3

Electrical and Magnetic Properties
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3.1 Introduction

The chemical non-reactivity of LLDPE materials with YBCO superconductors indicates their potential as substrates for YBCO films. In order to confirm their chemical compatibility with YBCO, it is important to study the electrical transport and percolation behavior in these superconductor-insulator composites. The concept of percolation can be used to understand the change in resistivity as a function of filler concentration in ceramic-polymer composites. Based on the concept of percolation, at a critical volume fraction of conducting particles in an insulating polymer matrix, the particles form a continuous chain thereby drastically decreasing the composite resistivity [3.1]. The associated positive temperature coefficient of resistance (PTCR) effect occurs due to the elimination of this continuous chain by the expansion of the polymer. This expansion occurs near the melting point of semicrystalline polymers.

The study of superconducting small aggregates, clusters and particles is very important from both fundamental and technological stand point [3.2-3.8]. Due to the granular nature of these materials with short coherence length [3.9] and large penetration depth [3.10] it is interesting to study the percolation and superconductivity of composites consisting of a superconductor embedded in an insulator medium. The percolation studies in superconductor-insulator composites are possible only on composite systems which are chemically non-reacting under the high processing temperature. A high $T_c$ superconductor-insulator system is very difficult to obtain without compromising the superconducting properties.

The possible applications of superconductor/polymer composites are in the areas of magnetic shielding and levitation where contact from one superconducting grain to another is not essential to the function [3.11-3.14]. It is the property of diamagnetic flux exclusion [3.15] and not the zero resistivity of these composites makes it a potential candidate for these applications. Levitation of a magnet above a high $T_c$ superconductor is one of the most attractive properties for superconducting applications. It could be used to construct bearings in rotating
machinery. It may be a more practical and promising near-term application. There have been intensive studies on the magnetic levitation forces of high T_c superconductors for bearing applications. Moon, et al. [3.16 – 3.23] and some other workers [3.24 – 3.27] have quantitatively measured force versus the magnet/superconductor separation, mechanical stiffness and lateral force.

High T_c superconductors have some inherent problems like brittleness, difficulty in shaping and chemical instability (for YBa_2Cu_3O_{7-x}) which have impeded the development of their applications. It is rather difficult to fabricate them into intricate shapes and bearing applications also demand high mechanical strength. Incorporation of the brittle ceramics into composites with metal or polymer is a good solution [3.28 – 3.33]. Therefore it is very important to evaluate magnetic levitation properties for composite materials. Weinberger et al. [3.29, 3.30] have studied the levitation force for YBaCuO/paraffin wax composite and suggested a prototype bearing using this type of composite [3.30]. Results show that composites are promising material for levitation bearing applications, but they did not report the volume fraction dependence (only one composition – 50 vol%). Besides, paraffin wax is not an ideal matrix material for bearing applications. These investigations showed that composites formed from ceramic superconductor and polymer exhibited good magnetic levitation at liquid nitrogen temperature, though zero resistivity was generally lost in the composites. We had recently reported [3.34] the magnetic levitation capabilities of linear low density polyethylene (LLDPE)/Y-123 composites.

This chapter deals with the electrical and magnetic properties of the superconductor/polymer composites. The mechanism of PTCR (positive temperature coefficient of resistance) effect, the percolation behavior, the temperature dependence of dc resistivity, the thermal expansion behavior of linear low density polyethylene (LLDPE), the temperature dependence of ac susceptibility and the volume fraction dependence of the levitation force in these composites are discussed in detail.
3.2 Percolation model

Percolation model was originally proposed to describe the spreading of fluid through porous media, branching polymers from a gel, electron migration in a solid, disease infection in a community and other similar phenomena [3.35]. Because of its generality and relative simplicity, this has found many applications ranging from the physics of quarks to the extraction of oil from sandstone.

Consider a regular lattice, where lattice sites can have two states either black or white [3.35]. A cluster is defined as a group of black sites connected by nearest neighbor distances, \( V = V_c \), a critical point below which, only finite clusters exist but for \( V > V_c \), a fraction of the black sites belong to an infinite cluster and a percolation is possible. Below the percolation threshold, \( V < V_c \), there is no infinite cluster of black sites. From \( V_c \), the fraction of sites belonging to the infinite cluster grows drastically, and it has a non-analytic point at \( V_c \). This non-analytic nature is a characteristic for the percolation threshold and is usually described by a power law asymptotically close to \( V_c \).

In the case of a superconductor-insulator composite system, the resistivity of the latter is very high. If superconductor is added to an insulator, the resistivity of the composite remains more or less same as that of insulator up to a critical volume fraction of superconductor in the composite. If the volume fraction of the superconductor increases beyond the critical volume, the resistivity reduces drastically to that of pure metal. The critical volume fraction of superconductor required to have a continuous network or to become an infinite cluster is called the percolation threshold value. The transport properties can be described by a set of exponential equations [3.2, 3.35, and 3.36]. The relations are,

\[
\rho = \rho_0 (V_m - V_c)^{-t} \quad \text{for} \quad V_m > V_c \quad (3.1)
\]

\[
\rho' = \rho'_0 (V_c - V_m)^s \quad \text{for} \quad V_m < V_c \quad (3.2)
\]
where ρ and ρ' are the resistivities of the composites, ρ₀ and ρ₀' are constants, \( V_m \) the volume fraction of the metal in the system and \( V_c \) the threshold volume, \( t \) and \( u \) are critical exponents describing the transport properties. The values of \( V_c \), \( t \) and \( u \) obtained for different systems of composites vary due to many factors. The critical exponents \( t \) and \( u \) are a measure of the order of interaction between normal metal and insulator. The value obtained for percolation threshold is around 17 volume % of metal in the system for a perfect metal-insulator composite without any interaction or reaction between the two. The expected values of critical exponents are \( t \sim 1.7 \) and \( u \sim 0.7 \) approximately. The values obtained by experimental methods vary slightly around this value. An appropriate variation of critical exponents from the above values indicates that the system is not forming a perfect non reacting composite. In these superconductor-insulator composite systems the percolation model holds and the superconductivity of YBCO is retained without deteriorating under severe heat treatment.

### 3.3 Mechanism of PTCR effects

Materials exhibiting a positive temperature coefficient of resistance (PTCR) have been widely used in temperature sensors, protective switches etc., which require a large positive temperature coefficient (PTC) and low resistivity below the switching temperature. Doped BaTiO₃ ceramics show a large positive temperature coefficient (PTC) of resistance and have been widely used. Although most of the commercially available PTC thermistors (temperature-dependent resistors) are doped BaTiO₃ [3.37 - 3.48] ceramics, composite thermistors have many advantages. First, they are more flexible than doped BaTiO₃ ceramics, and can be processed into complex shapes; second, the fabrication of composite thermistors is very simple, so the fabrication costs are lower than for doped BaTiO₃ ceramics. These advantages of composite thermistors have attracted the interest of many researchers [3.49 - 3.54].
The PTCR characteristics of the composites are influenced by the processing parameters which modify the surface states of the materials. At room temperature, the conducting particles dispersed in the polymer matrix form conductive paths through the composite, so that it exhibits low resistivity. At the switching temperature of the composite, the volume of the insulating polymer matrix expands abruptly, destroying the conductive paths formed at room temperature, resulting in an abrupt rise in resistivity of the composite. Thus, a PTC effect occurs. For composite PTC thermistors, the conductors to be used as conductive particles in the insulating polymer matrix have to be chosen carefully. For example, when metals such as silver, nickel and so on were incorporated into polymer matrices, the composite materials did not exhibit the PTCR effect. It has been discovered that when carbon black, V₂O₅, TiO₂, TiC, ZrB₂, TiB₂ are incorporated into polymer matrices separately, the composite materials can produce a large PTC effect [3.55 - 3.57].

Depending on the type of polymer chosen, the transition temperature at which the PTC phenomenon occurs can be changed. An important concept often used to describe the behavior of these composites is percolation. This allows one to understand the change in resistivity as a function of volume percent filler in such composite materials. The percolation threshold is defined as the filler volume fraction at which the resistivity, indicative of the insulating phase, [3.58] begins to decrease (Figure 1). This is associated with the point at which the filler particles begin to form conductive paths. As the concentration of filler is increased through the percolation region, more conductive paths are created through the composite. This region of filler concentration is where one would expect to see the largest PTC effects. Once the saturation region is reached, there are a large number of conductive paths, resulting in low resistivity. In addition, this is the region in which one would normally expect the PTC phenomenon to diminish.
Figure 3.1 [3.58]: A typical percolation curve which relates resistivity to volume percent filler in the composite.

For ceramic-insulator composites where the insulating phase is a crystalline polymer (such as polyethylene or nylon), the PTC phenomenon is generally observed at the polymer melting point \( T_m \). At \( T_m \), there is a discontinuous change in the specific volume with temperature and the magnitude of the change is a function of the degree of crystallization of the polymer. At room temperature the filler particles are essentially in contact, giving rise to a low resistivity. As the temperature increases, a large change in volume occurs at the melting point of the polymer. The polymer expands more quickly than the conductive particles, separating the grains and resulting in a rapid increase in resistivity of between 1 and 8 orders of magnitude [3.59, 3.60].

3.4 Experimental details

Details of the preparation of the superconductor and superconductor polymer composites are given in chapter 2. A series of composite samples of \( \text{YBa}_2\text{Cu}_3\text{O}_{7-\delta} \) and Linear Low Density Polyethylene with volume percentage of superconductor ranging from 10 to 90% are fabricated. Percolation studies, dc resistivity measurements, ac susceptibility measurements and magnetic levitation force
measurements are carried out. The electrical resistivity is measured by dc four probe method. All the samples including pristine YBCO pellet and those containing various percentages of YBCO filler are characterized for their dc resistivity in a temperature range of 0 to 300 K. The experimental procedure and set-up used are described in detail in chapter 2. The room temperature dc resistivity of the composites as a function of Y-123 volume concentration and the dc resistivity of the composites as a function of temperature between 293 K and 400 K are also measured with a Keithley solid state electrometer (model 610-C). The thermal expansion behaviour of linear low density polyethylene (LLDPE) is studied using a Linseis dilatometer L75/120LT in a temperature range of 0 to 140°C. The crystalline melting point of the polymer is determined by modulated differential scanning calorimetry (MDSC). The experimental details of MDSC are given in chapter 2 and the results are discussed in chapter 4. The field cooled (FC) and zero field cooled (ZFC) ac susceptibility measurements in the temperature range of 80 to 100 K and at a field strength of 25 Oe are obtained with a SQUID magnetometer (MPMS system, Quantum Design). The magnetic levitation force of these composites is measured by using an electronic balance technique and the volume fraction dependence of the levitation force is studied.

3.5 Results and discussion

3.5.1 Electrical measurements

The electrical characterization of these samples is first examined by studying their percolation behavior. The sample composition used for this study are Y-123/LLDPE, 10%, Y-123/LLDPE,20%, Y-123/LLDPE,30%, Y-123/LLDPE,40%, Y-123/LLDPE,50%, Y-123/LLDPE,60%, Y-123/LLDPE,70%, Y-123/LLDPE,80% and Y-123/LLDPE,90%. The sample size used for this study is 10 mm x 2 mm x 1 mm.
Figure 3.2: Room temperature dc resistivity versus volume fraction of Y-123 filler for Y-123/LLDPE composites.

Figure 3.2 shows the dependence of the room-temperature dc resistivity on the volume concentration of YBCO in LLDPE/YBCO composites. It shows the superconducting percolation threshold for YBCO-LLDPE composites to be located at about 20-30 volume percent filler. This means that, when the volume % of YBCO is ~30 or above, there are interconnected networks of superconducting grains for the supercurrent to pass through the composite material. At low percent Y-123 filler, the composites are like insulators which vary little with concentrations up to 20%. That is, at low percent Y-123 filler, the composites have large resistivity approaching that of LLDPE because the continuous network of superconducting grains breaks away and the superconducting particles are essentially separated from each other by polymer. A similar change in resistivity as a function of concentration of conducting particles was found by Newnham and coworkers [3.39 - 3.42], Shrout et al. [3.43] and others in V$_2$O$_5$-polymer, TiO-polymer, TiC-polymer and ZrB$_2$-polymer composites, which was explained by the concept of percolation. Percolation starts at around 20% of Y-123 and a large drop in resistivity...
is observed in the composition range 20 to 50%. That is the percolation region extends from approximately 20 to 50 volume percent. At 20% YBCO, termed the percolation threshold, the concentration of YBCO is large enough for the formation of conductive paths. Thus in the composition range between 20 and 50%, termed the percolation region, the larger the concentration of YBCO particles, the more conductive paths are formed through the composite, resulting in a large drop in resistivity for a small increase in YBCO concentration. This region of filler concentration is usually where one would expect to see large PTC effects as the conductive paths through the composites in this region are easily destroyed by expansion of the insulating matrix. Above the percolation region, there are so many conductive paths through the composite that it reaches a saturated state; therefore above 50% YBCO, the composites exhibit low resistivity which varies little with changes in YBCO concentration. A comparison with sintered pure superconductor shows that the resistivity even for over 50% samples is still quite high and this suggests that superconducting grains are not intimately contacting each other.

The relationship between resistivity and temperature for YBCO-LLDPE composites containing various YBCO concentrations is shown in figure 3.3. It can be seen that in the composition range between 30 and 50%, a remarkable increase in resistivity is observed in the vicinity of 122°C, which coincides exactly with the crystalline melting point of LLDPE as observed from the DSC thermogram of LLDPE (figure 4.1 (A), chapter 4). This phenomenon decreases and disappears at concentrations less than about 20 volume percent. This can be attributed to the fact that in crystalline polymer matrices, the mechanism of the PTC phenomenon is generally [3.61] associated with the melting of the polymer and consequent large volume change.
Figure 3.3: Dependence on temperature of the electrical resistivity of YBCO-LLDPE composites prepared with different YBCO contents.

Figure 3.4 shows the thermal expansion behaviour of LLDPE specimen that has been subjected to the same treatment as that has been given to prepare composite specimens. A dramatic increase in the expansion coefficient in the vicinity of 122°C can be seen. This indicates that there is a close connection between thermal expansion in the LLDPE and the PTC effects. We have shown in figure 3.2 that in the composition range between 30% and 50% YBCO the resistivity behaviour of the composites is consistent with percolation concepts. Therefore the conductive YBCO particles dispersed in the composite can form a number of conducting paths throughout the composite, resulting in a relatively low resistivity at room temperature. When heated, the LLDPE matrix expands more quickly than the YBCO particles near 122°C and this disrupts the conductive paths which are formed by the YBCO particles at room temperature, and eventually results in a rapid increase in the resistivity of the composites. Thus, a large PTCR effect is observed at 122°C, as that can be seen in figure 3.3. As the YBCO concentration is increased further, the PTCR effect gradually decreases and it is small at 50%
YBCO. One interpretation \([3.62]\) of this is that the destructive effect of the thermal expansion of the LLDPE matrix on the conductive paths formed by the YBCO particles is weakened as the volume concentration of LLDPE decreases, resulting in a decrease in the PTCR effect.

The percolation studies carried out on these composites confirmed the suitability of LLDPE as substrate for YBCO filler. Normal percolative conductivity could be observed in samples with 50 vol. % samples or less, but superconductivity did not occur. The amount of Y-123 seems to play an important role as the connectivity between particles for electrical percolation. The mechanism of the PTC effect in the materials is related to the percolation behavior of the YBCO - LLDPE composites and the thermal expansion of the LLDPE matrix.

![Thermal expansion of LLDPE](image)

**Figure 3.4**: Thermal expansion of LLDPE

To test these samples for bulk superconductivity, four point dc resistivity measurements are performed in a temperature range of 0 to 300 K. The sample composition used for this study are \(Y-123, 100\%\), \(Y-123/LLDPE, 10\%\), \(Y-123/LLDPE, 30\%\), \(Y-123/LLDPE, 60\%\) and \(Y-123/LLDPE, 80\%\). The sample size used for dc resistivity measurement is \(10 \text{ mm} \times 2 \text{ mm} \times 1 \text{ mm}\). The temperature-dependent electrical resistivity of pure YBCO and YBCO/LLDPE
composites are studied as a function of filler content and are represented in figures 3.5 and 3.6 respectively. A zero resistance superconducting transition temperature ($T_c$) of about 90K is obtained for pure YBCO. The normal state behavior of pure YBCO is almost linear and decreases with temperature indicating metallic in character.

![Graph](image)

**Figure 3.5**: Temperature dependence of electrical resistivity of 100% YBCO

Essentially, three types of temperature dependence of resistivity are observed, namely metallic, semiconducting and superconducting behaviors. It has been found that the resistivity of the composites increased rapidly with gradual increase in polymer contents. When the polymer content is increased from zero (figure 3.5) to 10 vol. % (figure 3.6 A), the resistivity of the composites are found to get transformed from superconducting to metallic. Furthermore, semiconductor type resistance behavior started to appear in composites with polymer content between 10 and 30 vol. % or at 30 vol. %. The poor conductivity generally observed in these composites was presumably [3.63] due to the absence of appropriate contacts between the superconducting grains caused by the addition of polymer and the presence of open pores introduced during material processing. Another possibility for this poor conductivity can probably be attributed [3.63] to the insulating LLDPE coated layer formed on the surface of Y-123 grains.
Figure 3.6: DC resistivity versus temperature for YBCO/LLDPE composites with polymer vol. % (A) 10 and (B) 30.

All other samples with vol.% of polymer higher than 30 exhibited semiconductor or insulator type behavior (figure 3.7) whose temperature-dependent resistivity is found to lie much higher than $10^6$ ohm-cm. At this point, the dc four probe method may become inappropriate for temperature-dependent resistivity measurements due to the severe dissipation of the small measuring currents in the composites. Instead, an alternative method, generally used in measuring the resistivity of plastics and elastomers, is considered; it employs high voltage input with small current to estimate the resistivities of the composites. The temperature dependent resistivity for the three samples investigated are comparable with those obtained from the composite systems of YBa$_2$Cu$_3$O$_7$/PVC and YBa$_2$Cu$_3$O$_7$/glass reported by Unsworth et al. [3.32] and Nies et al. [3.31], respectively.
The results obtained from resistivity measurements on the percolating system YBCO - LLDPE show that the superconductor and insulator remain as two separate phases in the composites with their own characteristics. The measurements of dc resistivity against temperature for the composite samples with greater amount of superconductor showed semiconducting behavior. This result suggests that the YBCO grains are not yet in close enough to permit bulk superconductivity, though normal metallic conductivity is present.

### 3.5.2 Magnetic properties

#### 3.5.2 (i) Magnetic levitation measurements

The composites are tested for their ability to levitate a small magnet at liquid nitrogen temperature. For levitation measurements we used the simple electronic balance technique. A small magnet is placed on the balance pan and the sample in liquid nitrogen container is located above the magnet. The weight change of the magnet is due to the repulsive force and the value of the force is given by

\[ F = M \times 9.8 \times (\text{m/s}^2) \quad (\text{N}) \quad (3.3) \]
where $M$ is the apparent mass change of the magnet. All samples are cooled down away from the magnet and then located at the same position. The force is measured at the same distance (about 2 mm). All the composite samples demonstrate magnetic levitation by lifting a small magnet in liquid nitrogen. The sample composition used for this study are Y-123, 100%, Y-123/LLDPE, 10%, Y-123/LLDPE, 20%, Y-123/LLDPE, 30%, Y-123/LLDPE, 35%, Y-123/LLDPE, 40%, Y-123/LLDPE, 45%, Y-123/LLDPE, 50%, Y-123/LLDPE, 55%, Y-123/LLDPE, 60%, Y-123/LLDPE, 65%, Y-123/LLDPE, 70% and Y-123/LLDPE, 75% respectively. Sample size used for levitation force measurement is pellets of 13 mm diameter and 1 mm thickness. Details of the experimental set-up for magnetic levitation are already described in chapter 2, section 2.12. Figure 3.8 gives the results of the force versus vol % of Y-123 for these composites at a fixed distance measured with the set-up shown in figure 2.11 in section 2.12 of chapter 2.

![Figure 3.8](image)

**Figure 3.8**: The magnetic repulsive force versus volume fraction of Y-123 for composites.
The data at 100% is for a sintered pure Y-123 superconductor (of 71% theoretical density). From the graph it can be seen that the force increases with increasing volume percentage of Y-123 powder in the composites. The tendency of saturation at above 60 volume % is due [3.32] to increasing air porosity in the composites. The scanning electron microscope (SEM) photographs (SEM results are discussed in chapter 5, section 5.3.3) showed that the 80% composite contained some big voids which was due to the scarce polymer binder [3.32] and the measured composite density (density measurement results are given in chapter 5, section 5.3.1) actually decreased [3.32]. Counting the air voids as the 3rd phase, the actual Y-123 superconductor phase decreases for the same dimension sample. This measurement shows that superconducting composite materials have a strong levitational capability and could be used for magnetic levitation applications. The composite structure has the obvious advantages of high strength and easier shaping in comparison with the pure superconductor.

These results suggest that for achieving large levitation forces, higher load composites are desirable (but not exceeding 60 % in this case). However, at very high loadings (typically, 60% and above), the porosity and the brittleness of composites also increase greatly. So in practice, a compromise has to made between high mechanical strength and high repulsive force.

3.5.2 (ii) Magnetic susceptibility measurements

The sample composition used for magnetic susceptibility study are Y-123,100%, Y-123/LLDPE,20%, Y-123/LLDPE,40% and Y-123/LLDPE,60%. The sample size used for this study is 10 mm x 4 mm x 1 mm. Representative ac susceptibility results for the Y-123 and composite samples under field cooled (FC) and zero field cooled (ZFC) conditions are shown in figure 3.9. The measurements taken in this experiment are normalized to the largest value achieved in pure sintered samples of YBCO.
Figure 3.9 (A) FC and (B) ZFC magnetic susceptibility of Y-123 and composite samples containing 40, 60 and 80% Y-123 as a function of temperature.

It can be seen that all of the composites showed the diamagnetic transition at around 90K, which is the same as that of the pure Y-123 sample. These plots clearly demonstrate that superconductivity is preserved for the Y-123 filler powder in composites, and there is no significant change of the superconducting transition
temperature. Clearly, the presence of LLDPE has no appreciable effect on this transition temperature. For temperatures below $T_c$, the magnitude of the susceptibility increases in accord with an increase in percentage volume of superconductor in both FC and ZFC cases. Comparing these figures, it can be seen that cooling in the 25 Oe field (FC) leads to less negative susceptibility values at almost all temperatures, with this effect probably being due [3.64] to flux trapping. This situation is most obvious at 81.4K where the FC values are approximately 50% of the ZFC values for all samples. This indicates that the magnitude of the Meissner effect (FC) is less than the shielding effect (ZFC) in these samples as has been noticed in earlier Y-123 studies [3.65, 3.66]. Obradors et al. [3.66] have reported two transitions in their Y-123 samples, the first (a superconducting transition) at ~91K associated with isolated grains, and the second (a phase transition) at ~82K associated with enhanced electrical connectivity between these grains. However, we did not observe any obvious shift in $T_c$ in the magnetization measurements as reported by Fuierer et al [3.67]. The single transition for both the parent Y-123 material and the composite samples indicate the dominant presence of isolated superconducting grains within such samples.
**Figure 3.10**: Magnetic susceptibility of (A) Y-123, 100% and (B) Y-123, 40% composite showing the crossing point between FC and ZFC curves.

Figures 3.10 (A) and (B) show these data replotted with both FC and ZFC curves on the same diagrams for the Y-123 and 80% superconductor sample respectively. The crossing point between the FC and ZFC curves (i.e., the point at which the shielding and Meissner effect have the same magnitudes) occurs at the same temperature for all samples, namely 88.8K. However, the susceptibility of this crossing point shifts progressively towards more negative values as the percentage of Y-123 increases.

**Figure 3.11**: Variation of 81.4K ac susceptibility for YBCO/LLDPE composites.
A plot of the 81.4K susceptibility values against volume fraction of superconductor shows the increase more clearly (figure 3.11). The linear nature of the plot indicates that the volume susceptibility of a composite with a dispersed superconducting phase may be calculated using a weighted average of the susceptibilities of the components; i.e.,

\[ c_c = v_{cs} c_s + v_{cm} c_m \]  

(3.4)

where \( c_c \), \( c_s \), and \( c_m \) are the composite, superconductor and matrix susceptibilities and \( v_{cs} \) and \( v_{cm} \) are the volumes of superconductor and matrix respectively.

From the susceptibility measurement studies it can be found that for temperatures below \( T_c \), the magnitude of susceptibility increases with increasing percentage of superconducting powder in the composites. These studies show that the magnitude of the Meissner effect (FC) is less than the shielding effect (ZFC) in these composites. Therefore areas such as shielding of magnetic fields are likely to be among the possible future applications of such superconductor/polymer composite materials and higher load composites are desirable (80% in this case) for such applications.

### 3.6 Conclusions

In a series of composites composed of conducting Y-123 particles in an insulating linear low density polyethylene (LLDPE) matrix, a large drop in resistivity with YBCO content at room temperature, which is consistent with percolation behaviour, is observed. A large positive temperature coefficient (PTC) of resistance is observed near 395K. These composites showed large PTCR effects of up to eight orders of magnitude. When the composition is in the percolation region or slightly above the percolation region, the composite exhibited a PTC effect with a constant PTC transition temperature of 122°C which coincides exactly with the crystalline melting point of the LLDPE matrix. Finally, the mechanism for the PTC effect in crystalline polymer composites is probably associated with thermal
expansion of the polymer, as evidenced by the sharp PTC transition at the melting point of LLDPE. No dc zero resistance transition is observed. The absence of zero resistance in these composites was presumably due to the absence of appropriate contacts between the superconducting grains and the lack of a conductive path necessary for a zero resistance transition to occur.

The Y-123 polymeric composites produced are found to have good flexibility compared to the superconducting materials and retained the magnetic levitation properties of the parent material. The levitation force measurement shows that the values of force are approximately proportional to the volume percentage of Y-123 in composites. This indicates that the superconducting loops responsible for levitation are localized in superconducting grains, and the weak link currents at grain boundaries have a very small effect. It also suggests that these composite materials can be used to replace the hard and brittle superconductor ceramics in levitating bearing applications. Magnetic susceptibility data indicate a single transition at about 90K consistent with isolated grains. The composites showed a large diamagnetic susceptibility that increases with increasing volume fraction of superconductor filler. The intrinsic diamagnetic properties of the superconducting materials are preserved in the composites and there is no change in the transition temperature of the superconductor. The parent compound Y-123 and the Y-123/LLDPE composites showed a single superconducting transition temperature of 90K. This study is used to investigate the applicability of a high strength and low melting thermoplastic polymer, LLDPE to improve the mechanical and fracture properties of an inherently brittle YBCO superconductor. YBCO/LLDPE composites offer better mechanical properties, greater machinability and easier shaping of the material into useful devices. These composites could have applications in the areas of electromagnetic shielding and levitation since the bulk conductivity values are extremely low at liquid nitrogen temperature.
3.7 Bibliography


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