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Conductive Rubber Composites Filled with Short Carbon Fibre and Their Application in Electromagnetic Interference Shielding material: A Review

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Abstract: The application of electrically conductive rubber composite is increasing in years to come to researchers as well as to industries. When used as conductive materials the merits are light weight, flexible, easy processing and chemically resistance. This review focuses on the electrical properties of short carbon fibre filled conductive rubber composites, summarizing key advances made on controlling rubber blend morphology to improve electrical conductivity and percolation limit in conductive composites. Short carbon fibre exhibits excellent conductive filler than conventional carbon black and offer lower percolation value due to its fibrous nature, and high aspect ratio(L/D). A high level key theories and mechanisms for conduction are reviewed. This review also focuses on factors effecting electrical properties like temperature and processing parameters. This also focuses on some important applications, like electrostatic charge dissipation, surface hearers, floor heating mat, touch control switches, strain sensor etc and potential application in electromagnetic interference shielding effectiveness.

KEY WORDS: Blend Morphology, Conductive Rubber Composite, Volume Resistivity, Electromagnetic Interference Shielding(EMI), Percolation limit, Short Carbon Fibre (SCF).

I. INTRODUCTION

The performance of Rubber to act as electrical insulators is the basis for their widespread use in the electrical and electronic fields [1-3]. Resistivity of rubber matrices is generally in the range of 10^{15} ohm.m. It is possible to impart electrical conductivity in rubber materials by blending rubbers with dispersing electrically conductive fillers like carbon blacks, carbon fibres, metal particles, graphene or conducting polymers such as polyaniline. Their fields of applications are now steadily extending. Conductive rubber composites are widely used for different application such as electrostatic charge dissipation, heat controlling floor mat, touch control switches, pressure sensitive sensor, EMI shielding materials, conductive component in different electrical and electronic equipments etc [4-6]. Among different type of conductive additives, carbon black is the most widely used for rubber matrices. It not only provides a high degree of conductivity but also imparts good reinforcement to the rubber matrix. However, for many applications high conductivity is the main requirement and mechanical properties of such system may be a secondary consideration. In many cases, short carbon fibre (SCF) may be a better choice as conductive filler than conductive carbon black, as it can provide higher conductivity at lower loading. Short Carbon fibre may be considered as chain like aggregate of carbon particles having long chain length and high aspect ratio (L/D). These SCF filled conductive composite have the advantages of ease of shaping, flexible, low density and wide range of electrical conductivities as well as corrosion resistance [7-8].

The present review article focuses on main advances of the electrical properties of carbon fibre filled conductive rubber composite, summarizing key advances made on controlling rubber blend morphology to improve electrical conductivity and percolation limit in conductive composites and application as EMI shielding materials. A high level key theories and mechanisms for conduction are reviewed during percolation and beyond percolation limit. This review focuses on factors effecting electrical properties like temperature, pressure, mechanical stress and different other processing parameters. This also focuses on some important applications like electrostatic charge dissipation, surface hearers, carbon fibre mat, controlled electrical resistivity materials, electromagnetic interference shielding effectiveness, touch control switches, strain sensor etc. of this composite.

II. CARBON FIBRE

There are various types of carbon fibre. Depending on their objectives they are classified according to the elemental composition, structure, technology of preparation or precursor raw materials. Their manufacturing technology is based on the high temperature pyrolysis of organic

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compounds like polymeric fibre materials, conducted in an inert atmosphere. Generally, polyacrylonitrile (PAN), pitch, viscose jute are used as precursor for carbon fibre preparation. The mechanical and electrical properties of the carbon fibre are mainly dependent on the precursor and technology of preparation.

Over ninety percent of PAN based carbon fibres are known as precursor fibres. Carbon fibres are manufactured from PAN in two stage processes Fig.1.

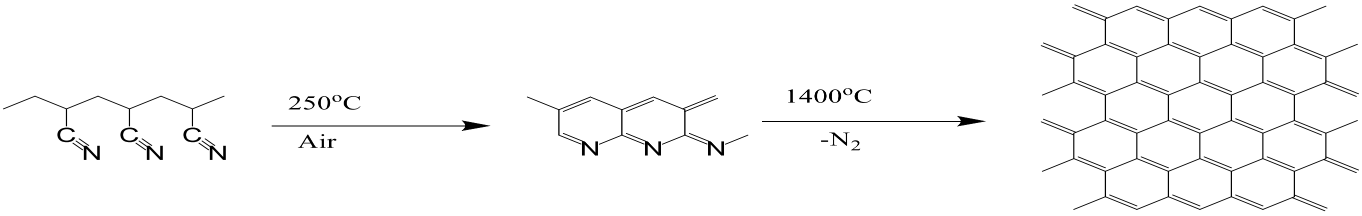

Fig.1. Reaction scheme from PAN

In the first step of the process commonly described as stabilization, serves to prepare the fibre for the pyrolysis of the solid phase called carbonization. In a protective atmosphere and at temperature up to 1400 ^{0}C, the ladder polymers of the stabilized fibres reorganize themselves into graphite like structure. Fitzer [9] proposed an idealized macromolecular structure of PAN based fibre obtained after the process of stabilization and subsequent carbonization of PAN Fig. 2. The carbonization of stabilized fibres results in gradual crosslinking of the chains, aromatization and finally in the formation of graphite like layered structure. The supramolecular structural models for carbon fibre are sheet like form (a ribbon like model). The layer is formed by the condensation process, which takes place during carbonization. Two dimensional layers of the hexagonal aromatic planes represent this. However Johnson [10-11] suggested a different model. In this opinion, the carbon fibre is a heterogeneous system of layered planes consisting of voids fig.3. The presence of conjugated double bonds in the fibre structure and less electron capturing group (e.g. oxygen, hydrogen containing groups) provides higher conductivity to the PAN based carbon fibre.

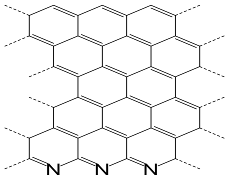

Fig.2.An idealized macromolecular structure of PAN based fibre [9]

The electrical performance of a conducting fibre composite depends on the formation of three dimensional networks. The upper limit to the conductance between opposite faces of composite black is the conductance of uniform wire of the conductor, whose length equal to the total volume of the conductor of the block [12]. In accordance with this equivalent wire limit the maximum conductivity δ_{max} that can be obtained with a volume fraction f_v, of a conductor of conductivity δ_c in a composite is

$$\delta_{max} = \delta_c . f_v$$

For a composite containing randomely distributed fibres orientation of fibres different from the electric field direction effectively reduces the conductivity from maximum limit. If the fibre content is high, inter fibre contacts will be sufficiently numerous for nearly all of the fibres to be active. Then the effect of branch points and dead ends can be neglected and the equation for the conductivity of a composite containing randomely oriented fibres can be approximated as :

$$\Delta \delta = 2/3\pi . \delta_c . f_v$$

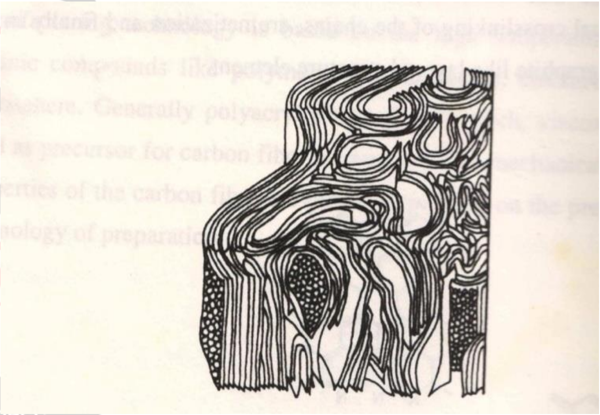

Fig.3 Schematic three dimensional representation of carbon fibre (Graphitic structure containing void) [11]

III. PERCOLATION LIMIT

The intrinsic conductivity of pure rubber matrix is very low in the order of 10^{-18} to 10^{-15} Ohm^{-1}.cm^{-1}. Initially on gradual increase in conductive fibre loading into the rubber matrix conductivity increases slowly. At low levels of carbon fibre loading the conductive particles are insulated by rubber matrix i,e the particles are isolated from each other and the composite conductivity is nearly equal to the pure rubber matrix. On gradual incorporation of short carbon fibre into the insulating rubber matrix, increases the conductivity of the composite system. As the filler loading increases a mutual contact between the carbon fibre occurs and a sharp increase in conductivity is observed in percolation zone (in fig. 4.). The change of conductivity with gradual increase in carbon fibre loading (Fig-4.) demonstrates a relative narrow filler loading range during

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which a small increase in loading will result a drastic increase in conductivity or decrease in resistivity. At this concentration the insulating rubber matrix converted to conductive one and this critical amount of filler necessary to build up a conductive composite is referred to as the percolation threshold. This is the concentration limit beyond which further increase in short carbon fibre loading there is no significant change in conductivity. Many conductive rubber composites exhibit percolation characteristic. The change implies some sudden dispersing state of conductive fibres to form a networks which facilitates the electrical conduction into the rubber composites. By studying electrical conductivity of high density polyethylene–carbon fibre composite mixed different concentration of carbon black , Calleja and co-workers recognized that carbon fibres provide charge transport over a large distance and carbon fibre improve inter fibre contacts [13-14]. As stated previously, the conductivity of conductive filler loaded polymer depends largely on the content or conductive filler. Both carbon black and SCF systems exhibit percolation phenomenon [15].

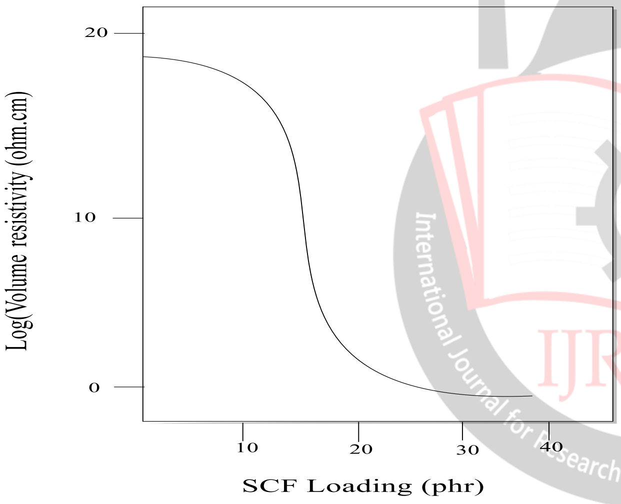

Fig. 4. Schematic of log resistivity versus conductive SCF loading

When conductive fibre content greater than the threshold, a significant increase in conductivity with increasing levels of conductive fibre is exhibited. This change in conductivity (σ) beyond the percolation threshold can be expressed in following form, as reported by Stauffer [16].

$$\sigma = \sigma_0(P - P_C)^t$$

Where P_C is the critical probability of formation of a conducting network, P is the probability of finding the conducting phase which is equivalent to the volume fraction of conducting phase above the critical concentration; σ_0 is the pre-factor (intrinsic conductivity of the filler) and t is the conductivity exponent. It is worthwhile that the SCF content to obtain the conductive network is much lower for SCF than that from carbon black particles. This can be ascribed to the fibrous nature of SCF which will aid the formation of the easy conductive network [17]. The preferential localization of carbon fibre at interface provides the continuous network. The percolation threshold depends on the phase morphology and distribution of conductive filler in the rubber blend. Conductive fibre tends to partition in one of two ways that benefits electrical conductivity at reduced loading. The first is carbon fibre distributed predominantly in one continuous phase and the other where the carbon fibres located preferentially at the interfacial region. There are several ways to decrease the percolation threshold of conductive filler concentration in rubber matrices, which are mainly based on the use of additives, the optimization of processing conditions, as well as the size, aspect ratio (L/D) (L= length of fibre, D= diameter of fibre.) of fibre distribution and porosity of carbon fibre [4]. This critical filler content must be as low as possible and still allows the composite to fulfill its electrical requirements, otherwise the mixture processing becomes difficult, the mechanical properties are poor and the final cost of the product will be high which is undesirable. Wessling [18] proposed a model, which he called the dynamic interfacial model for the percolation mechanism. The model treats the rapid increase in conductivity above a critical filler volume as a phase transition, wherein the dispersed conductive particle suddenly forms a flocculated phase. This phase transition occurs is dependent on the interfacial energy between the conductive fibre and the matrix polymer molecules as well as the temperature. The value of threshold concentration is also dependent on the viscosity of the rubber. The higher the viscosity of the rubber matrix higher is the percolation threshold [19-20]. Yuan and Wu found the conductivity of carbon black filled polyethelene and polypropylene composites increases with decrease in melt viscosity of the polymer matrix, which they attributed to ability of the low viscosity polymer to penetrate into and break up carbon black agglomerate [21].

The percolation threshold was found to be dependent on the fibre orientation and in the parallel direction occurs at a conductive fibre loading as low as about 3.65 volume percent compared to 4.5 volume percent in the perpendicular direction . Farimani et al [22] found the percolation threshold in fibre / pp (polypropylene) 4.5 phr. This has been explained by numerous conductive pathways formed via fine contacts of aligned conductive microbrils.

IV. METHOD OF PREPARATION CARBON FIBRE-RUBBER CONDUCTIVE COMPOSITE:

The short carbon fibre, initial length of ~4 -6 mm was mixed with the rubber or rubber blend in a **Brabender plasticorder** under identical conditions of time, temperature, rotor speed and sequence of mixing of all compounding ingredients. The mixes were sheeted out in a two roll mixing mill. There is another important method for preparation of carbon fibre and rubber composite which is **melt mixing**. SCF including other ingredients are mixed in melt condition of rubber in a suitable solvent and then evaporate the solvent. Then the mix is vulcanized at a specified time, temperature and pressure to get the required conductive composite [23].

V. NATURE OF RUBBER AND THE PERCOLATION LIMIT:

Polarity of rubber plays an important role to the critical content of filler. Miyaska and co-workers [24] investigated the effects of different types of polymer matrices on the conductivity of composite with respect to percolation limit. The higher the polarity of a given polymer, the larger the critical content is. Combining the results with the surface tension values of the polymer and critical carbon fibre content: the larger the surface tension of the polymer, larger the critical content is.[25]. It is reported enhanced conductivity of polymers with increasing polarity of the polymer [26-27]. Sau et al [28] showed that higher polar NBR registered less percolation limit than non polar rubber EPDM. It is also observed that blends of EPDM (non polar) and NBR (polar) having distinct interface, require relatively lower concentration of black compare to pure components to achieve percolation limit. Accumulation of conductive filler at the interface in the blend facilitates the formation of conductive networks in the matrix. Gubbels et al [29] reported that the percolation threshold can be efficiently decreased by the selective delocalization of carbon black particle in multiphase polymeric materials, that is at the interface of the rubber materials. Foulger reported [26] that the percolation threshold of the poly (ethylene co-vinyl acetate) (EVA) and high density polyethelene (HDPE) blend filled with carbon black is at lower carbon content than the individually filled HDPE or EVA. Similar results have been observed [30-31] in a composite blend of Poly styrene and HDPE PS/HDPE, poly-propylene/ poly-carbonate PP/PC, emphasizing the tendency of filled immiscible blends to exhibit enhanced conductivities above that of the individually filled polymers. One reason for this is an increase of carbon black at the interface between the two immiscible polymer blends which increase the electrical conductivity [32].

VI. MECHANISM OF ELECTRIC CONDUCTION

There are various mechanism of conduction have been proposed depending upon the type of filler and their concentration which include simple inter aggregate conduction, field emission, tunneling of electrons [33-34]. Maxwell [35] studied the conductivity of an insulating medium with evenly dispersed conducting spheres and obtained a relationship which has proved valid upto 10% volume of conducting component.

The conductive filler forms a few continuous chains (conductive networks) in the rubber matrix by the physical contact of filler particles. Through these continuous networks charged species (electron) can move from one end to the other end under an applied electric field producing the phenomenon of electrical conduction 36]. Scarisbrick [37] derived a relationship between resistivity and the volume proportion of conductive material for a mixture in which conducting particles are considered to be touching, in which the shape, size and orientation of the particles were also taken into account. Another important mechanism is Electric field radiation theory. It is assumed that an emission current is caused to flow by the high electric field being generated between conducting element separated by a gap of a few nanometer [38]. A special case of internal field emission is the tunneling effect. In the electron tunneling theory, the electrical conduction is believed to take place not only by inter particle contact but also by electrons being able to jump across a gap or tunnel through energy barrier between conducting elements in the polymer matrix 39]. Tunneling is a quantum mechanical process, which is expected to operate when the distance between conductive components within the insulating matrix close to threshold value, usually a few nanometers. From the conduction viewpoint, these gaps are equivalent to inter particle contact [40]. However, for one system it is difficult to reconcile the substantial disagreement that exists in the conduction theories put forward by various authors. Several other theories of percolation and conductive mechanism were also reviewed [41-42]. Wessling [18] proposed a model, which he called the ‘dynamic interfacial model for the percolation mechanism’. The model treats the rapid increase in conductivity above a critical filler volume as phase transition, wherein the dispersed conductive particles suddenly form a flocculated phase. The critical concentration where these phase transition occurs is dependent on the interfacial energy between the conductive particles and the matrix polymer and temperature. There are many approaches to explain the percolation behavior of the conductive composites, but no model is able to explain all of the different experimental results, since many factors come into play in such systems. For example, physical and chemical interaction of conductive fillers with the polymer can influence many properties of conductive composites, specially, in polymer blends. It seems that the actual conduction mechanism is quite complicated and the net result may be due to combined effect of different mechanisms.

Carbon nano tube based composites: In 1991, Carbon nanotube (CNT) were first reported by Ijima [43]. As with conductive black and conductive fibre, CNT have a unique combination of mechanical, electrical and thermal properties that make CNT excellent candidates to substitute or complement the conventional fillers in the fabrication of multifunctional polymer composites.

The CNT are classified into two types, singled walled carbon nanotube (SWNT) and multiwalled carbon nanotubes (MWNT). SWNT are seamless cylinders each made of a single grapheme sheet with diameter ranging from 0.4 to 2.3 nm and length usually on the order of

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micrometers [44-45] MWNT consist of two or more seamless graphene cylinders concentrically arranged around a central hollow core with interlayer separation having oute diameter 4-30 nm. CNT have been found to be attractive for increasing the electrical conductivity of insulating polymers at relatively low CNT contents. The reason behind the CNT emerging as potential filler is due to its high aspect ratio (L/D) as compared to the conventional carbon black filler [46]. Chen at al studied 5 wt% MWNT composites in ultrahigh molecular weight polyethylene-, ethylene-methyl methacrylate co-polymer (EMMA), and in blends of these two polymers [47].

VII. FACTORS EFFECTING CONDUCTIVE PROPERTIES:

The electrical conductivity of rubber composite is influenced by processing conditions like temperature, time of mixing and shear rate of mixing and the condition of cross linking during vulcanization [48-49].

Effect of Temperature:

Temperature co-efficient of resistance are of two types. The resistivity increases with increased temperature (PTC) and in some cases resistivity decreases with increase of temperature (NTC). These depend on polymer type, concentration and type of fillers as well as their interactions. One reason is difference of thermal expansion of conductive filler and polymer matrix. Usually the polymer matrix will expand more than the conductive filler due to their different physical properties. This uneven thermal expansion results in an increase of distance between conductive fillers, thus making electron tunneling more difficult. Depending upon the carbon black loading, the same polymer filler system showed anomalous behavior in temperature dependence of volume resistivity [50-51]. Narkis, Ram and Stein studied the electrical resistivity of peroxide and radiation cross-linked polyethylene/carbon black compounds as a function of black concentration and temperature during heating-cooling cycles [52]. The NCT effect is mainly observed due to the activation of the thermal emission of electron between the adjacent particles as observed in semiconducting materials [53]. In certain polymer filler system, anomalous behavior in temperature dependence of resistivity has been observed due to phase change in the modified polymer. Sau et al [54] studied on SCF filled conductive composites based on Nitrile rubber (NBR) and ethylene propylene diene rubber (EPDM) and their blend and explained PCT effect due to break down of conductive network due to higher thermal expansion of matrix rubber than SCF. Studies on thermoplastics filled with different types of carbon black showed several folds increasing in resistivity at temperature near the glass transition temperature (T_g) of the polymer [55]. Further, increase in temperature above T_g resistivity fall due to formation of independent conductive network as a consequence of enhanced motion of filler particles and lower viscosity of the polymer [56]. Few other phenomena are operative in the system simultaneously, which cause in increase in conductivity. These processes include; the flocculation of particulate filler, leading to formation of further conductive networks during heating; high temperature electron emission between two ends of black aggregates which are separated by a smaller gap; and aerial oxidation leading to the formation of polar groups [57]. During heating some oxidative crosslinking at the surface takes place, which promote conductivity [58]. The nature of polymers, the filler and its concentrations have a marked influence on temperature dependency of electrical resistivity [59]. Pramanik et al [4] related the resistivity variation with temperature to the blend filled with carbon fibre which shows PTC effect, whilst carbon black rich composite shows NTC effect. Abdel- Bary [60] reported that different type carbon black loaded Styrene Butadiene Rubber (SBR) system show PTC, NTC and zero behavior depending on filler type and concentration. Heavily loaded SBR shows PTC whilst, the lower filled composites shows NTC effect. Zero temperature effect arises from the carbon black which has a tendency to form aggregates.

Effect of Viscosity of rubber on electrical conductivity:

Another important factor which influence the conductivity of the composite is the viscosity of rubber matrix [17]. Rubber having a higher viscosity exerts much higher sheering force (torque) brittle carbon fibres during processing . The higher the sheering force, the more is is increasing the temperature this inter fibre contact resistance increases further and consequently the probably of hopping or tunnelling of electrons between gaps decreases. As a result the volume resistivity increases with the increase in the viscosity of the polymer matrix for the same amount of carbon fibre loading.

Effect of processing parameters

Pressure or sheering force during mixing rubber with filler and other ingredients has effect on conductivity. Greater shearing force during mixing leads to breakage of the SCF aggregate, change the aspect ratio, which will reduce their tendency to form conductive paths in the rubber matrices consequently the conductivity will decreases. Several author reported mixing time, mixing temperature and order of addition of ingredients have profound effect on the conductivity of composite materials [61]. Processing parameters during vulcanization also have influence on the electrical conductivity of the vulcanizate. The time and temperature of vulcanization have a considerable effect on the electrical conductivity of composite.

VIII. USES

There are several advantages of conductive rubber composites, light weight, good flexibility, good processibility, chemical stability, design capability, controlled electrical resistivity materials, cost effectiveness

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and easy regulation of electrical conductivity and mechanical performance with in a wide range over the usual conducting materials [62-63]. These composites can be used in electrostatic charge dissipation efficiently. Now, electrostatic charge is the major source of damage in electronic components, business machines, and medical industries as well as various other places like V-belt, in coal mines, rolls car, hoses and aerospace tyres.

Pressure sensitive sensor: In various places these conductive composites are used as pressure sensitive sensor. One of the earliest use of pressure sensitive sensor as axle information, sensor for vehicle assessments, calculation of toll tax [64]-[65]. Besides this there are many applications like pressure sensor for electric organs, switching element for key board, touch control switches used in several sophisticated instruments like computer, camera mobile and also for pressure control switch for swing door used in air and super market.

Strain Sensor: Strain causes some structural changes into the materials, which help in resistance. Strain sensor in which pressure sensitive rubber is used for comparative detecting purpose. These are used in various electronic applications in domestic electric devices. This is also used in volume control switches in different musical instruments.

Carbon fibre mats: Due to their flexibility, carbon fibre mats consisting of short carbon fibre and small amount of an organic binder are attractive for use as heating elements. In addition, they are attractive because they are in a sheet form, corrosion resistant, and can be incorporated in a structural composite. A mat comprising bare SCF and exhibiting low volume resistivity and high thermal stability up to 205^{0}C has been found to be an effective resistive heating element [66]

Electrical switching: Conductive fibre filled composites have been used as electrical switching., Electrical switching can be achieved by using a material whose electrical resistivity increases abruptly under a certain condition(e,g. when the temperature or electric field is above a threshold). The switching serves to protect electronic devices from damage resulting from exceeding the threshold. Polymer matrix composites containing discontineus electrically conductive fillers and filler concentration typically is in threshold zone the resistivity increases with increasing temperature, due to the large thermal expansion coefficient of of rubber matrix compare to the filler and consequent decrease in the chance of contact between adjacent filler units as the temperature increases. [67]-[69]

IX. ELECTROMAGNETIC INTERFERENCE SHIELDING EFFECTIVENESS:

Rapid procreation and implementation of electronic appliances and telecommunication technology emerges a new hazard known as electromagnetic interference (EMI), which affect human life, electronic devices and medical instruments. The growth of electronic devices across a broad spectrum of military, industrial, commercial and consumer sectors has created a new form of pollution known as noise or radio frequency interference or electromagnetic interference that can cause interference or mal functioning of equipment. These problems if left unattended can cause severe damage to communication system and safety operation of many electronic devices. So EMI shielding is very important and high demand to the today's society [70]¨ For effective shielding, materials should contain either mobile charge carriers or electric and magnetic dipoles to interact with electric and magnetic vectors of electromagnetic radiation for resisting electromagnetic energy from any external sources. From a long period of time, metal have been used as EMI shielding materials but upcoming trends shifts towards polymer nano-composite containing carbonaceous fillers have drawn great interest in the present scenario and technological field for their improved electronic and shielding effectiveness [71], but still now they have suffered through processing difficulties, poor dispersions and high production cost. Carbon fibre is good reflector of electromagnetic radiation. The reflection is valuable for electromagnetic interference (EMI) shielding and for guiding for electromagnetic wave. EMI shielding refers to the reflection or absorption of electromagnetic radiation by a material, which there by acts as a shield against the penetration of the radiation through the shield.. SCF filled rubber composites develop cost effective, light weight, flexible polymeric composite with improved EMI shielding effectiveness, altogether moderate mechanical and thermal stability at very low electrical percolation threshold [72]-[73].

Modification of polymer by addition of carbon black and carbon fibre can be used efficiently for EMI shielding [74]. Carbon fibres are attractive in the composite due to their oxidation resistance and thermal stability. The shielding provided by different conductive composites is dependent upon the conductivity of the composite as well as on the measuring frequency. Depending upon the shielding effectiveness at different frequency ranges, these materials are considered for use in several microelectronic devices. There are a number of reports in this regard [74]-[75]. Pramanik at al [76] studied electromagnetic interference shielding by conductive nitrile rubber composites containing carbon fibre and conductive carbon black at two different frequency ranges 200-1000 MHz and 8-12 GHz (X-band range). The SCF filled composites register higher shielding effectiveness compared to that of carbon black filled composites. Sau et al [54] and [77] reported the result of short carbon fibre filled conductive rubber composites as EMI shielding materials. Development of high performance EMI shielding materials from EVA-NBR and their blend filled with carbon black is reported [78].

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X. CONCLUSIONS

Carbon fibre filled conductive rubber composite is very significant and important now-a-days. Tailor made conductive materials can be obtained by controlling rubber and rubber blends and SCF loading. The conductivity in these composites is mainly due to presence of conductive networks. Polarity of polymer plays a very important role for conductive network formation. Higher the polarity of rubber matrix there is higher tendency of network formation and so lower is the percolation threshold concentration. Rubber blends provides unique morphologies and properties to reduce the percolation concentration and increase conductivity. Polymer blends of EPDM and NBR having wide difference in polarity and having well defined and distinct interface facilitate conductive network formation, consequent result is lower critical concentration. Accumulations of conductive filler at the interface in blend facilitate the formation of conductive networks in the matrix. Conductive acetylene black and conductive SCF can be used as suitable conductive filler. SCF with higher aspect ratio provides higher conductivity at lower concentration of SCF. Sometimes the mixture of SCF and acetylene black both can be used. Due to long fibrous nature , easy conductive network formation takes place at lower concentration compare to only carbon black or only SCF. So, there is a scope, to choose appropriate polymer blend and by choosing conductive filler or combination of fillers to improve the electrical performance of conductive composite. Suitable Polymer blend favours to achieve high conductivity at a lower concentration of conductive filler. Future work may be carried out in the study of electrical property of conductive rubber compound derived from EVA-LDPE, EVA-EPDM, NBR-EVA blends as these have cure compatibility. High compatibility of rubber matrix with carbon black and SCF uniformly distribution of carbon filler and other ingredients contribute positively to the conductivity. The amount of SCF, structure, porosity and orientation of of SCF, L/D ratio of SCF. particle size of SCF effects electrical properties of composites. To achieve required level of conductivity several issues must be kept in mind during processing and designing the materials. These composite materials have several smart applications in electrical and electronic industries. The applications also include resistance heating, floor heating, sensing, electrical switching etc. The SCF filled conductive composite is also very effective as EMI shielding materials in different field.

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