Processing Glass Fiber from Moon/Mars Resources

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Abstract

Processing of Lunar/Mars raw materials into usable structural and thermal components for use on a Lunar/Mars base will be essential for human habitation. One such component will be glass fiber which can be used in a number of applications. Glass fiber has been produced from two lunar soil simulants. These two materials simulate lunar mare and lunar highlands soil compositions. Short fibers containing recrystallized areas were produced from the as-received simulants. Doping the highland simulant with 8 weight percent boria yielded a material which could be spun continuously. The effects of lunar gravity on glass fiber formation were studied utilizing NASA's KC135 aircraft. Gravity was found to play a role in crystallization and final fiber diameter.

Introduction

With NASA's commitment to a permanent manned presence in low-Earth orbit (LEO), International Space Station (ISS), and eventual return to the moon, numerous studies have been undertaken in the areas of microgravity and lunar materials processing (Proceedings 1985; MRS Proceedings 1987). Continuous glass fiber processing is one such area of research interest. In LEO, the processing of optical and single crystal fibers may be enhanced due to the absence of gravity forces (Schlicta and Nerad 1991). In fact, a miniaturized fiber pulling apparatus has been developed (Schlicta 1988). On the lunar surface, abundant materials exist which can be used to produce structural materials. Similar materials should exist on Mars, but this paper will concentrate on lunar applications. The use of lunar regolith for the production of structural materials could greatly reduce the cost of construction and long-term habitation of a lunar colony. One lunar product, fiberglass, promises ease of manufacture and wide applicability (Criswell 1975). Continuous fiberglass can be utilized as reinforcement in structural composites, including pressure vessels, glass cables and woven-fiber insulation. The chemistry of lunar soils is similar to that of terrestrial basalts (Mackenzie and Claridge 1979; Allton,

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Galindo, and Watts 1985). Terrestrial basalt has been used to produce continuous glass fiber, with the chemical and mechanical properties similar to that of the standard E-glass (Chemical and Engineering News 1973; Subramanian, Yang, and Austin 1977). Comparable fibers have been produced with simulated basalt (Magoffin and Garvey 1990). This paper describes research which was undertaken to study the production of continuous glass fiber from two lunar soil simulants.

Experimental Methods and Results

Material

The materials used in this study were supplied by the University of Minnesota and are known as "Minnesota Lunar Simulant-1" (MLS-1) and "Minnesota Lunar Simulant-2"(MLS-2). MLS-1 is a low-titanium basalt (Weiblen, Murawa, and Reid 1990) similar in chemistry to that of Apollo sample 10084. The results of MLS-1 and Apollo sample 10084 are given in Table 1. The grain size of MLS-1 is similar to coarser lunar mare basalts (< 1mm) but is more equigranular, perhaps due to recrystallization (Weiblen, Murawa, and Reid 1990). Lunar soils generally contain varying amounts of glass and agglutinates due to micrometeorite impact (Papike, et al.). MLS-1 contains 10-30 weight percent glass products produced by processing in an in-flight sustained shockwave plasma reactor (ISSP) (Weiblen, Murawa, and Reid 1990). This compares to 10-80 weight percent found in lunar soil samples.

MLS-2 is a highlands simulant containing more silica and less titania than MLS-1. It also contains a great deal more alumina. Average starting compositions of MLS-2 are given in Table 2. Differential thermal analysis (DTA) was used to characterize each simulant and the glasses processed from each. The melting point for MLS-1 was determined to be
1200 °C (Figure 1). This was confirmed by heating a small amount of MLS-1 in a platinum boat at 1200 °C in a tube furnace and observing the material. Glassy MLS-1 was made by firing the simulant to 1450 °C for 24 hours in a box furnace, then pouring the melt on an aluminum quench block. This material was crushed and DTA performed. The result is shown in Figure 2. The exotherm noted at approximately 800 °C could be interpreted as recrystallization of the basalt material.

The DTA trace for MLS-2 yields a more complex situation. There is no clear evidence of distinct melting, but rather peaks indicating reactions and possible polymorphic transformations. DTA of glassy MLS-2 yields a trace with three exotherms and one endotherm (Figure 3). The exotherms likely represent recrystallization, while the endotherm may be due to structural transformation of the recrystallized material.

Viscosity measurements (Theta Industries, Port Washington, NY) of the MLS-1 and MLS-2 yielded the curves shown in Figures 4 and 5, respectively. The curves are plotted as log viscosity versus temperature. A curve for E-glass is shown for reference in Figure 6. This curve was plotted from tabulated viscosity data (Bansal and Doremus 1986). As can be seen from Figure 4, the viscosity of MLS-1 does not provide evidence the gradual decrease in viscosity with temperature as E-glass does. This implies that there is little or no working range to MLS-1. A comparative plot between MLS-1 and MLS-2

can be seen in Figure 7. In this case, viscosity in centipoise versus temperature is plotted. It can be seen from this plot that the MLS-2 has a higher viscosity at higher temperatures and a gentler slope. This implies a more stable working range.

Fiber Processing

In order to produce continuous fibers of MLS-1 and MLS-2, the apparatus shown in Figure 8 was constructed. It consisted of a platinum-wound furnace containing a single-hole platinum bushing, a power supply, and take-up reel. The furnace was mounted two feet above the take-up reel. The take-up reel was driven by an ordinary laboratory stirring motor. Vitrified simulant was placed into the bushing through the top of the furnace and heated to a temperature which allowed fiber spinning. Fiber spinning is initiated by hand drawing the fiber from the bushing orifice to the take-up reel using an alumina rod. Fiber was wound continuously until the bushing was empty of simulant.

Only short fiber segments were drawn from MLS-1. Ideal viscosity for fiber pulling is approximately 10,000 poise. For MLS-1, this viscosity lies well below the melting point and within the recrystallization range. It was observed that the simulant would recrystallize in the bushing below 1205 °C. Above this temperature molten simulant would run freely from the bushing orifice. This agrees with the viscosity data in Figure 4. The fibers which were successfully pulled showed small crystallites visible under a low-power microscope.

Longer segments of MLS-2 could be pulled; however, the same type of problems associated with MLS-1 occurred. In order to enhance the viscosity range of MLS-2, 8 weight percent of boric oxide was added to the raw simulant. Boric oxide is a glass former with low viscosity as compared to other glass-forming oxides (Doremus 1973). However, boric oxide shows anomalous viscosity behavior when mixed with glass modifiers. That is, the viscosity increases with additions of modifiers rather than decrease as seen with silicon dioxide. This has been attributed to the change in coordination number of oxygen with boron (Doremus 1973). Vitrified material was produced in the same manner as the two raw simulants. The doped simulant was pulled continuously at 1300 °C. Fibers as small as 30 microns in diameter were produced. Evidence of recrystallization was not observed using optical microscopy. Additions of boric oxide to MLS-1 did not enhance fiber pulling behavior.

Twenty-eight specimens from the wound fiber package of the doped MLS-2 were cut to 4-inch lengths and tested for tensile strength. The average fiber diameter was 45 microns. The mean strength was 60,000 psi with a standard deviation of 17,500 psi. To increase strength, the continuous doped fiber was produced with a polyvinyl alcohol sizing. The sizing was a 5 percent aqueous solution. The sizing was applied by pulling the fiber between two saturated pieces of felt. Each piece of felt was attached to a reservoir of polyvinyl alcohol solution. A hot-air gun was directed onto the fiber to dry the sizing before the fiber was wound on the take-up reel. Thirty-eight samples were tested for tensile strength. Average fiber diameter was measured to be 30 microns. The mean strength was 102,000 psi with a standard deviation of 40,000 psi. For comparison, E-glass fiber can have strengths as high as 500,000 psi.

Discussion

Using E-glass as an ideal glass-fiber forming material, the two raw simulants tested do not compare well. Both exhibit nonglass-like viscosity behavior and a strong tendency to recrystallization when the vitrified materials are heated to just below the melting point. Composition, of course, dictates these characteristics. The ability to produce continuous fiber from the doped MLS-2 indicates that the composition of the material was adjusted such that recrystallization tendencies were inhibited at the pulling temperature.

The strength of the doped material was seen to increase by 40,000 psi when coated. Since glass fails primarily from surface flaws, the coating acted to protect the as-spun fiber. It is felt that decreasing the fiber diameter to 10 to 15 microns will enhance strength.

Conclusions

It was concluded from this study that lunar simulants MLS-1 and MLS-2 in the as-received state were unsuitable for producing continuous glass fibers with the present capabilities. This was attributed to recrystallization near the melting point and a narrow viscosity range from which to pull the fibers. Doping MLS-2 with boric oxide yielded a material which could be pulled continuously. This is most likely due to compositional changes resulting in a wider viscosity pulling range and suppression of recrystallization. Breaking strength of doped MLS-2 was increased by coating the fiber with polyvinyl alcohol during the spinning operation. The decrease in fiber diameter from 45 microns to 30 microns could also account for some of the strength increase.

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Key Words

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