An innovation of embedded alumina/acrylic rubber composite materials

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Introduction

Composite materials are made from a filler, either particles, flakes or fibres, embedded in a matrix made of polymer, metal or glass.[1] Some particles require a small amount of water, or some other polar molecule, to show a significant electrorheology effect. Particle diameters range from 0.1 to 100 microns. The suspensions are fairly concentrated, with particle volume fractions ranging from 0.02 to 0.50.[2] Nevertheless, according to the broadest definition, a composite is any material consisting of two or more distinct phases, combining an insulating ceramic and a polymer host, to form a flexible composite material to suit particular properties such as mechanical, electrical, thermal and/or a coupling between these properties. Making composite materials, by a combination of an insulating ceramic (alumina) and a polymer (acrylic elastomer, AR71) of suitable properties, means not only choosing the right materials processed in a particular way, but also, with coupling them with the best possible design structure. Nowadays the most popular choices in applications of composite materials are biomedical devices, artificial muscles, biomimetic actuators, vibration isolators, and smart engineering devices.[1–3]

The aim of this study is to study particulate volume fractions and size distribution of alumina (dispersed phase) in acrylic elastomer, AR71 (matrix or continuous phase) in terms of ER solid effect to FTIR, storage modulus, and XRD.

Materials

Aluminium oxide (Al_2O_3) was purchased from Sigma-Aldrich Chemical Co., Ltd., USA. The specific gravity of alumina powder is 3.90 g/cm^3. Alumina, an inorganic non-metallic material, can be considered a typical representative of the groups of structural ceramics. Alumina has good creep strength, high hardness and high wear resistance, chemical inertness and resistance against high temperature corrosion even when operated in air, as well as high electrical resistance.[4] The starting acrylic rubber (AR71) was supplied by Nippon Zeon Co., Ltd., USA. The AR71 was a fast curing type in a milk-white slab, suitable for moulded products, such as seals and gaskets. The mooney viscosity, Tg, and specific gravity of AR71 are 50, –15°C, and 1.11 g/cm^3, respectively. ER suspensions, with the percentage of alumina particulate volume fractions (%V/V) of 0.0000 (AR71/Al_0), 2.7430 (AR71/Al_1), 5.3400 (AR71/Al_2), 7.8010 (AR71/Al_3), 10.1380 (AR71/Al_4), 12.3600 (AR71/Al_5), 14.474 (AR71/Al_6), 22.000 (AR71/Al_7), were prepared. Polar molecules, acrylic rubber (AR71) samples, were dissolved and swollen by a 10% by volume acetone medium.

Experimental

ER suspensions, with alumina particulate volume fractions of 0.00000 (AR71/Al_0), 0.02743 (AR71/Al_1), 0.05340 (AR71/Al_2), 0.07801 (AR71/Al_3), 0.10138 (AR71/Al_4), 0.12360 (AR71/Al_5), 0.14474 (AR71/Al_6), 0.22000 (AR71/Al_7), were prepared. Polar molecules, acrylic rubber (AR71) samples, were dissolved and swollen by a 10% by volume acetone medium. The suspensions were prepared by stirring at room temperature for 24 h. The suspensions were poured into a glass mould to make a sheet-shaped gel and were allowed to dry slowly, and were covered with a glass plate to avoid dust and bubbles at room temperature overnight. The dried samples were milk white.

Table 1. Mid-IR peak patterns of acrylic rubber and alumina composite materials.

Wave number (cm^{-1})	Functional groups
3450	OH stretching (ref. CAS 7732-18-5)
2980	CH stretching vibration of O-CH_2CH_3 (ref. CAS 9003-01-4)
1727, 1780	>C=O and C=C stretching of acrylic rubber (ref. CAS 79-10-7)
1446	CH_3 asymmetric deformation (ref. CAS 9003-01-4)
1378	CH_3 deformation of O-CH_2CH_3 (ref. CAS 79-10-7)
1250	Asymmetric C-O-C stretching vibration of rubber (ref. CAS79-10-7)
1156	R-CO-R symmetric stretching (ref. CAS 79-10-7)
980, 1021	=C-H and C-O-O-H bending (ref. CAS 79-10-7)
852	C-O-O-C of rubber (ref. 20)
796	Al-O-C stretching
580 and 650	Al-O stretching

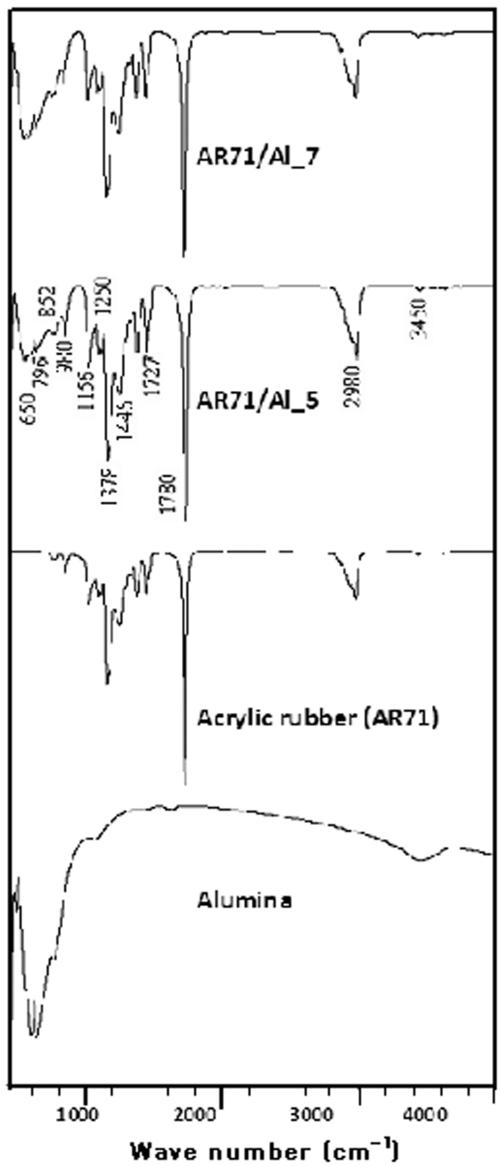

Figure 1. Mid-IR spectra of acrylic rubber, alumina, and acrylic rubber-alumina composite samples.

Results and discussion

The FTIR spectra of alumina (Al_2O_3), acrylic rubber (AR71), and the AR71/Al_2O_3 composite materials are shown in Figure 1 and data tabulated in Table 1.

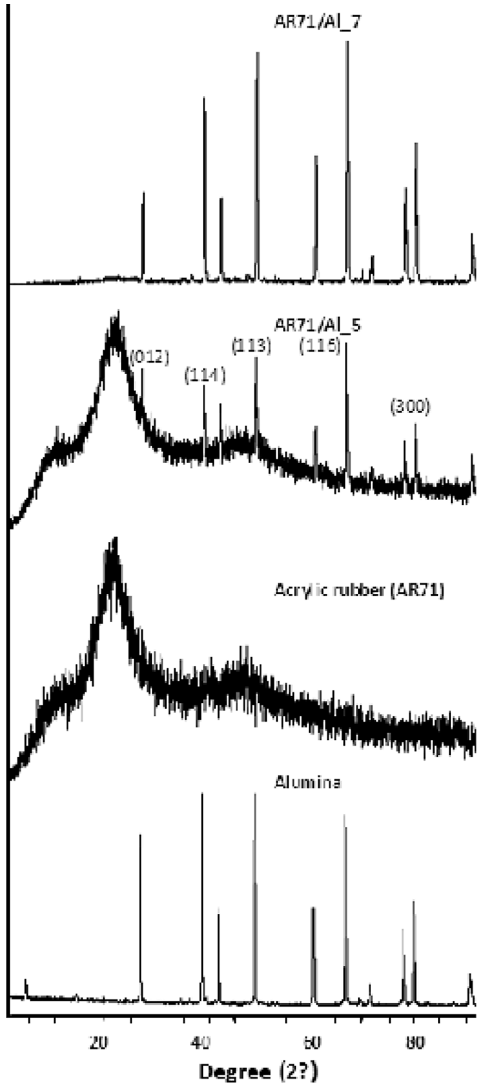

Figure 2. XRD patterns of acrylic rubber, alumina, and acrylic rubber-alumina composite samples.

The characteristic peaks of AR71/Al_5 were a 3450 cm^{-1} ν(O-H), 2980 cm^{-1} ν(C-H) and ν(CH_2), 1727 and 1780 cm^{-1} ν(C=O) and ν(C=C), 1446 cm^{-1} and 1378 cm^{-1} (CH_3 asymmetric deformation), 1250 cm^{-1} ν(C-O-C), 1156 cm^{-1}(R-CO-R), 980 and 1021 cm^{-1} δ(=C-H) and δ(C-O-O-H), 852 cm^{-1}(C-O-O-C), 796 cm^{-1}(C-O-Al), and 580 cm^{-1} and 650 cm^{-1} (Al-O). Our FTIR result is confirmed by the results reported by Jha and Bhowmick.[5]

The X-ray characteristic peak of pure acrylic rubber, AR71 is the amorphous phase. The XRD patterns of pure alumina powder resemble those recorded at the International Centre for Diffraction Data (JCPDS patterns of aluminium oxide, rhombohedral form 00-042-1468 and 01-073-1512, and aluminium oxide hydrate, hexagonal form 01-070-0384). After doping, AR71/

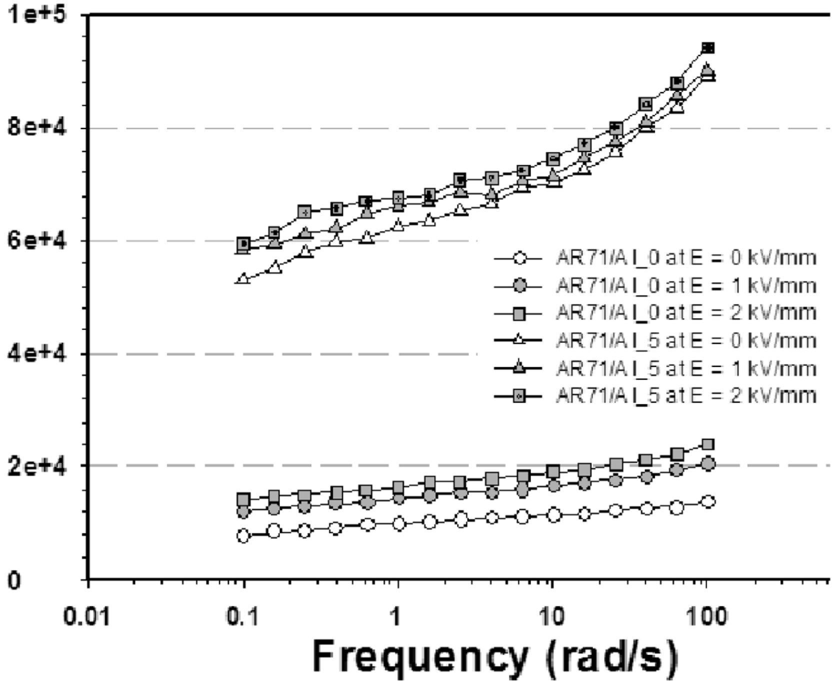

Figure 3. Storage modulus applied electrical field strength.

Al_2O_3, indicated that the rhombohedral form, which is the corundum phase, resembled those recorded JCPDS number 00-042-1468, and 01-073-1512 as shown in Figure 2.

The alumina particles are uniformly dispersed in the acrylic elastomer (AR71) matrix. The phase compositions of composite materials compose of amorphous and crystalline phases depending on the volume fraction of alumina particles.

Figure 3 shows that the experimental result indicated that the dynamic storage modulus, G', increased steadily with the increase of optimum particulate volume fraction.

The increasing of G'_o can be attributed to the effect of alumina particles acting as reinforced fillers.

Conclusions

Our results suggest that alumina (Al_2O_3) particles can be used as a filler to absorb energy loss and to store additional elastic energy within the acrylic rubber matrix. Acrylic rubber molecules contain C-O bonds and alumina particles compose of ionic bonds. The ER properties, G'; G''; and $\Delta G'_{2kV/mm}/G'_o$, under the oscillatory shear mode, of AR71/Al_2O_3 for the effects of electric field strength and particulate volume fraction are measured. The best composite sample obtained was the AR71/Al_5. With and without an electrical field, the dynamic moduli G'_o, $G'_{2kV/mm}$, G''_o, $G''_{2kV/mm}$, and $\%\Delta G'/G'_o$ of the AR71/Al_5 composite material were 62986, 65990, 9754, 6591, 4.55%, respectively. The AR71/Al_2O_3 composite materials can be used for biomimetic actuators, artificial muscles, vibration isolators, and smart engineering devices.

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