Chapter

DC Conductivity of Activated Carbon Filled Epoxy Gradient Composites

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Abstract

This chapter reports the DC conductivity behavior of activated carbon powder filled epoxy gradient composites. Gradient composites are the composite materials in which the there is gradually variation in some direction to achieve gradient in properties. Graded materials are generally defined as the materials, which exhibit variable functional performance with location and show continuous variations in morphology and composition. Functionally graded metal matrix composites have been of great practical importance. Graded metal matrix composite have gradual compositional variations from ceramic at one surface to metal at the other, leading to special advantages of smooth transition in thermal stresses across the thickness and minimized stress concentration at the interface of two dissimilar materials. Therefore graded metal matrix composites are finding applications in aggressive environments with steep temperature gradients such as turbine components and rocket nozzles. Since the properties of material in FGMs are variable across the entire material, and depends on the spatial position of the material. Functionally graded materials are designed with varying properties such as changing their chemical properties, changing mechanical, magnetic, thermal, and electrical properties. Now a days there are FGMs designed as stepwise-graded materials, while others are fabricated to have continuous-graded materials depending on their areas of application.

Keywords: activated carbon powder, epoxy, gradient, DC conductivity, composites

1. Introduction

Activated carbon powder filled epoxy composites having 3 wt.% of activated carbon powder and epoxy resin have been developed. DC conductivity measurements are conducted on the graded composites by using an Electro-meter in the temperature range from 28 to 150°C. DC conductivity increases with the increase of distance in the direction of centrifugal force, which shows the formation of graded structure with the composites. DC conductivity increases on increase in activated carbon powder content. Activation energy was calculated and showed ionic conduction in the composites. Polymers with conductive fillers have many applications in solid state devices, mostly in fabrication of polymer light-emitting diodes, microelectronic components, optical displays as battery and fuel cell electrodes, antistatic media, corrosion-resistant materials, etc. [1–3]. The advantage of using conductive filler is that it is possible to control their electrical conductivity.

Besides good electrical conductivity and optical characteristics, conducting polymers have several other advantages as plasticity, low cost, lightweight and ease of fabrication [4–6].

Functionally graded composites are a novel class of composites which shows unique properties. Their graded property can be used as medical implants, for thermal protection in space vehicles, and they can be used as thermoelectric converter for energy conservation. Due to their versatile nature, they are widely used in nano, opto-electronic and thermoelectric materials also. Future applications of carbon nanotubes (CNT) reinforced functionally graded composite materials (FGCM) is expected to unique material having a wide range of possibilities in various areas such as aerospace, energy, automobile, medicine and structural industry. These materials can be used as gas adsorbents, probes, chemical sensors, nanopipes, nano-reactors, etc.

FGM can be used according the desired applications in biomedical application, as implants in human body to function properly without destroying the surrounding tissues.

Nigrawal and Chand has studied the dielectric properties of activated carbon filled epoxy composites and reported that small values of activation energy obtained at higher frequencies suggested that the conduction in the composite was due to hopping of charge carriers [7].

Epoxy resins are used as a thermosetting polymer matrix for the preparation of the conductive polymer composites [7–9]. Most of the electrically conductive polymer composites consist of carbon fibres or carbon black. A degree of conductivity is achieved when the concentration of the fillers is high enough so as to form a conductive network within the polymer matrix and such critical concentration, is known as percolation threshold. Conductivity of polymers containing conductive fillers, depends on the size and shape of the filler particles, spatial distribution and the contact resistance [10–14] and also determines the conditions of charge transport. Polymers have wide applications as electrical and electronic materials in the field of electro-photography and opto-electronics [15, 16] and can also be used as interfacial barrier layers and protective coatings. However, prior to using these materials in these specialized applications it is essential to know fundamental properties such as the mechanisms of electrical conduction, charge storage, etc.

It is well known that the addition of nano size additives into polymers has paved way for advanced technologies, such as in electrochemical displays, sensors, catalysis and redox capacitors, etc. [7]. For instance graphene based polymer composites possess potential applications in radiation and electromagnetic shielding, antistatic, shrinkage and corrosion-resistant coatings, and other mechanical and functional attributes such as stiffness, barrier, conducting capabilities, light emitting devices, batteries and other functional applications. Other potential applications could be for high temperature conducting adhesive, or for the bipolar plates for polymer electrolyte membrane fuel cells. Several carbon additives have also been utilized to enhance the properties of a polymer, the most popular being carbon blacks, carbon nanotubes [15–19].

During curing of the thermoset matrix, an internal stress comes and increases the pressure between and decreases the contact resistance. Development and modification of carbonaceous materials in necessary to increase the specific energy and power of supercapacitors, by controlling the pore size distribution, introducing electroactive metallic particles or electroconducting polymers [17–19].

It was reported that conductive polymer composite sensor array made from carbon black with polymers [20, 21].

An activated carbon has extended surface area, microporous structure, high adsorption capacity and high degree of surface reactivity. Activated carbon can be used into various structures such as fill-form, felt-form and fabric-form for various applications [22].

Different types of activated carbon powder and as well as activated carbon fibers with surface area in the range of 86–3000 m^2/g were used for electrical double-layer capacitors [23, 24].

The conductivity of conductive filler polymer systems depends on the filler type, concentration, structure, surface properties, and conductivity properties of the matrix, distribution of particles in the matrix, contacts between particles, and particle orientation. It is well known that carbon black (CB) particles with a larger structure may render a relative high conductivity [25].

In a recent study effects of carbon nanotube on volume fractions, slenderness ratio, and core-to-face sheet thickness ratio on free vibration behavior of sandwich beams with functionally graded carbon nanotube-reinforced composite was reported. Numerical results were also reported to compare the behavior of sandwich beams of carbon nanotube-reinforced composite face sheets to those with functionally graded carbon nanotube-reinforced composite face sheets [26].

Flexural properties of epoxy nano composites increased on addition of 1 and 5% vol nano-activated carbon as compared to neat epoxy. A noticeable increment in flexural strength and modulus, was observed on addition of 1 and 5% vol nano-activated carbon as compared to pure epoxy. The effect of potassium hydroxide and phosphoric acid treatment on activated carbon epoxy nano composites were also investigated. The flexural toughness of both the composites were in range between 0.79 and 0.92 J. It was reported that the flexural strength of activated carbon-bamboo stem, activated carbon-oil palm, and activated carbon-coconut shell reinforced epoxy nanocomposites showed almost same value in case of 5% potassium hydroxide activated carbon [27].

In case of many FGMs components, properties varies in thickness direction [28]. However, in many modern applications these material have variable properties in both thickness and axial directions [28]. In a paper a gradient material in which properties varies in both aspects are developed and studied [28, 29]. Such smart materials are known as bidirectional functionally gradient (BDFGMs) materials. In which laser metal deposition based AM technique was used [29].

2. Materials and methods

Activated carbon powder used in this study was obtained from Ranbaxy Fine Chemicals, New Delhi, India. Epoxy used in this study was obtained from Hindustan Advanced Materials (India) Pvt. Ltd., Chakala (east), Mumbai, India. Activated carbon powder filled epoxy gradient composites have been developed by using centrifugation process. In this process centrifugal force is applied in the X direction. Gradient samples are prepared from the activated carbon powder filled mix having 3 wt.% of activated carbon powder. Activated carbon powder was added to a mix of epoxy resin and hardener (10:8). Total mix was thoroughly stirred with the help of a glass rod. Details of set up and process of making gradient composites are as reported in earlier patent (Chand and Hashmi) [27]. Total mix was thoroughly stirred with the help of a glass rod at 24°C for 2 min. The total mix was kept in a cylindrical mould to make graded sample. The sample with mould was rotated at 800 ± 50 RPM at a radius of 130 mm. Graded sample pin was removed from the mould after post curing at room temperature for 24 h. Composite pin was sliced into four pieces starting from centre to periphery and designated as sample 1, 2, 3 and 4, respectively. Samples were coated on both the sides by air drying type silver paint before the electrical measurements.

Density of activated carbon powder filled epoxy gradient samples was measured by using a Mettler Toledo precision balance.

2.1 Resistivity measurements

Resistance (R) values of activated carbon powder filled epoxy gradient samples were measured by using a kiethley electrometer model 610°C in the temperature range ranging from 28 to 150°C. Heating rate was kept constant at 1°C/min.

DC conductivity (σ_{DC}) values were calculated by using the following relation

$$\rho = R^{*} A/l \quad (1)$$

where R is the resistance value of the sample; A (cm^2) is the area of the electrodes; and l (cm) is the thickness of the sample.

Conductivity was calculated by using the following formula.

$$\sigma DC = 1/\rho \quad (2)$$

2.2 Density measurements

Densities of activated carbon filled epoxy resin composites were determined by using a Mettler Toledo precision balance.

3. Results and discussion

Figure 1 shows the schematic view of the gradient composite sample prepared using a mix of activated carbon powder and epoxy. This schematic diagram shows the distribution of activated carbon powder in the composite.

Table 1 lists the density of activated carbon powder filled epoxy gradient composites at different distances from periphery. This shows the increase of distance from periphery decreases the density of the composite. This is due to the decrease in activated carbon content. **Figure 2** shows the variation of DC conductivity with temperature for activated carbon powder filled epoxy sample 1. In this plot DC conductivity increased at 108°C then at 112°C it became constant up to 128°C and then there is a sudden increase in DC conductivity after 128°C, and it increases up to 150°C.

Figure 3 shows the variation of DC conductivity with temperature for activated carbon powder filled epoxy gradient composites sample 2. This plot shows that up to 98°C there is no increase in DC conductivity. After 106°C there is a sudden increase in DC conductivity with increase of temperature and a peak was found at 138°C temperature. This plot shows that there is an increase in DC conductivity with the increase in activated carbon powder content at all temperatures. Another important

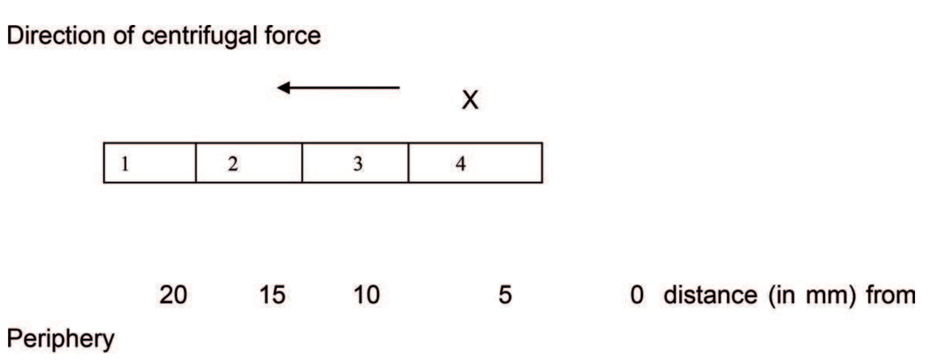

Figure 1.
Schematic diagram of activated carbon distribution in four sections.

Sample no.	Density (g/cc)
Sample 1	1.000
Sample 2	1.05317
Sample 3	1.06169
Sample 4	1.0999

Table 1.
Lists the density (ρ) values of gradient composite at different distances.

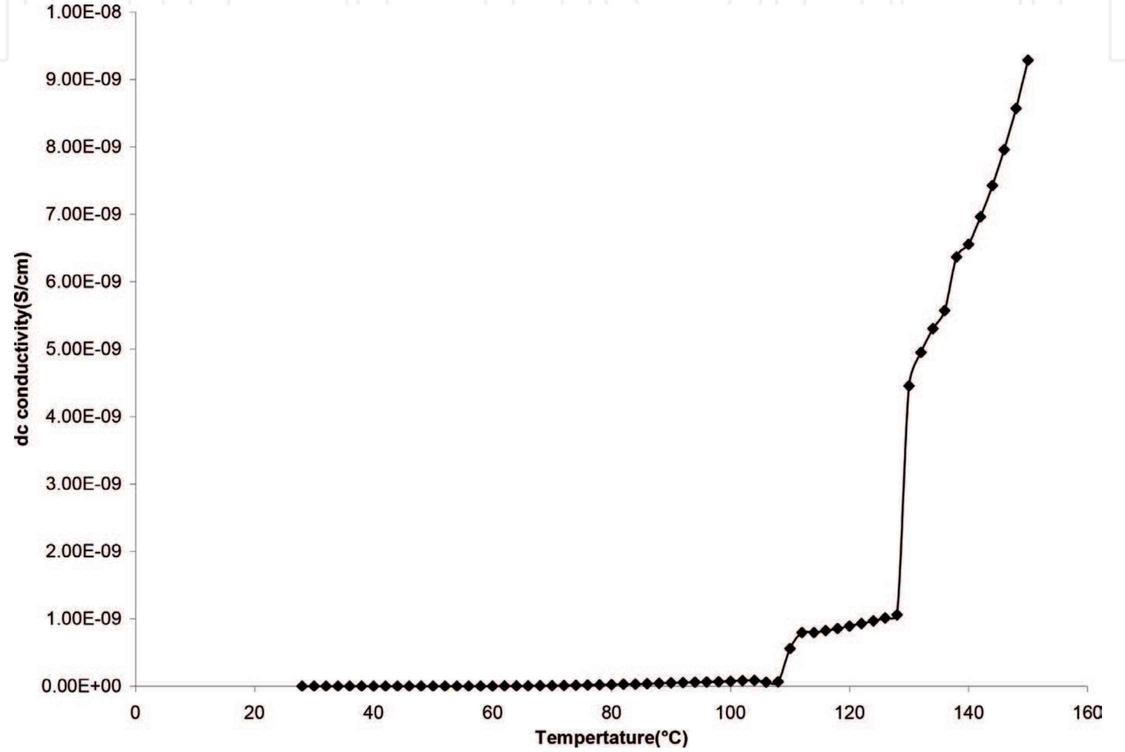

Figure 2.
Variation of DC conductivity with temperature for activated carbon filled epoxy sample 1.

observation is that there is a peak shift towards the higher temperature side with increase in activated carbon powder content.

Figure 4 shows the variation of DC conductivity with temperature for activated carbon powder epoxy gradient sample 3.

It has been observed that DC conductivity suddenly increases after 100°C in all the cases. Increase of DC conductivity appeared at 124°C and it goes on increasing up to 150°C.

Figure 5 shows the variation of DC conductivity with temperature for activated carbon powder filled epoxy gradient composites sample 4. DC conductivity increases from 110°C then after 132°C there is an increase in DC conductivity.

It was reported that electrical conductivity of reinforced papers with respect to the weight fraction of Ag-plated carbon fiber increased with increasing content of carbon fiber. Due to the three-dimensional contacts between carbon fibers the electrical conductivity of the paper increased irrespective of the increase in thickness. The electrical conductivity of the reinforced paper having the Ag-plated carbon fiber was high because of the large number of pores formed on the activated carbon fiber [30]. When the volume percent of carbon content is increased or decreased, the material exhibits a change in resistivity. Heating can affect the conductivity of the polymer material on increasing the temperature [31]. On increasing

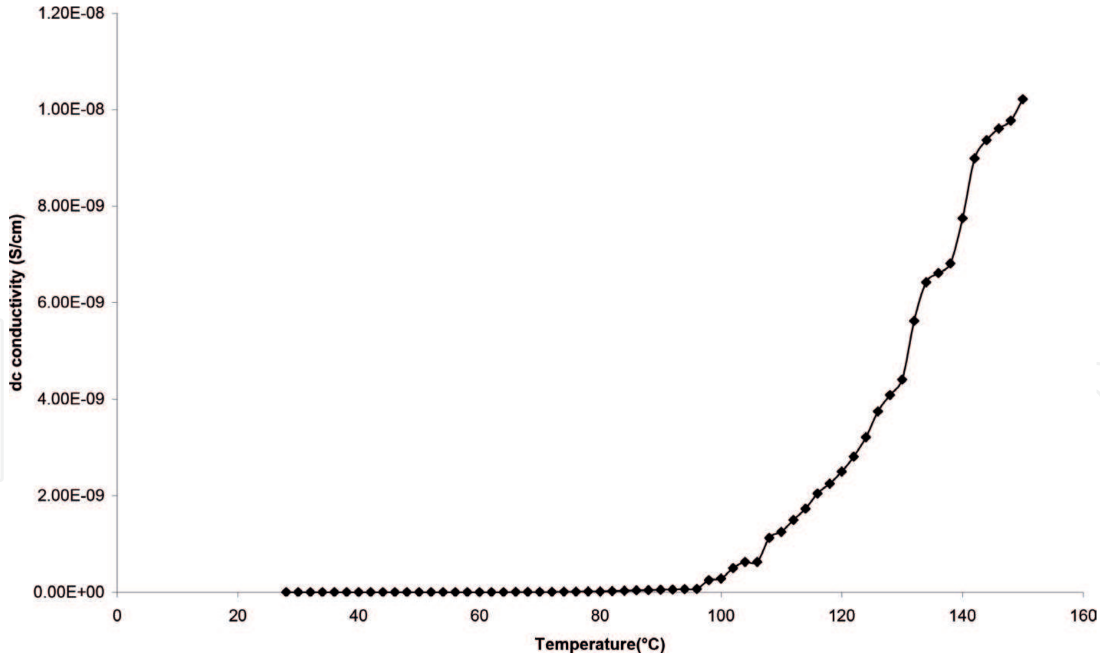

Figure 3.
Variation of DC conductivity with temperature for activated carbon filled epoxy sample 2.

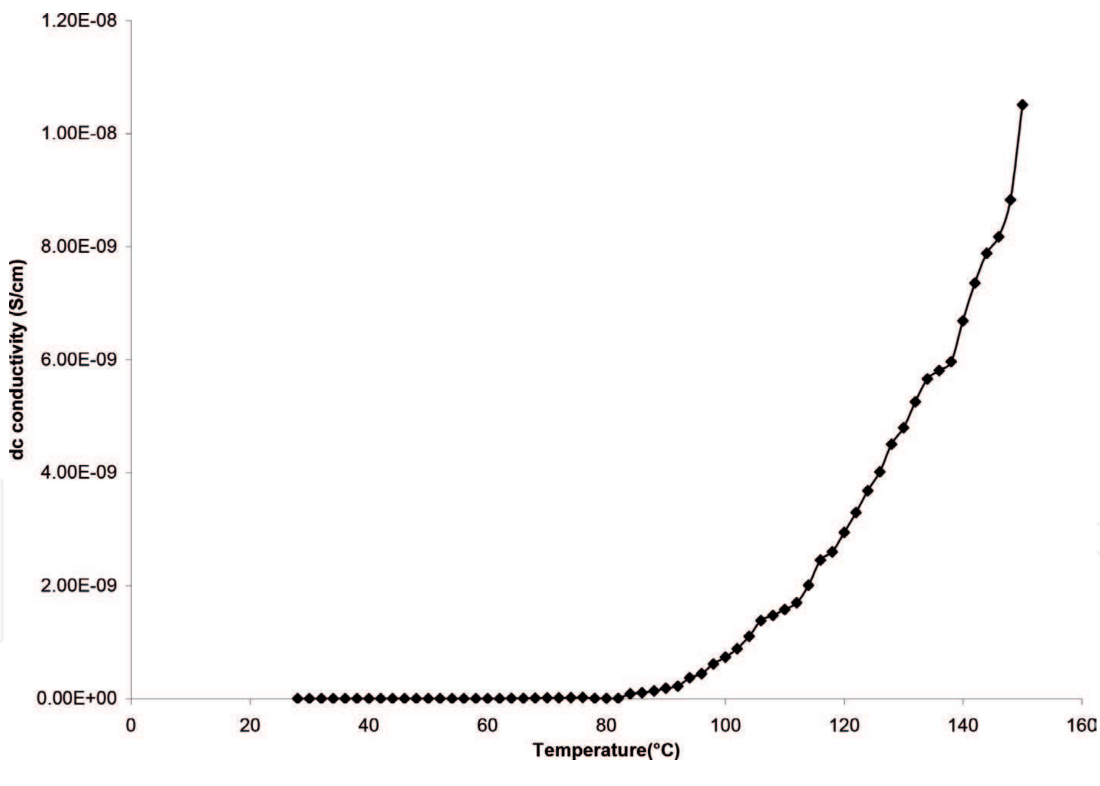

Figure 4.
Variation of DC conductivity with temperature for activated carbon filled epoxy sample 3.

temperature polymer expands as compared to CB aggregates and the interparticle distance between the aggregates increases, which causes destruction of conductive networks and as a result there is an increase in the resistivity with temperature.

It was reported that the electrical resistivity (ρ) of composite at low temperature is dominated by the electronic properties of the nanotubes, and tunneling nature [32–34].

$\ln \sigma$ vs. T^{-1} plot for activated carbon powder filled epoxy has been analysed by using the following Arrhenius equation.

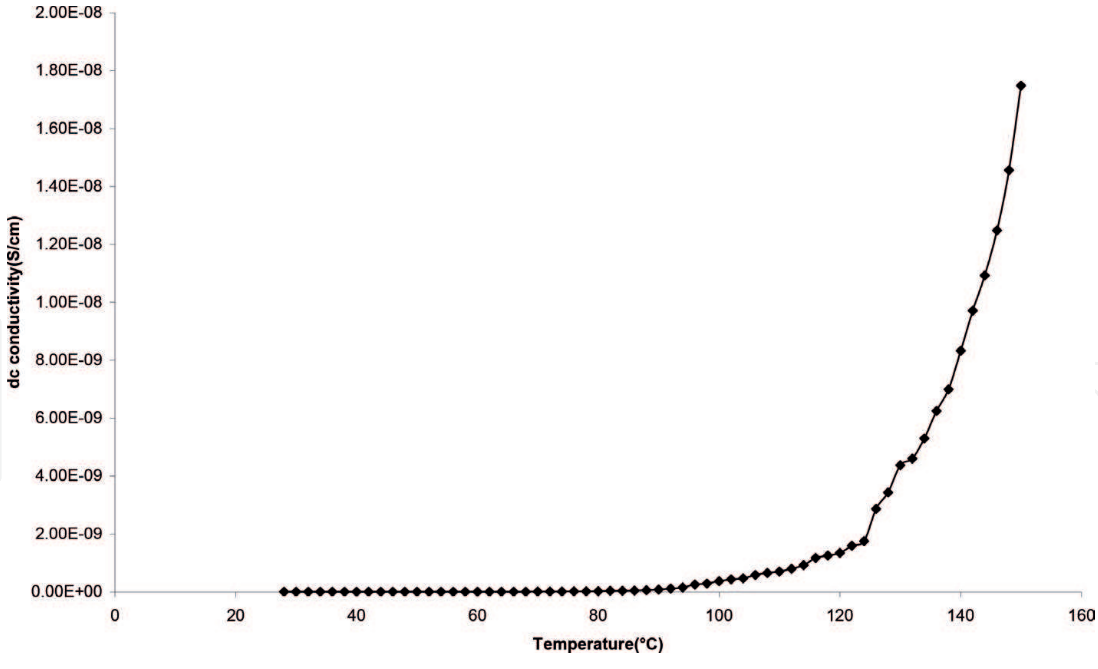

Figure 5.
Variation of DC conductivity with temperature for activated carbon filled epoxy sample 4.

Sample no.	Activation energy (eV)
Sample 1	1.056682
Sample 2	1.224812
Sample 3	1.278476
Sample 4	1.297912

Table 2.
Lists the activation energy (eV) of sample 1, sample 2, sample 3, and sample 4.

$$\sigma = A\ \exp^{-W_E/KT} \tag{3}$$

where W_E is the activation energy of conduction; k is Boltzmann's constant; A is a constant; and T is the temperature in (K).

On increasing filler concentration, conductive paths among the filler particles increase, and the average distance becomes smaller as a result conductivity of the composite increased.

4. Conclusions

a. DC conductivity value increases from sample 1 to sample 4. This shows the existence of graded structure (**Table 2**).

b. Increase of activated carbon content increases the DC conductivity.

c. Different transition points are observed in DC conductivity plots in different samples. Transition temperature shifts to lower side with the increase in activated carbon content.

d. Activation energy decrease with increase of activated carbon content in the samples.

e. These developed graded polymeric matrix composites having gradual variation of composition from carbonaceous filler at one surface to polymer dominated other end can be developed for desired electrical applications. Different type of sensors such as electrical resistance sensors, current sensors and temperature dependent sensors are required for various applications. Graded polymeric composites show variable resistivity behaviour, which can have potential applications in electromagnetic shielding, antistatic, corrosion-resistant coatings, conducting capabilities, light emitting devices, batteries and sensors. By virtue of the improved thermal stress relaxation and adhesive properties etc. Graded polymeric composites show variable resistivity behaviour, which can have potential applications in electromagnetic shielding, antistatic, corrosion-resistant coatings, conducting capabilities, light emitting devices, batteries and sensors.

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