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POLYMERIC MATERIALS SCIENCE IN THE MICROGRAVITY ENVIRONMENT

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1. INTRODUCTION

While the utilization of polymers and polymeric composites for coatings, optical components and even structural materials in space is becoming very widespread[1], relatively little attention has been given to basic polymeric materials science in this unique environment. Polymers are a very diverse class of materials that are in many ways unlike their low molecular weight organic and inorganic counterparts, metals, inorganic glasses, proteins and other materials that have been studied in space. The properties of polymers are intimately related, not only to their composition, but also to their "history". Samples with the same chemical composition may exhibit radically different physical, chemical, mechanical and optical properties due to different molecular weight distributions, different thermal histories, different processing conditions, etc.[2] Since the properties of these materials are so strongly tied to their history, and thus their processing environment, it is evident that a whole new area of polymeric materials science may be opening up with the coming access to the microgravity environment.

Because of the immaturity of this field at this time, it is only possible to use "broad strokes" in painting a picture of the potential for polymeric materials science in the microgravity environment. Undoubtedly, many new and exciting areas of research will emerge in the coming years as polymer scientists become more familiar with the nature of the research opportunities in space. In this paper, however, only three general areas of potential activity will be discussed: studies of solventless polymerization chemistry, studies of the polymeric solid state, and studies of polymer composite processing. In each case, an attempt will be made to give a brief background, to outline some of the relevant materials issues and to describe typical conditions under which studies might be of interest.

2. POLYMER CHEMISTRY

A typical polymerization reaction is shown schematically in figure 1. In the terrestrial laboratory, polymerization of monomers frequently is carried out in a suitable solvent at a moderately elevated temperature (usually <100 °C). The polymerization may be promoted either by the thermal energy itself or by the use of chemical initiators, catalysts or ionizing radiation.[3] In such reactions, n may reach a value of 10^5 or more with molecular weights surpassing 10^6.

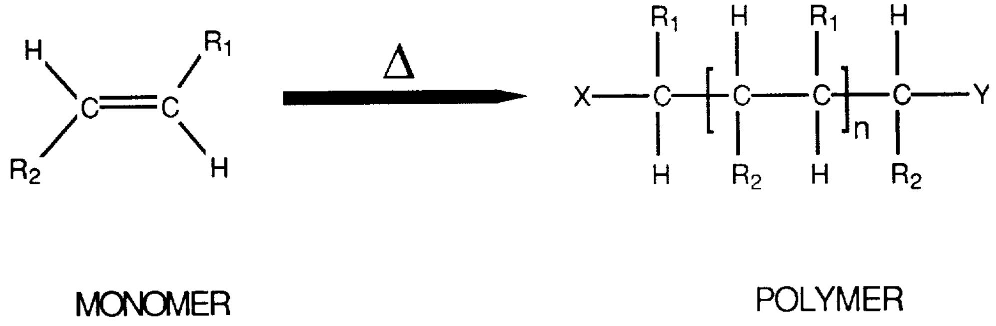

Figure 1. Typical polymerization reaction.

For many applications of polymeric materials it is desirable to achieve as high a molecular weight as possible. Low molecular weight polymers are typically inferior with respect to properties such as mechanical strength, modulus, processability, etc. In terrestrial polymerization reactions, the achievable molecular weight is many times limited by solubility of the high polymer in the reaction solvent. Polymerization in the gas phase, in the absence of solvent, might be one route to higher molecular weight materials. However, on earth gravity or diffusion to the walls of the reaction vessel would cause the growing polymer chains to be removed from the reaction zone and would thus limit the ultimate achievable extent of reaction.

Utilization of a containerless processing facility in the microgravity environment for polymerization in the gas phase could alleviate the problems arising from gravity and diffusion and might lead to new very high molecular weight polymers. The reaction could be initiated by UV irradiation of the monomer vapor. Conditions required in the reactor would be fairly mild. Temperatures of 20-100 ^{o}C with a stability of +/- 5 ^{o}C would be desirable. Heating and cooling rates would be in the range of 1-10 deg/min and hold times at temperature would be in the range of minutes to hours.

3. STUDIES OF THE POLYMERIC SOLID STATE

Polymeric materials may be categorized in three general classes according to the nature of their solid state, including glassy polymers, semicrystalline polymers and crystalline polymers. In most cases, the state of a given sample is controlled by the processing history. For example, a thermoplastic polymer may be heated to its molten state and then cooled at various rates. If the melt is quenched, that is, cooled very rapidly by immersion in cold water or liquid nitrogen, a glassy material may result. Such totally amorphous glasses are in a nonequilibrated state. These materials "age" and their properties change with time as the glass relaxes toward the ideal equilibrium state. The exact nature of the glass depends on the cooling rate and other conditions existing at the time of formation. An example of a volume-temperature plot for a glassy polymer cooled from the melt at various rates is shown in figure 2. It is seen that the specific volume of the glass is clearly a function of the cooling rate. During formation of the glass "free volume" is incorporated into the matrix. Once the glass is formed, the aging process mentioned above begins and proceeds at a rate which depends on the aging temperature, the amount of "free volume" and any external forces acting on the materials. The aging results from reorientation of the polymer chains in the glass and results in significant changes in many properties. It is possible that the microgravity environment might have significant effects on the nature of the glasses that can be formed or on the rates of their relaxation. For example, possibly highly uniform polymer glasses could be fabricated. Furthermore, the physical aging properties of such materials in the space environment are largely unknown. Investigation of this process in the absence of gravity could yield valuable information on the nature of the relaxation processes and the prediction of behavior of polymers in space.

With some materials, if the polymer melt is cooled very slowly in a controlled manner, a highly crystalline material with high order may be achieved. If the melt is cooled at some intermediate rate, various degrees of crystallinity may be incorporated into the matrix along with amorphous regions resulting in the formation of a, so called, semicrystalline solid.

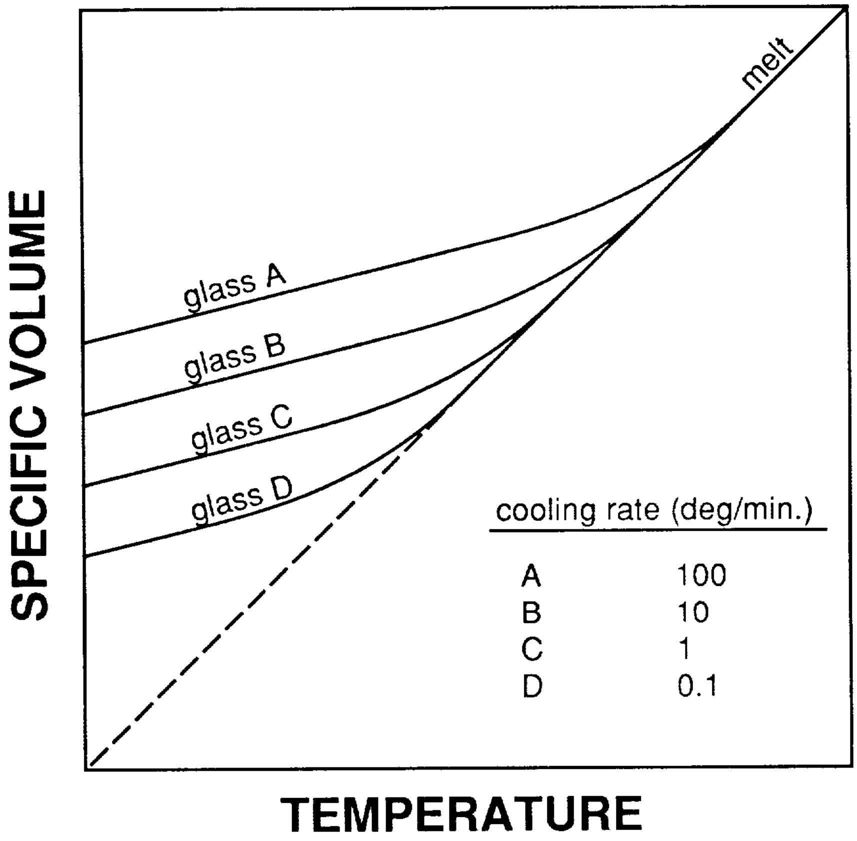

Figure 2. Volume-temperature relationship for a glassy polymer.

The nature of polymer crystals or crystalline domains is quite complex.[4] Several different crystalline forms are known including spherulites and lamellae. The type, size and distribution of the crystalline domains are known to be functions of the crystallization conditions. Again, as in the case of the polymer glasses, little is known about the effects of gravity on the formation of crystallinity in polymers. It is possible that highly oriented, highly crystalline materials could be produced in the microgravity environment which would show interesting and useful properties.

The study of phase transformations in polymeric materials in the microgravity environment would require a wider temperature range and better thermal control than in the polymer chemistry studies. Temperatures as high as 700 °C could be needed to melt or soften some of the materials. Heating and cooling rates in the range of 0.1-100 deg/min could be required with temperature stability of +/- 0.1 °C. Hold times in the range of minutes to hours would be anticipated.

4. POLYMER COMPOSITE PROCESSING STUDIES

Many useful applications of polymers involve the fabrication of composite materials. In the context of this paper, a composite should be understood to be any mixture or blend of different materials. The advantages of composites are of course that the desirable properties of widely different materials may be incorporated into a single element. A well known example of this would be the high strength, lightweight graphite/epoxy composites. The availability of a particular composite material clearly depends on its processability. In general, composites are made by "mixing" two or more components and then allowing the system to "set" in some manner. In some cases, the "mixing" has to be carried out in a highly controlled fashion. An example of this would be the production of fiber reinforced polymer resin composite prepreg which is used to fabricate multi-ply laminate structures. In the case of particle reinforced composites, however, the key to good performance involves true mixing of the components to achieve a homogeneous blend and maintaining the good mixture during cure. This can become a problem if the densities of the components are significantly different. Consider the hypothetical example of a polymer filled with macroscopic metallic spheres. If the uncured resin had a suitably low viscosity to allow for good mixing, then it would be difficult to keep the metal spheres from settling out during the initial stages of cure. Such mixing problems could be overcome in the microgravity environment and could allow for the fabrication of some highly unusual composite materials.

The conditions of cure for polymer-based composites are similar to those required for the phase transition studies. The temperatures would be in the range of 50-400 ^{o}C. Heating and cooling rates would be in the range of 1-50 deg/min. A typical temperature sequence for the cure of composite is shown schematically in figure 3. Cure times would range up to many hours. One additional complication would be that in some cases, it would be desirable to cure under high pressure (up to 1000 kPa), as in an autoclave. It is not clear what sort of problems, if any, this requirement would raise.

5. SUMMARY

The microgravity environment presents some interesting possibilities for the study of polymer science. Properties of polymeric

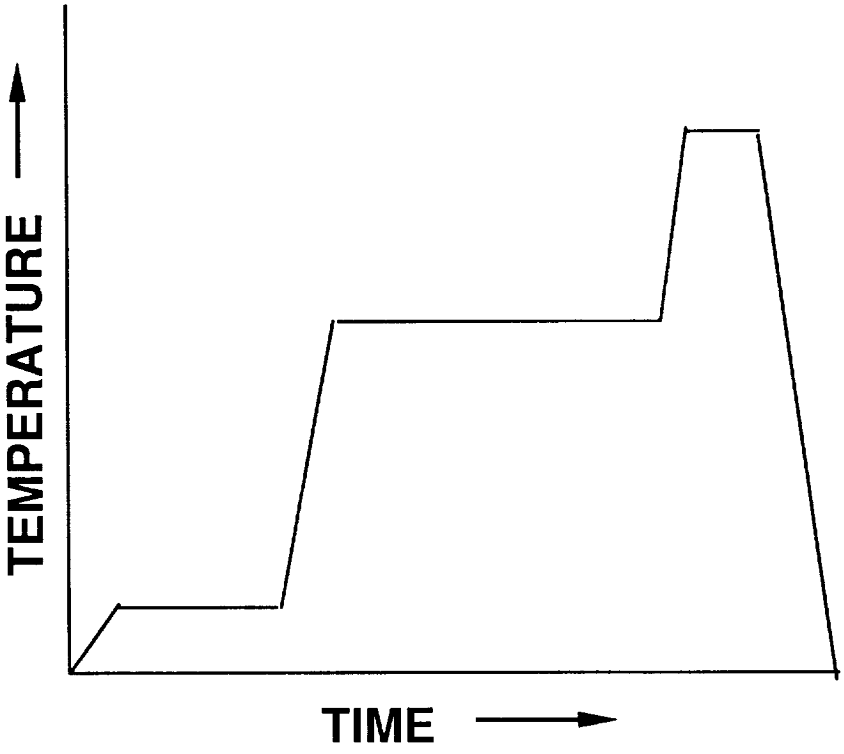

Figure 3. Typical heating curve for cure of composites.

materials depend heavily on their processing history and environment. Thus, there seem to be some potentially interesting and useful new materials that could be developed. The requirements for studying polymeric materials are in general much less rigorous that those for studying metals, for example. Many of the techniques developed for working with other materials, including heat sources, thermal control hardware and noncontact temperature measuring schemes should meet the needs of the polymer scientist.

6. REFERENCES

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