CHAPTER I

CHAPTER – I

INTRODUCTION TO COMPOSITE MATERIALS

1.1 DEFINITION AND CLASSIFICATION

The word composite means, "consisting of two or more distinct parts". Thus a material composed of two or more distinct materials or phases as its constituent parts may be considered as a composite material. A composite material may be well suited for a particular application than the original materials [1]. It is a physical mixture of two or more than two macro or micro constituents that differ in form and chemical composition and are essentially insoluble in each other [2].

A composite material consists of two components. One that gives bonding is called the matrix and the other is the reinforcing or strengthening material. Composites are mainly classified into three groups based on the microstructure of the reinforcing component:

a) Dispersion strengthened composites - In these materials fine particles of 0.01 to 0.1μ diameter are uniformly dispersed in a volume concentration of 1 to 15% in the matrix.

b) Particle strengthened composites - These are characterized by the dispersoid size greater than 1 μ in a volume proportion greater than 25%.

c) Fibre reinforced composites - The reinforcing phase spans the entire range of size from a fraction of μ to several mils in diameter and the entire range of volume concentration, from a few % to greater than 70% [3].

In group 'a' type of composites the load is fully borne by the matrix whereas in fibre reinforced composites the load is primarily borne by the fibres. In particle reinforced composites the load is borne by both the components.

1.1.1 PARTICLE REINFORCED COMPOSITES

In these composites the particle dimensions are exactly same in all directions. There are two subtypes of particle reinforced composites viz. large particle composites and dispersion strengthened composites.

1.1.1(A) LARGE PARTICLE COMPOSITES

The term 'large' is used to indicate that the particle matrix interaction cannot be treated on atomic or molecular level and rather continuous mechanism is to be used. For most of these composites the particulate phase is harder and stiffer than the matrix. The reinforcing particles restrain movement of matrix phase in the vicinity of each particle. In essence the matrix transfers in some of the stress that the particle bears which is function of load. The effect of degree of reinforcement on the mechanical behaviour depends on strong bonding at matrix interface. Some polymeric materials to which fillers have been added are really large particle composites [4].

1.1.1(B) DISPERSION STRENGTHENED COMPOSITES

Metals and alloys may be strengthened by uniform dispersion of fine particles of very hard and inert materials. The dispersed phase may be metallic or non-metallic. Oxide materials are often used. The strengthening mechanism involves interaction between the particles and dislocations within the matrix. The dispersion strengthening effect does not last longer as the dispersed phase is chosen to be unreactive with the matrix.

So far the studies on composite materials are limited to their mechanical properties since they are mainly used in structural or high temperature applications. The physical properties such as ME effect have been rarely studied.

1.2 NEED AND ADVANTAGES OF COMPOSITES

In the modern and constantly developing technological scenario the existing materials cannot meet the industry requirements even after the special treatments are given to them for improvement of mechanical properties such as stiffness, toughness and high temperature strength. Recently, the interest has been shifted to exploit metallic or ceramic matrix composites for electrical applications.

Besides mechanical properties the other technologically important properties like dielectric behaviour, magnetic and ferroelectric characteristics of composites can also be manipulated using various shapes and composition of the components. Some examples of these are underground cables (sodium metal which is chemically reactive is enclosed in polyethylene), superconducting ribbons (composite of Nb_3Sn deposited on Cu) and synthetic hard superconductors (liquid lead is forced under pressure into porous glass fibers) etc. Since composites can be tailored for a specific applications they seem to be the promising materials for exploitation in yet other unexplored applications [3,5].

1.3 MAGNETOELECTRIC COMPOSITES

A new class of physical properties of composite materials is that of "product properties" in which the phases or sub-materials of the composites are selected in such a way that an effect in one of the phases leads to a second effect in the other phase. Following the concept of product property as suggested by Van Suchtelen [6], a suitable combination of piezomagnetic (ferrite) and piezoelectric (ferroelectric) can give rise to magnetoelectric effect. The composites exhibiting magnetoelectric effect (ME effect) are termed as magnetoelectric composites. ME effect is due to the strain induced in the ferrite phase that is mechanically coupled to a stress induced in the ferroelectric phase. The coupling results in an electric voltage[6,7,8].

In other words,

ME effect = (mechanical / magnetic) x (electrical /mechanical)

$$= \left[\frac{\text{Strain Induced}}{\text{magnetic field}}\right]_{\text{ferrite}} \times \left[\frac{\text{Electric voltage}}{\text{Stress Induced}}\right]_{\text{ferroelectric}}$$

Thus this effect results from the interaction between different properties of the two phases in the composites[9]. It is important to note that neither the ferrite nor the ferroelectric phase on its own exhibits the ME effect, but suitable combinations of these two phases can exhibit a remarkable magnetoelectric effect [6,9,10].

To realise the ME effect the following guidelines must be kept in mind [8,10].

1) The two phases must be in equilibrium.
2) Perfect mechanical coupling between the two phases should be ensured.
3) The value of magnetostriction coefficient of the piezomagnetic phase must be high.
4) The value of piezoelectric coefficient of the piezoelectric phase must be high.
5) The accumulated charge carriers must not leak through the piezomagnetic phase. Hence this phase should have resistivity comparable to the piezoelectric phase.
6) Proper electric poling strategy to pole the ferroelectric phase of the composite and similarly proper magnetic poling strategy to pole the magnetic phase of the composite is to be adopted to realise high ME effect [11, 12].
7) The transition temperature T_C of either phase must be greater than the room temperature to facilitate poling and the relaxation time for charge compensation has to be long.

1.4 LITERATURE SURVEY

The first theoretical prediction of ME effect was given by Dzalyoshinskii [13] in antiferromagnetic Cr_2O_3. Astrov and Folen et. al. [14, 15, 16] gave an experimental evidence of ME effect in Cr_2O_3. Boomgaard et. al. [17] prepared ME composites of Ni(Co,Mn)Fe_2O_4 and $BaTiO_3$ and observed high ME output (130 mV/cm/Oe) in unidirectionally cooled composite (60% Ni (Co, Mn) Fe_2O_4 - 40% $BaTiO_3$) as compared to the same composite prepared by double sintering method. Laletin [18, 19] investigated the $NiFe_2O_4$ - PBZT and $CoFe_2O_4$ - PBZT systems. He observed dE/dH value of the order of 60 mV/cm/Oe for 50-50 mole percent of $NiFe_2O_4$ and $BaTiO_3$ and 12 mV/cm/Oe for 30: 70 mole percent of $CoFe_2O_4$ and $BaTiO_3$. Lopatin [20] investigated the $Ni_{0.9}Co_{0.1}Fe_2O_4$-PZT composites and obtained a value of 110 V/cm/Oe, for compositions varying from 35 to 55 wt % of ferrites. Gelyasin [21] observed a maximum value of magnetoelectric output in 20 mole % $NiFe_2O_4$ composite with $BaTiO_3$. Suryanaryana et. al. [8] have investigated the $CoFe_2O_4$-$BaTiO_3$, $LiFe_5O_8$-$BaTiO_3$ composites prepared by solid state reaction and $LiFe_5O_8$-$BaTiO_3$, $NiFe_2O_4$–$BaTiO_3$ composites prepared by sol gel method. They obtained high value of dE/dH (450 μV/cm/Oe) in 40 mole % $NiFe_2O_4$–60 mole % $BaTiO_3$ composite. Surprisingly no ME signal was obtained for $LiFe_5O_8$–$BaTiO_3$ composite though $LiFe_5O_8$ has high magnetostrictive coefficient. Mahajan et. al.[22] have noted ME effect in $NiFe_2O_4$-$BaTiO_3$ composites. Recently, Patankar et. al. [23] have investigated the $CuFe_{1.8}Cr_{0.2}O_4$ - $Ba_{0.8}Pb_{0.2}Ti_{0.8}Zr_{0.2}O_3$ composites prepared by solid state reaction. They obtained a value of dE/dH (182 μV/cm/Oe) in 30 mole % $CuFe_{1.8}Cr_{0.2}O_4$ - 70 mole % $Ba_{0.8}Pb_{0.2}Ti_{0.8}Zr_{0.2}O_3$ composite.

1.5 APPLICATIONS OF MAGNETOELECTRIC EFFECT

The devices whose action is based on ME effect is magnetically operated optical device in the visible and infrared regions. The other devices of this type are spin wave oscillators in spin wave electronics, ferroelectromagnetic wave generators, sensor buttons, instruments for recording constant and variable magnetic fields, high speed power and signal distribution, tunable filters etc.

One of the important scientific applications of the linear and higher order magnetoelectric effects resides in the fact that they give us precious information for determining the magnetic point groups and magnetic space groups. Some other important scientific applications are -

1) Accurate determination of magnetic phase transition temperatures and critical exponents.
2) Study of defects in magnetic phases.
3) Study of switching and poling of antiferromagnetic domains by simultaneous application of electric and magnetic fields
4) Magnetic and electric field induced phase transitions(e.g. spin-flop and metamagnetic transitions[24].

1.6 ORIENTATION OF THE PROBLEM

The ME effect in ferrite- ferroelectric composites has recently attracted much attention owing to the interest in using them for broad band magnetic field probes which exhibit exceptionally flat frequency response. Magnetoelectric composites are also used as sensors, isolators, phase shifters, modulators, waveguides, transducers etc. Materials showing ME conversion can also be used as thin film wave guides in integral optics and fibre communication technology [25].

Taking into consideration these and high value of ME conversion factor observed in $Ni_{0.9}Co_{0.1}Fe_2O_4$ -PZT composites (110V/cm/Oe) with $Ni_{0.9}Co_{0.1}Fe_2O_4$ as magnetostrictive phase, the present work on the studies of electrical properties of $Ni_{0.75}Co_{0.25}Fe_2O_4$ – $Ba_{0.8}Pb_{0.2}TiO_3$ composites having higher content of $Ba_{0.8}Pb_{0.2}TiO_3$ phase was undertaken.

The present work involves -

1) Preparation of ME composites by ceramic method.
2) X-ray diffraction studies to confirm the formation of ferrite and ferreolectric phases.
3) Measurement of ac and dc conductivity and thermoelectric power to understand the conduction mechanism and
4) Measurement of static magnetoelectric conversion factor.

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