Measurement of the cryogenic tensile properties of polymer composites

Pan Q.Y., Fu S.Y. , Zhang Y.H., Li Y.

Cryogenic Materials Division Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100080, China

In this paper, measurement of tensile strength, modulus and strain of polymer composites was conducted on a universal testing machine using our self-designed tensile testing jigs at cryogenic temperature. The cryogenic tensile properties of nanofiller reinforced polymer composites have been studied as a function of filler contents and compared with that at room temperature. The results showed that there exists an optimal filler content corresponding to the maximum strength and modulus. And it was shown that the tensile strength and Young's modulus of the polymer composites were generally higher at 77 K than that at room temperature except at the 20 wt % of clay for clay/polyimide nanocomposites. Moreover, the elongation to failure has much lower values at the cryogenic temperature (77 K) compared with that at room temperature.

INTRODUCTION

The research and development of polymeric materials for cryogenic applications have been intensified in recent years, especially in the fields of space science, superconducting magnet technology and also the other advanced cryosurgery and cryobiology in the medical field technologies [1-5]. However, at the present time, a judgment on the utility of a specific polymer material under cryogenic conditions usually requires a test demonstration because of the limited condition available and the uncertain influence of many factors such as sample geometries, test methods and environmental variables. There is, therefore, much to be done to develop the test technology for measurement of the cryogenic properties of polymers. In this paper, tensile testing jigs have been designed for measurement of cryogenic tensile properties of polymer composites. The tensile properties of nanofiller reinforced polymer composites have been studied then at room and cryogenic temperatures (77 K) taking into account the effects of filler contents.

EXPERIMENTAL DETAILS

The polymer composites were synthesized in our laboratory. The PI/MMT composite films were prepared via in-situ polymerization. The sizes of film specimens were respectively 10 mm×90 mm (room temperature) and 10 mm×120 mm (cryogenic temperature). The gauge length was 50 mm. The thickness of films was 25-39 um, and the specimens were cut from free films. Another, the silica nano-particles were incorporated into epoxy resin by sol-gel process and SiO_2/epoxy nanocomposites with different silica contents were then prepared. Cryogenic tensile properties of polymer composites were measured at a loading rate of 2 mm/min with a RGT 20A Testing Machine using our cryogenic system.

In general it's very hard to measure the cryogenic mechanical performance of polymer composites with high accuracy and credibility because the polymer composite samples are not easy to be clamped using commercial tensile jigs. Moreover, the commercial jigs have other disadvantages such as complex structure and big volume etc. In order to study the cryogenic properties of polymer composites, the tensile jigs suitable for measurement of the cryogenic tensile properties of plastic materials are designed in terms of the standard of ASTM D638-01, see Figure 1. The self-designed jigs have some advantages over commercial jigs. Its volume is about 1/10 and its weight is about 1/16 of the commercial jigs. The self-designed jigs are simple and convenient to be fixed for tensile testing at low temperature. Moreover, the entire measurement system can be conveniently connected to the cryostat which allows the low temperature to be reached and maintained. Cryogenic strain gauge extensometers were used to measure the specimen deformation. Then, the results for cryogenic tensile strength, modulus and strain of polymer composites can be obtained using a tensile testing machine. Another set of self-designed jigs have also been designed for measurement of the cryogenic tensile properties of polymer films, which are not given because of the limit of the paper length.

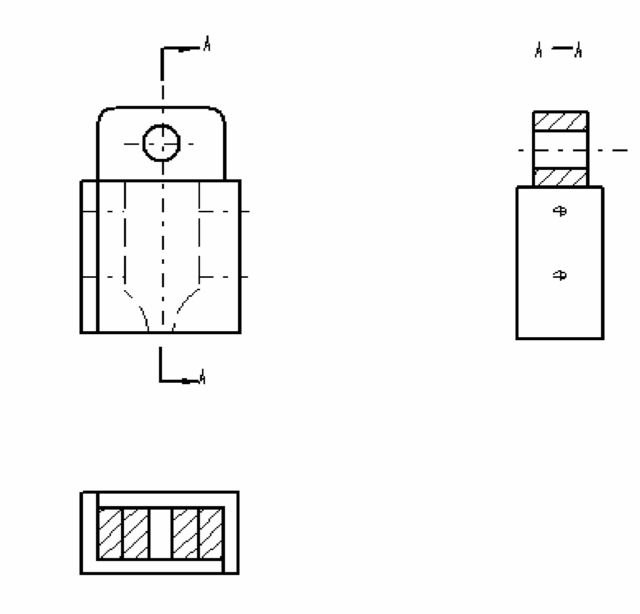
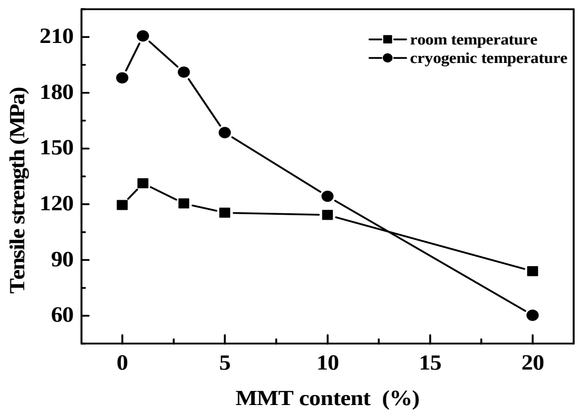


Figure 1. Drawing of the self-designed tensile jig for measurement of cryogenic tensile properties of polymer composites.

RESULTS AND DISCUSSION

In this study, the results for the tensile properties of the PI/MMT composite films and the SiO_2/epoxy nanocomposites measured using our self-designed system at room and cryogenic (77 K) temperatures are shown in Figure 2 and 3 taking into account the effects of filler contents. Similar results for the tensile properties at room temperature have also been obtained using normal commercial jigs that are not suitable for measurement of cryogenic tensile properties of polymer composite films. Figure 2 and Figure 3 showed that the effects of the clay content on the tensile strength and the elongation at break of PI/clay hybrid films at room and cryogenic (77 K) temperatures. It is exhibited that the tensile strength of the PI/clay hybrid films was generally higher at 77 K than that at room temperature except at the 20 wt % of clay. This observation is reasonable because the polymer molecules are tightly arranged at cryogenic temperature so that the strength at cryogenic temperature is higher than that at room temperature. The exception at the 20 wt % of clay for clay/polyimide nanocomposites can also be reasonably explained. Since at such a high clay content the clay aggregates would be very severe, the cracks formed easily during cryogenic tensile testing would then extremely readily propagate along the aggregate/polyimide interfaces at cryogenic temperature, leading to a lower strength. Moreover, the elongation to failure has much lower values at the cryogenic temperature (77 K) when compared with that at room temperature. This is due to the fact that the polymer molecules become frozen and are much more brittle at cryogenic temperature, bringing about lower ductility at cryogenic temperature when compared with room temperature.



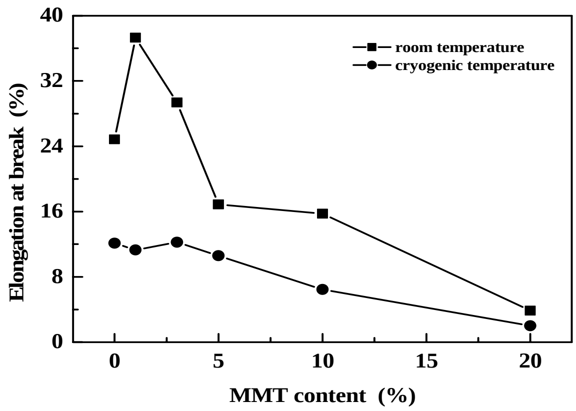


Figure 2 Effects of the clay content on the tensile strength of PI/clay hybrid films at room and cryogenic (77 K) temperatures.

Figure 3 Effects of the clay content on the elongation at break of PI/clay hybrid films at room and cryogenic (77 K) temperatures.

Table 1 Tensile properties of SiO_2/epoxy nanocomposites at room and cryogenic temperature (77 K).

The specimen composition	Tensile strength（MPa）		Tensile modulus（GPa）		Elongation at the break (%)	
	300 K	77 K	300 K	77 K	300 K	77 K
RAL-230 （epoxy）	47.5	72.7	1.50	4.85	6.5	1.6
2 wt % SiO_2/RAL-230	50.2	84.6	1.54	5.44	16.6	1.8
4 wt % SiO_2/RAL-230	46.3	102.5	1.51	6.30	15.5	2.3

Table 2 Comparison of the tensile properties of SiO_2/epoxy nanocomposites at room temperature (300 K) using the self-designed and commercial jigs

The specimen composition	Tensile strength（MPa）		Elongation at the break（%）	
	Commercial	Self-designed	Commercial	Self-designed
RAL-230（epoxy）	45.5	47.5	6.0	6.5
2 wt % SiO_2/RAL-230	51.2	50.2	16.2	16.6
4 wt % SiO_2/RAL-230	48.1	46.3	14.8	15.5

The cryogenic tensile properties of SiO_2/epoxy nanocomposites at room temperature (300 K) and cryogenic temperature (77 K) were investigated (see Table 1). Similar results for the tensile properties at room temperature have also been obtained using normal commercial jigs that are not suitable for measurement of cryogenic tensile properties of polymer composites. Table 2 showed the tensile properties of SiO_2/epoxy nanocomposites at room temperature measured with the two different jigs. It can be seen that the self-designed jigs have little effect on measured results for the tensile properties of SiO_2/epoxy nano-composites, indicating that our self-designed jigs can be employed to precisely measure the tensile properties of polymer composites. Moreover, it can be seen that the tensile strength and Young's modulus of the SiO_2/epoxy nanocomposites were generally higher at 77 K than that at room temperature. The results showed that the addition of 2wt% SiO_2 leads to an increase of 16% in tensile strength and 12% in Young's modulus, the addition of 4wt% SiO_2 brings about an increase of 36% in tensile strength and 30% in Young's modulus compared with room temperature, while the elongation-to-break nanocomposites have a dramatic reduction with the addition of SiO_2 because the materials become brittle. The improvement of the strength and modulus at cryogenic temperature by the addition of silica nanoparticles can be easily understood because the filler-matrix interface adhesion becomes stronger at cryogenic temperature because of clamping stress while the stiffness of inorganic nano-particles have a much higher modulus than that of polymer matrix. The above results exhibited that self-designed tensile testing jigs suited well for measurement of tensile properties of composite materials at low temperature.

CONCLUSIONS

In summary, as shown above, all the measured results can be reasonably explained. It is thus believed that our self-designed mechanical testing system can be credibly used to measure the cryogenic tensile properties of polymer composites.

REFERENCES

1. S. Nishijima, T. Okada, Y. Honda. Evaluation of epoxy resin by annihilation for cryogenic use. Advances in cryogenic engineering. Vol 40:1137.
2. D. Evans. Turn, layer and ground insulation for superconducting magnets. Physica C. 354 (2001):136-142.
3. S. Usami, H. Ejima, T. Suzuki, et al. Cryogenic small-flaw strength and creep deformation of epoxy resins. Cryogenics. Vol 39(1999):729.
4. H. Yamaoka, K. Miyata and O. Yano. Cryogenic properties of engineering plastic films. Cryogenics (1995) 35:787-789.
5. Takefumi Horiuchi and Tsutomu Ooi Cryogenic properties of composite materials. Cryogenics (1995) 35:677-679.