Characterization of Polybenzimidazole (PBI) Film at High Temperatures

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April 1992

Prepared for  
Lewis Research Center  
Under Contract NAS3-25266
Polybenzimidazole, a linear thermoplastic polymer, was evaluated for use as high temperature capacitor dielectric. The material was characterized with and without heat treatment in terms of its dielectric properties in a frequency range of 50 Hz to 100 kHz. These properties, which included the dielectric constant and dielectric loss, were also obtained in a temperature range from 20°C to 300°C with an electrical stress of 60 Hz, 50 V/mil present. The ac and dc breakdown voltages of silicone oil-impregnated films as a function of temperature were also determined. In this paper, the experimental procedures and the results obtained are discussed.

**EXPERIMENTAL PROCEDURE**

Polybenzimidazole (PBI) films of 1.5 mil thickness, manufactured by Hoechst Celanese, were used in these investigations. The PBI film is a linear thermoplastic polymer which has excellent thermal stability and strength retention over a wide range of temperature [3]. It is chemically stable and is used as reinforcement of high performance composites, filament winding and structural applications. Some of the properties of the film are given in Table I.

| Service temperature (°C) | >300 |
|--------------------------|------|
| Shrinkage (%) @ 315°C    | 3    |
| Density (g/cc)           | 1.2-1.4 |
| Dielectric constant      | 4.4-16.2 |
| Dissipation factor (x10^-2) | 2.4-57  |
| Dielectric strength (KV/mil) | 4-7  |
| Volume resistivity (ohm.cm) | 10^-10^-16 |
| Surface resistivity (ohm/sq.) | 5x10^-10  |

The experiments carried out were performed on as-received (control C) as well as on heat-treated (HT) samples. Heat treatment was done by heating the material in an oven at a temperature of 60°C for a time duration of 6 hours. A capacitance measurement system (General Radio Precision Capacitance System 1621) together with a set of concentric ring brass electrodes were used in the measurement of the dielectric constant and the dissipation factor of the samples at room temperature in a frequency range of 50 Hz to 100 kHz. These properties were further characterized in a temperature range of 20°C to 300°C with an applied electrical stress of 60 Hz, 50 V/mil using Tettex Instruments, Type 2821 Capacitance System and Type 2914 Dielectric Test Cell.
RESULTS AND DISCUSSIONS

The dielectric constant and the dissipation factor at room temperature as a function of frequency are shown in Figures 1 and 2, respectively. These properties of the film were obtained in the frequency range of 50 Hz to 100 kHz for both the as-received as well as those of heat-treated sample at 60°C for 6 hours. It can be clearly seen that both properties exhibited significant decrease after heat treatment. For example, at any given frequency, the decrease in the dielectric constant amounted to about as much as 50% of the original value. Similarly, the value of the dissipation factor decreased sharply after the film was heat-treated. It is believed that the reduction in the values of the dielectric properties after heat treatment is due to the removal of any moisture present and possibly to some thermally-induced molecular agitation phenomenon in the polymer.

A comparison of the ac and dc breakdown voltages at room temperature of control and heat-treated samples is given in Table II. Also listed are the data for both dry as well as for silicone fluid-impregnated samples. In general, the breakdown strength increased slightly after heat treatment. Once again, this might have been due to the removal of trapped moisture upon heating the material. Table II also shows that the breakdown voltages of the impregnated samples are much higher than their dry counterpart. This happens because the impregnant, which has higher dielectric strength than air, penetrates the material and fills up microvoids and gas cavities as these are usually considered as primary sites for breakdown initiation.

The ac and dc breakdown strengths of impregnated PBI films before and after heat treatment as a function of temperature are shown in Figures 5 and 6, respectively. It can be seen that for either case, ac or dc, the dielectric strength reduces slightly with increase in temperature. This reduction in the breakdown voltage can be attributed to the softening of the polymer film when exposed to high temperatures. It can also be noted that the heat-treated samples displayed, at any given temperature, higher dielectric strengths than those of the untreated film. This is due to the fact that in addition to removing any trapped moisture in the film, the application of heat would have facilitated and lead to better impregnation of the material.

CONCLUSION

The results obtained in this work indicate that the PBI film remained relatively stable when exposed to temperatures as high as 200°C. At higher temperatures, the film, however, exhibited an increase in its dielectric properties. Its breakdown behavior displayed week dependence on temperature as both the ac and dc dielectric strengths exhibited slight decrease with increase in temperature. It is believed that improvement in the manufacturing and processing of the film can possibly result in good electrical and other properties that are more stable with temperature. Further research and experimental studies are required to better and fully characterize this and other materials for potential use as high temperature capacitor dielectrics.

ACKNOWLEDGEMENTS

This work was supported by NASA Lewis Research Center, Contract # NAG1-25266, Task Order # 5423-01, "High Temperature Dielectrics." The authors thank J. E. Ramirez and E. J. Powers (Hoechst Celanese Co.) for supplying the film and I. Myers and S. Domitz (NASA L&RC) for their technical contribution.

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| Table II. Effect of heat treatment on the dielectric strengths of dry and impregnated PBI films. |
|---------------------------------------------------------------|
| sample          | dry [kV] | imp [kV] | dry [kV] | imp [kV] |
| as-received     | 5.69     | 9.36     | 8.52     | 9.13     |
| heat-treated    | 6.36     | 9.40     | 9.75     | 10.26    |
Figure 1. Dielectric constant versus frequency for control(○) and heat-treated(●) samples.

Figure 2. Dissipation factor versus frequency for control(○) and heat-treated(●) samples.

Figure 3. Dielectric constant of heat-treated samples versus temperature while stressed at 60 Hz, 50 V/mil.

Figure 4. Dissipation factor of heat-treated samples versus temperature while stressed at 60 Hz, 50 V/mil.

Figure 5. Dependence of ac dielectric strength on temperature. (○:control; ●:heat-treated)

Figure 6. Dependence of dc dielectric strength on temperature. (○:control; ●:heat-treated)
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Polybenzimidazole, a linear thermoplastic polymer with excellent thermal stability and strength retention over a wide range of temperature, was evaluated for its potential use as the main dielectric in high temperature capacitors. The film was characterized in terms of its dielectric properties in a frequency range of 50 Hz to 100 kHz. These properties, which included the dielectric constant and dielectric loss, were also obtained in a temperature range from 20 °C to 300 °C with an electrical stress of 60 Hz, 50 V/mil present. The ac and dc breakdown voltages of silicone oil-impregnated films as a function of temperature were also determined. The results obtained indicate that while the film remained relatively stable up to 200 °C, it exhibited an increase in its dielectric properties as the temperature was raised to 300 °C. It was also found that conditioning of the film by heat-treatment at 60 °C for 6 hours tend to improve its dielectric and breakdown properties. The results are discussed and conclusions made concerning the suitability of the film as high temperature capacitor dielectric.