MECHANICAL AND ELECTRICAL PROPERTIES OF STYRENE- BUTADIENE-STYRENE/ ALUMINIUM COMPOSITES

N.M.Renukappa[1], Siddaramaiah*[,2,3], R.D.Sudhaker Samuel[1], T.Jeevananda[3],
Nam Hoon Kim[4] and Joong- Hee Lee[3,4]

[1]Department of Electronics & Communication Engineering, Sri Jayachamarajendra College of Engineering, Mysore - 570 006, India;

[2]Department of Polymer Science and Technology, Sri Jayachamarajendra College of Engineering, Mysore – 570 006, India;

[3]Bin Fusion Research Team, Department of Polymer & Nano Science and Technology, Chonbuk National University, Jeonju, Jeonbuk, 561-756, South Korea

[4]Department of Hydrogen and Fuel Cell Engineering, Chonbuk National University, Jeonju, Jeonbuk, 561-756, South Korea

Abstract

A series of styrene-butadiene-styrene/aluminium (SBR/Al) composites have been compounded with different weight ratios of Al. The prepared SBR-Al systems have been characterized for different mechanical properties such as tensile strength, tensile modulus and surface hardness have improved with the increase in content of Al in SBR matrix. This may is because of the increase in polymer-filler interaction. The electrical properties such as volume conductivity, surface resistivity, dielectric constant, dissipation factor (tan delta), and break down voltage of SBR/Al composites have been measured with reference to volume fraction (V_f), frequency and temperature. The resistance of the SBR-Al composites is found to be ohmic. The voltage-current (V-I) characteristics for SBR-Al also exhibit a linear relationship indicating the ohmic behavior.

INTRODUCTION

Composites made with insulating polymer and filler are useful engineering applications and they play an important role in high voltage fields such as potential grading materials, thermally conductive materials and are used as key parts in copying machines. For instance, from the combination of different fibers or fillers with polymer matrices, polymer composites can be produced for use in the electronic industry, for its dielectric properties for use as capacitors [1-2]. In electrical and electronic industries, these composites are used for making panels, switches and insulators. By mixing insulating polymers with conductive fillers they can be easily configured into various complicated shapes. Various conductive fillers including metal powders, such as Al, Cu, Au, Ag and stainless steel or carbon and graphite powders are employed [3-4] for composites fabrication. A survey of literature reveals that systematic studies on electrical properties of aluminum (Al) powder filled rubber composites are seldom reported. This article reports the effect of the V_f of Al, frequency, temperature and relative humidity on some electrical properties of SBR-Al systems.

2 EXPERIMENTAL

Preparation of composite materials: The Al filler (Al), SBR-1502 and technical grade ingredients like processing oil, accelerator, wax, etc., have been used without further purification. The Al with different weight ratios viz. 10, 20, 30, 40, 50, 70 and 90 % was mixed with SBR along with 3g ZnO, 1.5g stearic acid, 4g paraffin wax, 5g resin and 3g TMPT in a two-roll mill. The compounded rubber was vulcanized under 100 psi load at 155^0C for 15 min.

Techniques: Tensile behaviour was measured using Hounsfield universal testing machine (4302 model) as per ASTM D 882 method and surface hardness as per ASTM D 2240. Electrical properties of Al filled SBR composites were measured using a precisions LCR meter model 4285A and model 4192A HEWLETT PACKARD.

3. RESULTS AND DISCUSSION

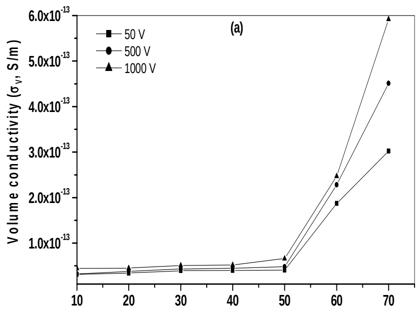
3.1 Mechanical Properties

The measured mechanical properties such as tensile strength, percentage elongation at break, tensile modules and surface hardness of SBR-Al are given in Table 1. The table indicates that the tensile strength increases with increase in Al content up to 60 phr. Further increase in Al content reduces the tensile strength of the composites. A significant improvement in tensile modulus and surface hardness is observed with increase in filler content. This result clearly indicates that there is a good interaction between polymer-polymer, filler-filler and polymer-filler components.

3.2 Electrical Properties

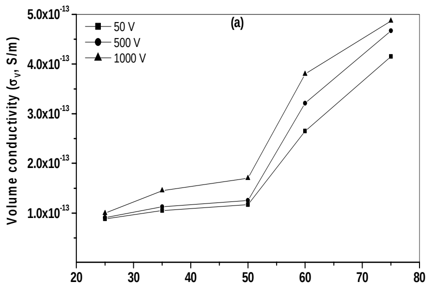
3.2.1 Volume conductivity

(i) Effect of volume fraction: Conductivity of composites increases as conducting filler increases in the insulating media (Figure 1). Increase in conductivity follows a nonlinear behavior. At lower dosage of filler (0-50 phr) the increase in conductivity is insignificant and above 50 phr of Al, a significant increase in conductivity is noticed. At lower dosage of Al, conducting particles are far apart and hence, the conductivity of the composite remains the same as that of an insulator. The conductivity of the composite does not change appreciably until the V_f of the metal particles reaches a critical V_f value and that increases precipitously beyond critical V_f. This is due to fact that conducting filler is coated by insulator (SBR) matrix.



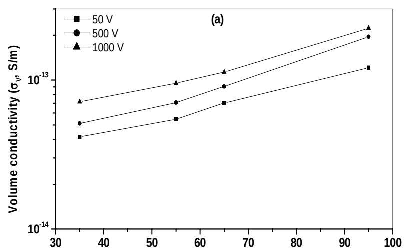
Volume fraction (phr)

Figure 1. Effect of volume fraction on conductivity of SBR-Al composites



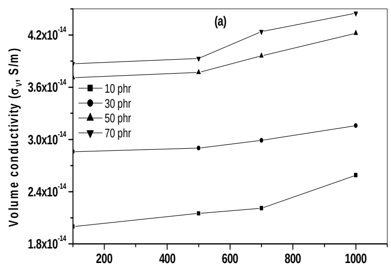
Temperature (^oC)

Figure 2. Effect of temperature on conductivity of SBR-Al for 10 phr Al filler.



Rrelative humidity (RH, %)

Figure 3. Plot of conductivity verses relative humidity for 10 phr Al filled SBR composites



dc potential (V)

Figure 4. Effect of dc potential on volume conductivity of SBR-Al composites

(ii) Effect of temperature: Figure 2 indicates that conductivity varies exponentially with temperature, similar to semi-conductor. The observed increase in the conductivity with Al concentration is attributed to the percolation behavior, where composites exhibit a sudden transition from insulator to semi-conductor phase at certain filler concentrations. This sensitive transition is a characteristic of the percolation threshold which is mainly attributed to the rapid increase in the total surface area of the very fine Al particles with much surface contact and aggregate connections.

(iii) Effect of relative humidity: The variation in conductivity as a function of RH for 10 phr of Al filled SBR systems is shown in Figure 3. From the figure it is observed that there is a linear variation in conductivity with RH.

(iv) Effect of dc potential: The plot of conductivity as a function of dc potential for SBR-Al is shown in Figure 4. A marginal increase in conductivity is observed with increase in voltage. This is because the fact that applied dc potential induces orientation polarization. The effect of dc potential is insignificant for lower dosage Al filled system.

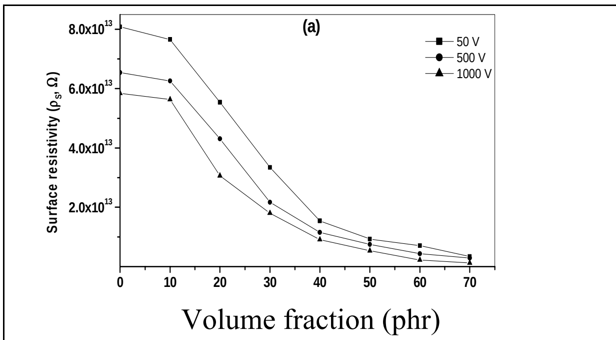
Table 1. Physico-mechanical properties of SBR-Al composites

Al content in SBR (phr.)	Tensile strength (MPa) ±1.5 %	Elongation at break (%) ±2 %	Tensile modulus (MPa)±1.5 %	Surface hardness (Shore-A) ±1.5
10	1.5	500	1.12	33
20	1.6	500	1.25	38
30	1.9	500	1.47	44
40	1.9	500	1.48	46
50	2.0	500	1.49	49
60	2.2	480	1.52	51
70	1.9	460	1.55	54

3.2.2 Surface resistivity

(i) Effect of volume fraction (V_f): From Figure 5 it is observed that the variation of surface resistivity occurs in three transitions. First, second and third regions occur in the Al content range 0 -10 phr, 10 -50 phr and 50 -70 phr respectively. In the first region a slight reduction in surface resistivity is observed and a drastic reduction takes place in the second region. A slight reduction in surface resistivity can be observed in the third region. It is observed that at low filler content the resistivity of the composites is only slightly different from that of the base polymer. However, beyond certain critical filler loading, a significant drop in resistivity is observed. This is because, region the increase in filler concentration simply depends on increase in the number of networks formed.

(ii) Effect of temperature: The effect of temperature on surface resistivity values of SBR-Al have been studied (Figure 6). A considerable reduction in surface resistivity value is observed with increase in temperature.



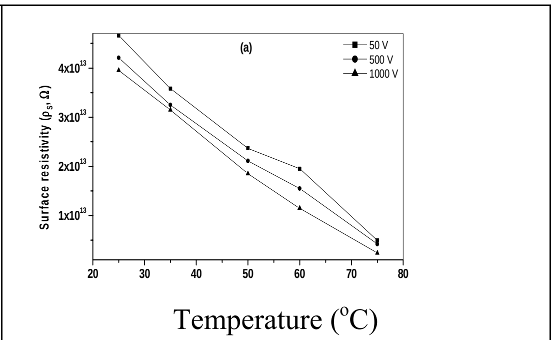
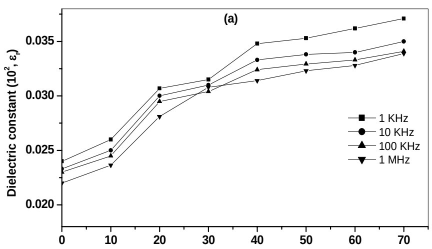


Figure 5. Effect of volume fraction of conducting filler on surface resistivity of SBR-Al	*Figure 6. Plot of surface resistivity verses temperature for SBR+10 phr Al composites*

3.2.3 Dielectric constant (ε_r)

(i) Effect of volume fraction (V_f): The effect of V_f of Al filler on dielectric constant (ε_r) of SBR-Al composites at different frequencies has been studied (Figure 7). From Figure 7 it is noticed that ε_r increases with increase in dosage of Al.

(ii) Effect of frequency: The ε_r value increases with increase in dosage of Al filler. Lowest ε_r value is noticed for unfilled SBR systems as compared to Al loaded systems. A gradual reduction in ε_r values with increase in frequency is observed from the plots for all formulation. A slight reduction in ε_r can be seen in the 10^1 - 10^3 KHz frequency range.



Volume fraction (phr)

Figure 7. Plot of dielectric constant verses V_f of Al for SBR-Al composites

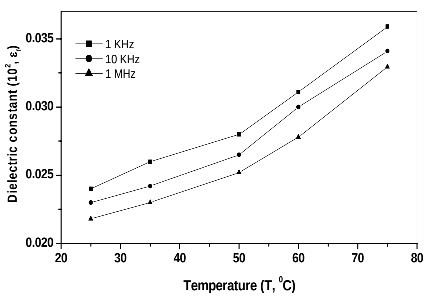


Figure 8. Plot of dielectric constant verses temperature for 10 phr Al filled SBR-Al

(iii) Effect of temperature: The plot of dielectric constant (ε_r) versus temperature at different frequencies for SBR/Al composites is shown in Figure 8. Dielectric constant increases with increase in temperature following a nonlinear behavior. The variation in $\varepsilon_{r\ is}$ is not identical for different formulations. This is because 10 to 30 phr Al loaded systems behave like a base polymer, whereas >50 phr Al loaded systems behave as semi-conducting materials.

3.2.4 Dissipation factor (tan δ)

The variation of tan δ with V_f of Al for SBR-Al systems at different frequencies. It is such that dissipation factor increases with increase in V_f of Al. From the figure a considerable increase and nonlinear in dissipation factor is observed with increase in V_f. It was not possible to measure tan δ with further increase in frequency (> 10 MHz), because system becomes unbalanced. A gradual increase in tan δ value is obtained with increase in frequency up to 10^3 KHz. Further increase in frequency (>10^3 KHz) yields a considerable increase in tan δ value for high dosage of filler filled systems.

3.2.5 Breakdown voltage (BDV)

The effect of conducting filler content on the breakdown voltage (BDV) of SBR-Al at different temperatures is shown in Figure 9. With increase in filler content upto 30 phr a slight decrease in BDV value is noticed.

Voltage-current characteristics of SBR composite: V-I characteristics of SBR-Al systems obtained is shown in Figure 10 for different Al loaded systems and it exhibits a linear relation indicating ohmic behaviour of the material.

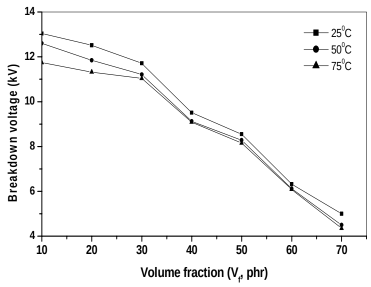


Figure 9. Effect of V_f of conducting filler on breakdown voltage of SBR-Al

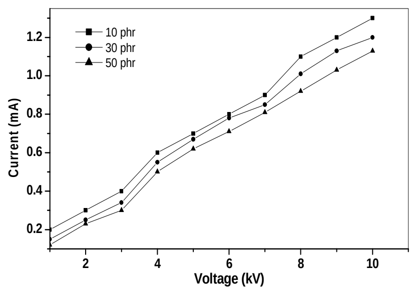


Figure 10. Voltage-current characteristic plots for SBR-Al composites

5.4 CONCLUSION

This study has essentially dealt with the mechanical and electrical properties of insulator-conducting SBR-Al composites. The tensile strength tensile modulus and surface hardness increase with increase in Al content and 60 phr filler loaded composite is the optimised composition. In addition to this the insulation properties also not affected significantly upto 30 phr Al. The resistance of the SBR-Al composites is found to be ohmic and its resistivity depends on the Al concentrations. A significant influence of V_f and temperature on conductivity and surface resistivity are observed.

Acknowledgements: Authors would like to express their sincere thanks to Chonbuk National University and to the BK-21 program for their financial support.

5.0 REFERENCES

1. Wu W., Wallace E.R., Lin E.K., Lynn G.W., Glinka C.J., Ryan E.T., Ho H.M., J. Appl. Phys., **87**, 1193-1200 (2000).
2. Jo M.H., Park H.H., Kim D.J., Hyum S.H., Choi S.Y., Paik J.T., J. Appl. Phys., **87**, pp. 1299 (1997).
3. Margolis J.M., “Conductive Polymers and Plastics”, (Chapman and Hall, New York, 1989).
4. Delmonte J., “Metal/polymer Composites”, (Van Nostrand, New York, 1990).