MICROWAVE PROCESSING OF THIN SHEET MATERIALS

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ABSTRACT

This program has been initiated in an effort to develop a generic microwave technology for the continuous, roll-to-roll manufacturing of high value polymer thin sheets, for example, pre-impregnated glass cloth (prepreg) for printed circuit board manufacture. Another goal of this program is the elimination of EPA listed solvents such as methylethylketone (MEK) used in the manufacture of prepreg for electronics applications. This will be accomplished by the development of water-based resin materials which cannot be processed with existing equipment without substantial modifications. The microwave technology will lead to improved energy efficiency for film drying, heating, etc. to reduce product cost. This program is partially funded by the New York State Energy Research and Development Authority (NYSERDA), the Electric Power Research Institute (EPRI) and the New York State Gas and Electric Corporation (NYSEG).

INTRODUCTION

The application of microwave energy to the processing of materials has proven to have a number of advantages over conventional processing. The typical advantage is faster heating rates, due to greater temperature uniformity and therefore larger penetration depth of the radiation in most materials, which results in shorter production lines or shorter process cycles. Normally, however, microwave processing is considered only for thick cross-section materials, to gain the full benefit of the technology.

IBM Corporation initiated a study in 1988 to investigate the processing of thin polyimide films on a ceramic chip carrier using microwave radiation (1-4). This effort succeeded in demonstrating the use of a single mode microwave (2.45GHz operating frequency) applicator to cure polyimide films in under 10 minutes (a 10 hour process using conventional thermal curing). New microwave applicators and process control algorithms were developed for processing in a single batch mode. The success of this effort and the increased understanding of microwave capabilities lead to the present investigation of exploiting microwave processing for continuous material applications. However, there are numerous challenges to be addressed the least of which is a means of obtaining a uniform spatial distribution of microwave energy across a sheet which is wider than the wavelength of the radiation.

The use of microwave energy for the processing of thin sheet-like materials is seldom considered. Although the material may be thin, quite often it is still too thick for alternative technologies, such as infra red (IR), UV-Vis, e-beam or convection curing when very high temperature ramp rates are required, in combination with good uniformity. The reason for this is that the penetration depth of conventional and IR heating is typically less than a few micrometers resulting in a nonuniform temperature gradient through the thickness of the sheet under accelerated heating conditions. In these cases, microwave radiation becomes very attractive because of the large penetration depth of the radiation, but unfortunately, there are no microwave applicators or control systems currently available which are designed for thin sheet processing.

APPLICATIONS AND MARKET TRENDS

Although there are many current and new applications for such a technology, including the preheating of rubber sheet material for industrial roofing, high cost paper production (eg. photographic paper), thin film drying, preheating for filament winding operations, for aerospace and missiles, etc, we propose to focus the use of this technology initially on the fabrication of resin impregnated glass fiber cloth (prepreg) for the electronics and composites industry. Prepreg is the base material used in the fabrication of circuit boards, structural members for aerospace, sporting equipment, automotive and civil transportation. There has been a tremendous growth in the production and fabrication of composite materials fueled by the rapid expansion of the electronics and aerospace industries in the 1980's.

The world market for printed wiring boards (PWB's), for example, has increased at an average rate of $2 billion dollars per year since 1983 to a current value of ≃$25B. Unfortunately, the US market share has decreased from 50% in 1983 to 25% in 1989, with further erosion predicted by industry marketing research organizations to 23% by 1994, as can be seen in Figure 1.

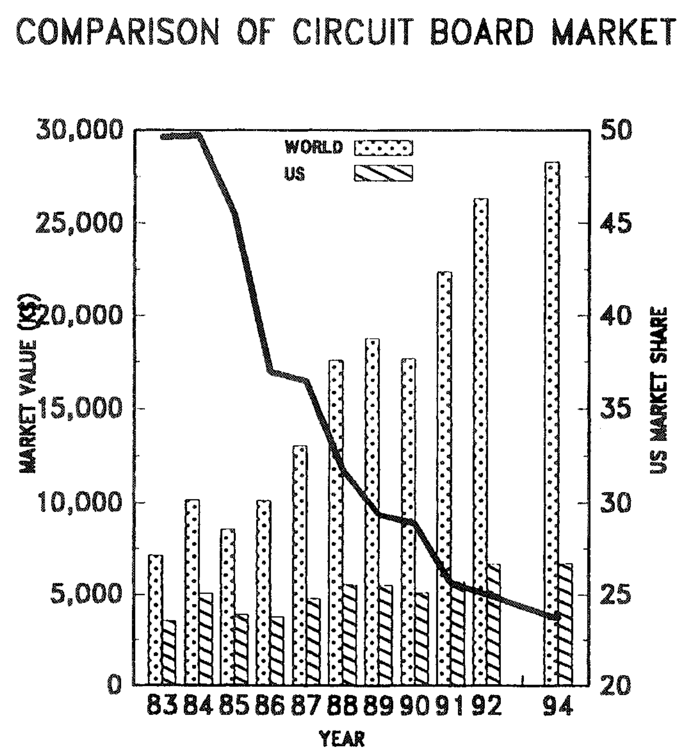

Figure 1. Comparison of US Market Share and Market Value

Similarly, the US share of the $1.7B market (in 1987) for high performance structural composites has shown a decrease to 50%, with a continued erosion expected with the decrease in national defense spending which drives the research and development of these light weight, high strength materials. Some factors contributing to the decline in the US market share are the high cost of manufacturing facilities and labor, increasingly more stringent environmental laws, and long development cycle times. A strong growth in market share has occurred in the far east. History has shown that as one industry, or part of one industry moves offshore, the remainder tends to follow. In the case of printed circuit board manufacture, this includes lamination, drilling, plating and etching operations, and along with it go the engineering and development jobs. The prepreg fabrication facilities for electronics and structural applications are located at many sites scattered throughout the USA. The largest single producer of prepreg and circuit boards in the US is the IBM facility in Endicott, NY. This site is involved with all stages of circuit board manufacture, from the production of prepreg to the fabrication of completed circuit boards for computers ranging from mainframes to PC's. Unless new processing technology is developed, continued offshore pressure on these US based industries will eventually result in essentially all of this industry relocating to areas such as Mexico and the Far East, resulting in a substantial job base moving out of the US, with a corresponding impact on the support services, utilities and tax base.

ELECTRONIC PRINTED WIRING BOARD PRODUCTION METHODS

In circuit board fabrication, prepreg manufacture has the greatest impact on environmental emissions, since the resin (usually an epoxy resin) is first dissolved in a low boiling solvent, such as methyl ethyl ketone (MEK) to control viscosity and ensure efficient wetting of the resin on the glass to form a uniform coating. The glass cloth is then dipped through a tank containing the solvent resin and passed up a "treater tower" which consists of a number of ovens or hot air jets heating the web to remove the solvent and partially cure the resin (B-stage) in a continuous operation. A schematic of the process can be seen in Figure 2. After removal from the web, the solvent is then vented to the outside or burned (with up to 600 lbs of CO_2 / hour for a medium sized facility) depending on the environmental regulations at the location of the treater tower. This accounts for about 20M lbs of solvent per year industry wide, or about 4% of the total US production of MEK. In addition to the environmental hazard, there is also the risk of explosion or fire within the treater facility, as well as the risk of solvent exposure to operators. The latter not only drives the cost of new installations, but places a severe limitation on the types of solvents that can be used. This restricts the number and types of resins that can be processed - thereby limiting the applications of these materials and development of advanced composites.

For PWB's, the prepreg is subsequently laminated with copper foil on both sides and the copper patterned to form lines. A number of these structures (cores) are then laminated together to form the circuit boards. There are some inherent limitations in existing treater facilities which cannot easily be overcome. Due to the size of the prepregging unit and the ancillary equipment, there is no practical way of recovering the solvent utilized. Currently, most resins contain approx. 40% solvent, which can account for the evolution approx. 250 lbs of solvent per hour on a typical manufacturing line. The current method of disposing of this solvent is to incinerate it, corresponding to about 600 lbs. of CO_2 per hour or about 5M lbs of CO_2 per year for a single prepregging treater tower.

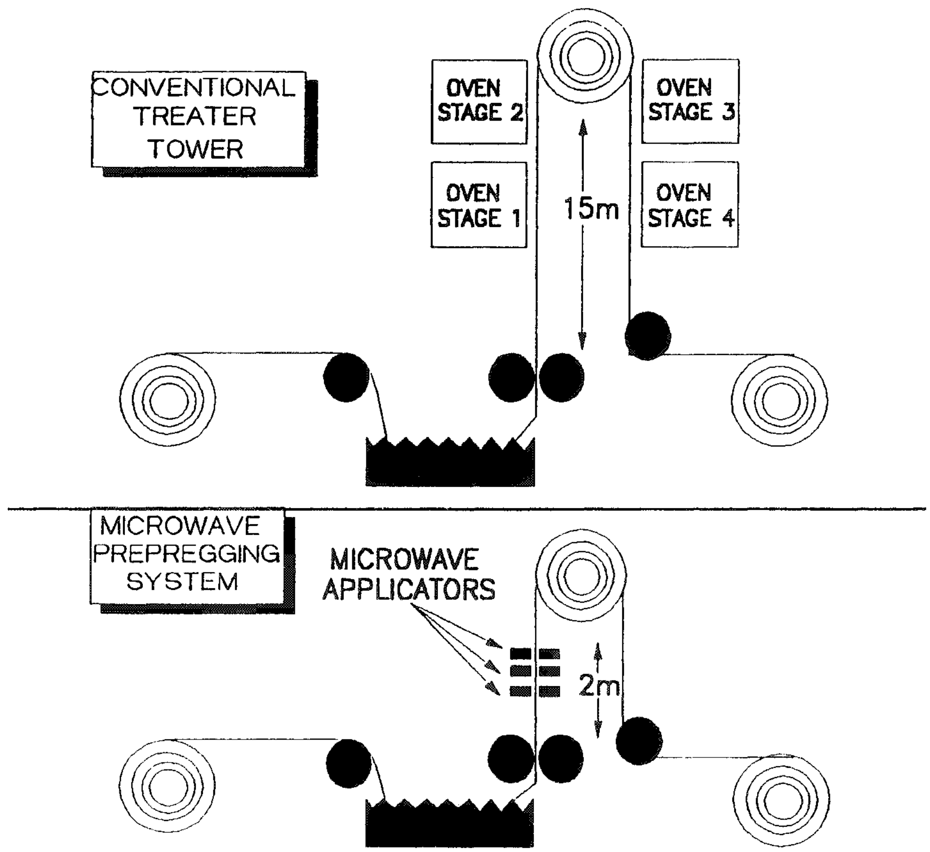

Figure 2. Comparison of Conventional and Proposed Microwave Prepreging

Due to the size of the tower, approx. 2-3 hours is required to modify and stabilize the temperature of the ovens and 2-3 weeks are required to develop a process on a new material. Thus, short runs of specialty product are not cost effective. Furthermore, because the tower is so large, the solvents that can be utilized are severely limited. The solvent of choice is a ketone such as MEK which is low boiling and highly flammable posing a significant fire and explosion hazard. This limits the types of resins that can be processed to only ketone soluble systems. Approximately 4% of the US production of MEK (20 million lbs/year) could be eliminated by moving to a water based resin system. Finally, the prepreg cycle must be redetermined for each new resin because the process is not easily scaled from hand treater towers to pilot lines to manufacturing towers due to different heat transfer and uniformity at each stage. This requires ~2-3 weeks development time, resulting in significant additional development cost due to the substantial waste of resin and reinforcing material. A more compact system would be more cost effective and reduce the development time.

ENERGY AND ENVIRONMENTAL IMPACT

The expected more stringent environmental laws will limit the continued use of solvent coating, as seen by the addition of methylethylketone (MEK), the most common solvent used in prepregging, to a list of controlled solvents which include known carcinogens and ozone depleting materials, such as the chlorofluorocarbons (CFC's). The best alternatives lie in the use of melt, powder and emulsion coatings in which the powder is carried by water. For the manufacture of prepreg for PWB's the best alternative is in water-based resin systems which still permits a liquid phase to carry the resin into the closely weaved cross-ply glass bundles. However, water-based emulsions cannot be processed economically with existing treater tower equipment due to the high heat capacity of the water carrier compared to MEK. Therefore, to effectively process water-based resins requires new technology and tooling.

The use of microwave radiation with specially designed applicators has the flexibility to accommodate conventional, solvent-based processing methods in addition to water-based and powder coating. This is primarily due to the strong absorption of microwave radiation by water and the improved heat transfer to the resin. The present effort is devoted to the development of an entire processing technology and application, and material development. This effort will potentially lead to additional technology spinoffs, although as much use as possible will be made with existing technology.

The limiting factor in the speed of production of prepreg today lies in the heat transfer rate to the resin and fiber in the tower. Hot air jets are currently used in a bid to transfer heat into the materials. Unfortunately, this method of heat transfer is relatively inefficient with the resulting wastage of energy. Using the current methods, heat transfer efficiency is approx 1 - 2%. The only methods available to improve this and therefore produce a more cost effective product, is to (i) slow the speed of the web, so it is in contact with the heated regions longer (which slows production and results in higher costs); (ii) increase the height of the tower (which is very expensive); and (iii) improve the method of heat transfer and therefore the efficiency. The latter is easily accomplished with microwave radiation, with an efficiency from the power outlet as high as 65% possible, with the correct design applicator. For a typical tower operations this results in the heat utilization being reduced from 1MW to approx 20 - 30kW - a substantial reduction. Additionally, the electrical usage is approximately 220 kW for the operation of fans to circulate the air and drive the motors pulling the prepreg cloth. This can be reduced substantially since (i) the air circulation is substantially reduced; (ii) the weight of the prepreg in the tower is reduced due to the substantial reduction in the height of the tower. In addition to the other benefits of being able to handle new materials, environmentally superior, etc., this technology will directly result in a reduction in energy upon installation.

APPLICATION FOR CONTINUOUS SHEET PROCESSING USING MICROWAVE ENERGY

Microwave processing This is an enabling technology and the leverage it provides is in the applications and the industries it can impact. By developing a technique to uniformly apply microwave energy on large width webs, substantial technical leverage can be realized in a number of areas, the most significant being energy efficiency and environmental responsibility.

The large multimode systems currently used cannot cure uniformly over the width of the sheet material, a problem familiar to all home microwave users. The poor uniformity of these systems has resulted in a barrier, preventing the greater application of this technology and limiting commercial applications - especially in sheet applications. To develop a microwave technology with commercial attractiveness, it is necessary to combine a specially designed applicator with in-line sensors and controls which can monitor the processing, in conjunction with a suitable algorithm to control the microwave power. These controls become essential as the heating rates become very large, approaching 500 °C/min, to prevent thermal runaway and subsequent fluctuations in the quality of the material being processed. Industries and uses which would benefit from the technology to be developed in this program include:

1. The fabrication of rubber sheet for the industrial roofing market is an established industry with annual US sales of about US$150M. Microwave processing is already used in the rubber industry - one of the first applications for this technology introduced in the 1970's - and is the

preferred method for the fabrication of door seals for automobiles, etc, providing premium quality and simultaneous cost saving over conventional processing. While the current microwave technology enables the processing of continuous rubber door seals, it is not amenable to the processing of sheet due to poor uniformity and lack of process controls inherent with multimode applicators.

2. Polymer coating industry - the curing and drying of coatings on paper products or fabrics will be more efficient. Since microwaves can effectively couple into an emulsion, a thermally sensitive paper or substrate will not be subjected to high temperature excursions. New products, difficult to process with conventional heating, may be realized e.g. emulsions on photographic paper.
3. The processing of photographic paper which is extremely thermally sensitive, curing of coatings on paper products other than acrylates should be feasible, once a microwave applicator with sufficient uniformity and the control software is developed. Other similar applications include the production of color photocopy paper. Microwave processing offers a method for providing a wider manufacturing window by reducing the temperature needed to dry these coatings.
4. The drying of polymer films prior to a lamination step is important to a number of industries, including the manufacture of absorbant materials, photographic film, holographic film. The current methods are inefficient and slow, requiring long drying stations, thereby impacting the economics of the process. A microwave system, with the good uniformity and appropriate control circuitry would have an impact on a very wide range of manufacturing processes.
5. New, automated filament winding applications - currently this is accomplished with a very narrow tow of about 1 - 2". This technology would allow a "tow" of 50 inches or more wide to be used, dramatically reducing the cost of the composite;
6. The development of new resins and materials which are tailored specifically for microwave processing;
7. Control system - development of the in-situ controls and feed-back monitors could be used in many industries;

CONCLUSION

The development of this generic technology will bring direct and rapid assistance to the prepreg industry, but also provide indirect benefits to other composites manufacturing and high technology industries in the form of new and more cost effective materials and processes. Ultimately, this technology can assist a wide range of manufacturing opportunities throughout the US, providing jobs and a technology base on which to build for the future.

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