or triarylsulfonium).

Epoxy resins present a wide variety of structures (epoxidized polybutadienes, epoxy novolacs…Fig.3) and many of them can satisfy for this technology and can be used for establishing kinetic modeling of the curing process [3] & [4].



(a)

(b)

Fig. 3. Bisphenol-A (a) and novolac (b) epoxy resins.

However, some properties of available commercial products are not suitable for the targeted application (high viscosities or high outgassing especially). In this context, the authors focused on tailor-made resins to comply the requirements.

3. THE TAILOR-MADE COPOLYMERS

Tailor-made copolymers with epoxy side-groups appear as a promising solution and as a real innovation wrt in-orbit polymerization.

They can be designed and synthesized to have both a low outgassing and a low viscosity by controlling the molecular weight and the polymer architecture (Fig.4), this being one of the most critical point in this study due to the fact that these properties are opposing.

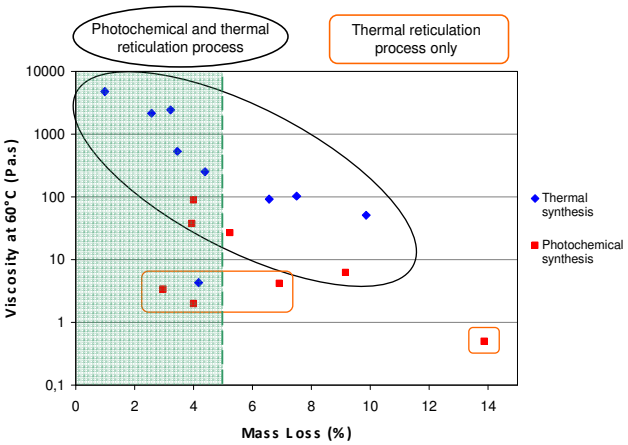


Fig. 4. Viscosity and outgassing properties of different tailor-made copolymers (outgassing results from tests performed with special procedure: 6h @ RT + 0.2°C/min from RT to 150°C (P=2Pa)).

The resulting composite material prepreg, with impregnation rate close to 40%, have TML (Total Mass Loss) and RML (Mass Loss after water vapor regained) lower than 1% following ESA ECSS Q 70 02 [5].

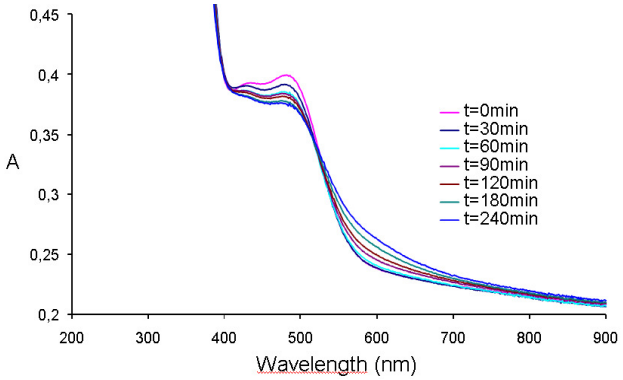
4. REACTIVITY ASSESSMENT

4.1. Spectroscopic monitoring

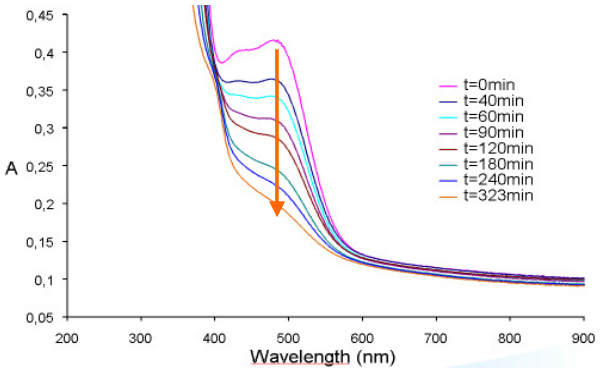
The polymerization reaction of epoxy resins initiated with visible light and amplified by limited thermal post-curing can be assessed thanks to spectroscopic monitoring: UV / Visible monitoring to observe the initiator photolysis and to define the initiator half-life

duration, FTIR monitoring to measure the epoxy function consumption.

Analysis allowed defining the factors having an influence on the photolysis kinetic: light source (LED, halogen lamp…), sample thickness, nature of the resin and temperature during photolysis (Fig.5).



(a)



(b)

Fig. 5. Initiator photolysis (dissolved in copolymer) at room temperature (a) and at 50°C (b).

4.2. Photocuring of resin samples

Some correlations were established between well-defined curing conditions, conversion and glass transition temperature. The factors under investigation were: irradiation duration and temperature, post-curing duration and temperature.

The experiments showed for example that maximum conversion π was obtained after 1h post-irradiation baking and was strongly linked to the temperature. It is also possible to increase the conversion under controlled conditions and, consequently, to increase the glass transition temperature (measured by Dynamic Mechanical Analysis on resin bar samples (Fig.6)).

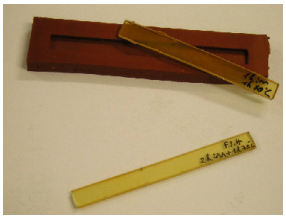


Fig. 6. Typical mould and resin bar samples.

Preliminary composite materials, made with copolymers and glass fiber fabric, and cured following the polymerization cycle: 5h of lighting (at 50°C) + 1h at 80°C (post-baking) exhibit very interesting mechanical properties: tensile Young modulus of 13 GPa and tensile strength around 160 MPa.

5. BREADBOARDING ACTIVITIES

Currently, in the frame of the ESA funded research program named "Ultra Light Structures" (photo-initiated polymerization) several breadboards, whom all the materials and sub-systems are compliant with in space environment, were successfully manufactured.

The main steps of the manufacturing of a rigidizable boom are described below:

- Internal layer (bladder) integration
- Structural layer preparation and integration
  - Copolymer and photoinitiator mixture
  - Spreading of the active formulation onto a supporting film
  - Formulation transfer onto glass fabric assisted with vacuum
  - Wrapping of the prepreg (Fig.7)

Fig.7: Prepreg integration.

- Double Layer Insulation integration

- Manual folding of the boom
- Deployment Control System integration
- Curing system integration (Fig.8)

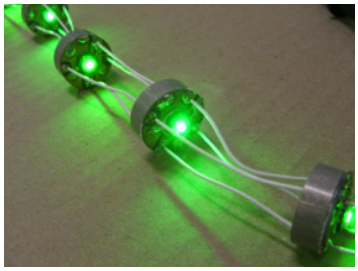


Fig.8. Curing system.

Once manufactured, the breadboards were deployed and rigidized on-ground (Fig.9). Finally, the mechanical performances were assessed (bending and buckling tests).

Fig. 9. TRP ULS project breadboard: boom with a 4.5m length.

6. CONCLUSION

The proposed chemistry and processes for in-orbit polymerization of composite structures prove to be efficient and satisfy the main requirements of such an innovating technology.

Currently, tailor-made copolymers seem to be the most promising solution for in orbit curable composite manufacturing. Indeed, their properties can be easily handled to cope with the requirements of a specific application, whereas no commercial products comply with all requirements.

7. REFERENCES

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