EFFECTS OF SAMPLE GEOMETRY ON ELECTRICAL AND MAGNETIC PROPERTIES OF Bi-BASED HIGH T_c SUPERCONDUCTORS

by
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ABSTRACT

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In this thesis, the effects of sample geometry on electrical and magnetic properties of Bi-Based high Tc superconductor was investigated. To do such investigation, firstly it was neccessary to prepare samples which was being later used in the experiment. Bi-2223 ceramic powder was prepared by solid state reactions. For the experiment it was necesary to prepare 3mm diameter, 12mm long cylinder samples and then to open 0,5mm, 1mm and 1. 5mm diameters holes on the exact middles of them as axial. First samples with no holes was produced and annealed all the samples at 830^{o}C in air for 48 hours duration. Then, holes as axial were opened on the middles of no hole samples which was prepared earlier. To determine the effects of sample geometries, the measure of magnetic susseptibility was taken on each sample by a means of AC susceptometer. DC transport critical current densities were measuring. The graphics and assessments of the all measurements were provided and the effects of sample geometry were disscused in this thesis.

Key Words: Superconductivity, High Temperature Superconductivity, BSCCO, Magnetic Sussceptibility

ÖZET

Bi-TEMELLİ YÜKSEK T_c SÜPERİLETKENLERDE NUMUNE GEOMETRİSİNİN ELEKTRİK VE MANYETİK ÖZELLİKLERE ETKİSİ

AYŞE AKBIYIK
Yüksek Lisans,Fizik Bölümü
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Bu tezde BSCCO temelli yüksek sıcaklıktaki süperiletken maddelerin geometrilerinin maddenin elektriksel ve magnetik özellikleri üzerindeki etkisi incelendi. İncelemeyi yapabilmek için öncelikle deneyde kullanılacak numuneleri hazırlamak gerekiyordu. Deneyler için Bi-2223 seramik toz, katı-hal tepkimeleri ile hazırlandı. Deney için 3mm çapında 12mm boyunda silindir numuneler hazırlamak ve bunların tam ortalarından eksenel olacak şekilde 0.5mm,1mm ve 1.5mm çaplarında delikler açmak gerekiyordu. Öncelikle deliksiz numuneler üretildi ve 48 saat boyunca 830^0C da ısıl işlem uygulandı. Daha sonra hazır haldeki bu deliksiz numunelere eksenel olarak farklı çaplarda delikler açıldı. Numunenin geometrisinin etkisinin belirlenebilmesi için AC susceptometer kullanılarak, her bir numune üzerinde manyetik alınganlık ölçümü yapıldı. Doğru akım kullanılarak kritik taşıma akımı yoğunluğu ölçüldü. Bütün ölçüm sonuçları, oluşturulan grafikler ve bunların değerlendirilmesi tez içinde verildi. Numunenin geometrisinin etkileri tartışıldı.

Anahtar Kelimeler: Süperiletkenlik, Yüksek Sıcaklık Süperiletkenleri, BSCCO, Manyetik Alınganlık

To My Parents. . .

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TABLE OF CONTENTS

Page

LIST OF FIGURES

CHAPTER 1

The History Of Superconductors

Major advances in low-temperature refrigeration were made during the late 19th century. Superconductivity was first discovered in 1911 by the Dutch physicist, Heike Kammerlingh Onnes. Onnes dedicated his scientific career to exploring extremely cold refrigeration. On July 10, 1908, he successfully liquified helium and produced only a few milliliters of liquid helium that day, but this was the new beginnings of his explorations in temperature regions previously unreachable. Liquid helium enabled him to cool other materials closer to absolute zero (0 Kelvin), the coldest temperature imaginable. Absolute zero is the temperature at which the energy of material becomes as small as possible.

In 1911, Onnes began to investigate the electrical properties of metals in extremely low temperatures. It had been known for many years that the resistance of metals fell when cooled below room temperature, but it was not known what limiting value the resistance would be approached, if the temperature was reduced to very close to 0 K. Some scientists, such as William Kelvin, believed that electrons flowing through a conductor would come to a complete halt as the temperature approached absolute zero. Other scientists, including Onnes, felt that a cold wire's resistance would dissipate. This suggested that there would be a steady decrease in electrical resistance, allowing for better conduction of electricity. At some very low temperature point, scientists felt that there would be a leveling off as the resistance reached some ill-defined minimum value allowing the current to flow with little or no resistance. Onnes passed a current through a very pure mercury wire and measured its resistance as he steadily lowered the temperature. Much to his surprise, there was no leveling off of resistance, let alone the stopping of electrons as suggested by Kelvin. At 4.2 K, the resistance suddenly vanished. Current was flowing through the mercury wire and nothing was stopping it, the resistance was zero. According to Onnes, "Mercury has passed into a new state, which on account of its extraordinary electrical properties may be called the “superconductive state". The experiment left no doubt about the disappearance of the resistance of a mercury wire. Kamerlingh Onnes called this newly discovered state, superconductivity.

Onnes recognized the importance of his discovery to the scientific community as well as its commercial potential. An electrical conductor with no resistance could carry current any distance with no losses. In one of Onnes experiments he started a current flowing through a loop of lead wire cooled to 4K. A year later the current was still flowing without significant current loss. Onnes found that the superconductor exhibited what he called persistent currents, electric currents that continued to flow without an electric potential driving them. Onnes had discovered superconductivity, and was awarded the Nobel Prize in 1913.

Whenever a new scientific discovery is made, researchers must strive to explain their theories. By 1933 Walther Meissner and R. Ochsenfeld discovered that superconductors are more than a perfect conductor of electricity, they also have an interesting magnetic property of excluding a magnetic field. A superconductor will not allow a magnetic field to penetrate its interior. It causes currents to flow that generate a magnetic field inside the superconductor.These currents balance the magnetic field that would have otherwise penetrated the material.

This effect, called the Meissner Effect, causes a phenomenon that is a very popular demonstration of superconductivity. The Meissner Effect will occur only if the magnetic field is relatively small. If the magnetic field becomes too great, it penetrates the interior of the sample and the sample loses its superconductivity. In

1957 scientists began to unlock the mysteries of superconductors. Three American physicists at the University of Illinois, John Bardeen, Leon Cooper, and Robert Schrieffer, developed a model that has since stood as a good mental picture of why superconductors behave as they do. The model is expressed in terms of advanced ideas of the science of quantum mechanics, but the main idea of the model suggests that electrons in a superconductor condense into a quantum ground state and travel together collectively and coherently. In 1972, Bardeen, Cooper, and Schrieffer received the Nobel Prize in Physics for their theory of superconductivity, which is now known as the BCS theory, after the initials of their last names.

In 1986, Georg Bednorz and Alex Müller, working at IBM in Zurich Switzerland, were experimenting with a particular class of metal oxide ceramics called perovskites. Bednorz and Müller surveyed hundreds of different oxide compounds. Working with ceramics of lanthanum, barium, copper, and oxygen they found indications of superconductivity at 35 K, 12 K above the old record for a superconductor. Soon researchers from around the world would be working with the new types of superconductors. In February of 1987, a perovskite ceramic material was found to superconduct at 90 K. This discovery was very significant because now it became possible to use liquid nitrogen as a coolant. Because these materials superconduct at significantly higher temperatures they are referred to as High Temperature Superconductors.

Since then scientists have experimented with many different forms of perovskites producing compounds that superconduct at temperatures over 130 K. Currently, many governments, corporations and universities are investing large sums of money for research in High Temperature Superconductors. The ease of cooling new superconductors has greatly influenced vast efforts in the development of new materials, material fabrication, and changing theory of the behaviour of superconductors at relatively high temperatures. In addition, electrical power applications for the high temperature superconductors are expected to now be practical, thanks to the increased machine reliability and decreased cost associated with the cooling of such devices at temperatures greater than 20 K.

CHAPTER 2

2. 1 A Brief Presentation of Superconductivity and Bi-Based Superconductors

Polycrystalline sintered samples of Bi-2223 superconductors exhibit two current paths; intra-grain and inter-grain current paths. The thin film samples have very high critical current densities, in the order of $10^6 A/cm^2$ at **77 K** in zero fields. The grains are connected by weak links at grain boundaries in polycrystalline ceramic samples. The inter-grain critical current density is extremely sensitive to applied field.

It has been shown that in rectangular samples the demagnetising factor can lead to a significant difference between the internal and the applied fields [1]. This means that critical current densities are not a unique function of the applied field, but by scaling the field with the demagnetising factor becomes a unique function of local fields when averaging regions are large compared with the grain size.

When silver wires are used to make composite Bi-2223 materials, shape of the silver wire has not been effective in microstructure development although the presence of silver wire has been reported to be effective [2]. Polak have developed an inductive method to measure critical current density of disk shaped samples [3] and they claim that their method can be expanded to ring shaped samples. Net shape of the manufactured samples is determined by the particular manufacturing method used [4].

2.2 Flat Samples

A theoretical analysis is presented for the critical state of an infinitely long type-II superconducting strip characterized by an arbitrary field dependent critical current density $J_c(B)$. The analytical framework and present numerical solutions were developed for the quasistatic current-density and flux-density profiles, as well as the hysteretic magnetization curves, for a sample subjected to a time dependent perpendicular applied magnetic field. The field dependence of J_c has a strong influence on the shape of the hysteretic magnetization curves.

A preprint reports on self-field measurements and calculation procedures yielding a methodology for determining critical current density distributions in flat samples of arbitrary shape. The normal component of the self-field $B_z(x,y)$ is measured at grid points in planes above the sample using a scanning Hall probe, and the results are inverted to obtain profiles of the magnetization and current density in an $YBa_2Cu_3O_{7-d}$ disk and a half disk.

The shape effect in superconductors is usually treated by using the demagnetising factor (N), defined in terms of an ellipsoidal approximation to the sample geometry [5, 6]. However, for a superconductor with large critical current density, J_c, this is wrong not only quantitatively but qualitatively [7]. Numerical calculations of the magnetic field distribution of a disk-shaped superconductor in the partially critical state have been performed by many researchers . They found that for a disk of radius R and thickness $t<<R$, the field distribution within the superconductor in completely critical state become severely curved. However, for the ratio $t=R > 0,5$, the vortex lines can be approximated by straight lines.

Wire in tube geometry has improved the superconducting and mechanical properties of (Bi,Pb)-2223/Ag tapes in the literature [8]. Authors attribute the improvement on the increased Ag-ceramic interface.

Sample geometry is also important in Bi-2223 wires and tapes especially for AC transport losses. In this respect wires with square and round cross-sections behave differently and both have lower critical current density compared to tapes, round wires being worse. Filament configuration is also important for current carrying capacity [9] and filament isolation is also an extremely important factor in multi-filamentary superconductors [10]. On the other hand flatter tapes have higher magnetic field losses [11] while other reports claim that wider tapes have lower self-field transport current losses [12]. The imaginary part of the AC susceptibility X'' depends on both sample geometry and amplitute of external field. The geometry dependence of X'' is most pronounced in the case of a field independent critical current density [13]. In bulk samples of YBCO, magnetic response of the sample in AC susceptibility measurements has been reported to change with the samples' thickness [14]. A similar case can well be expected in Bi-based superconductors. Sample shape has been reported as an important factor in determining transport critical current density of the samples by measuring current-voltage characteristics [15].

CHAPTER 3

3.1 Experimental Content

3.1.1 Superconducting Powder Preparation

Superconducting $Bi_{1.8}Pb_{0.35}Sr_{1.9}Ca_{2.1}Cu_3O_y$ samples were prepared by the standard solid-state reaction method. The weighed powders of Bi_2O_3 (99. 99%), *PbO* (99. 9+%), $SrCO_3$ (99. 9+%), $CaCO_3$ (99+%) and *CuO* (99+%) in the cation ratio of *Bi:Pb:Sr:Ca:Cu* =1.8:0.35:1.9:2.1:3 were thoroughly mixed by ball grinding for 24 h. After milling, the mixed powders were calcined in air at temperatures of 700, 750 and 800 ^{o}C for 24 hours durations. The powder was ball milled after each calcinations step. The calcined powder was used for preparation of the bulk samples.

3.1.2 Sample Preparation

After obtaining the Bi-2223 powder as described above, the next step was to pelletise this powder in to cylindrical bulk samples. In order to achieve this, we have first planned to make a pressing apparatus as seen in Figure 1. This apparatus was made with a wire erosion machine by Çelebi Makina in Düzce. It has four holes for different sample geometries. One hole was for pressing a sample without any hole in it, in other words to press a solid cylindrical sample. The remaining three holes was for to making hollow cylinders of bulk Bi-2223 samples. Inner diameters of these hollow cylinders are 0,5mm, 1mm and 1.5mm. At the bottom there is a pin of 0.5mm, 1mm or 1.5mm diameter which inserted in to the 3mm diameter hole. Then powder in put in to 3mm hole around the inserted pin which can slide down as the powder in the 3mm hole was compacted. A 3mm diameter die is inserted in to the hole and pressed with a few tons force.

This pressing apparatus did not work since the ceramic powder got stuck to the steel material and it was not possible to remove the pressed bars out of apparatus without damaging. Many trials did not produce any successful result.

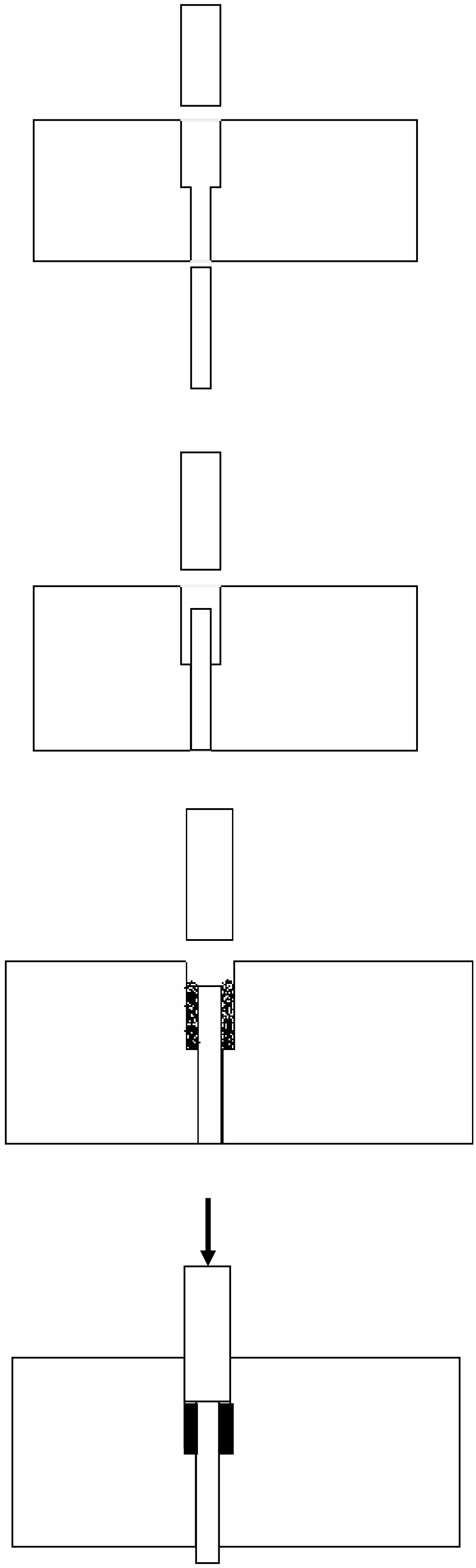

Figure 1: The drawings of the pressing apparatus used to pelletise the powder.

After these trials, we have decided to produce solid cylindrical bar samples and make the holes afterwards. We kept the outer diameter limited to 3mm since the ac susceptility system in Ankara University to measure these samples has a sample measurement chamber no bigger than this size. We had a new die made by Çelebi Makina as seen in Figure2.

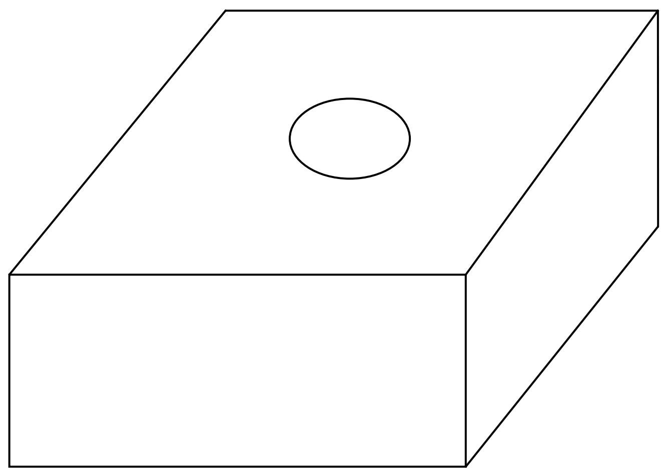

Figure 2: Die with 3mm diameter single hole.

We have again encountered the same problem as the ceramic powder stuck to the pressing dies. In order to remove the pressed bar from the pressing die more easily, we used Vaseline as lubricant. We applied vaseline as a thin layer on the surfaces of parts of the pressing die where they will come in to contact with ceramic powder. Even with the use of vaseline, we could not get the sample out of the pressing die.

We then decided to have another pressing die made. A photograph of this die which was produced by Çelebi Makina is seen in Figure 3. This die is made with four blocks of steel connected with screws. The 3mm diameter hole in the middle was made by wire erosion machine. After pressing the bar sample, the die was separated into four parts by unscrewing, exercising extreme care. We again had to use vaseline to remove the sample from the die in one piece. Even so, some of the samples were sliced in the middle along the length while separating the die.

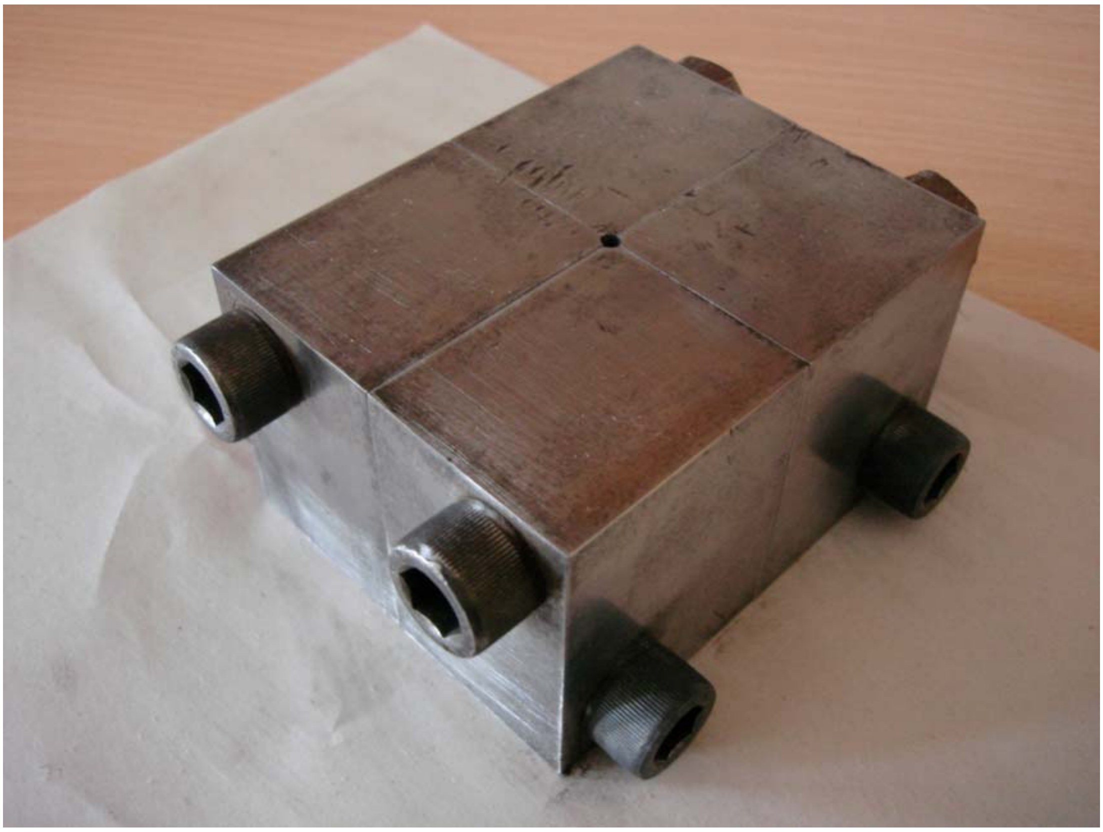

Figure 3: The photograph of the die.

We have eventually managed to prepare bar samples of various lengths of 10-12mm. We have altogether prepared 15 samples. After preparing the cylindrical bar samples, we annealed all the samples at 830^{o}C in air for 48 hours duration. Making the holes in the samples was not possible before the heat treatment since any mechanical force would break them in to pieces. Annealing temperature was chosen as 830^{o}C through our previous experience.

After the annealing process the samples were hard enough to make hole in them through cylinder axis. Important thing in this step was not to disturb cylindrical symmetry of the sample, in other words to make can exactly centred hole. We first tried to make holes using a thin diamond drill. We made the hole but it was off centre. Then as a next trial we used arc drilling machine which is a complementary equipment for wire erosion system. This machine was able to drill holes in conducting samples but our samples were not conducting enough for the operation and increasing the voltage has burnt our sample.

We again tried to drill the holes with thin diamond drills. This time we used a drill with a special sample holder system to make the holes central. Using this system we made a number of samples with 0, 5mm, 1mm and 1.5mm diameter holes. Some of the samples were broken. After the drilling process, we obtained 2 samples with 0.5mm hole, 2 samples with1 mm hole and 2 samples with 1.5mm hole. We kept 1 sample without any hole for comparison.

3.1.3 AC Susceptibility Measurements

After preparation of the samples, we planned to make ac susceptibility measurements to examine the effect of samples' geometry. We first used a home made system and made some measurements. To compare the results we obtained with the results of a professional system, we measured our samples in the ac susceptibility system in Ankara University Solid State Physics Laboratory. Although we planned to make measurements at different applied magnetic field magnitudes, we could only make three measurements. We measured samples with 0.5mm, 1mm and 1.5mm diameter holes using 111 Hz and 20 A/m ac magnetic fields. After these measurements, the system has been broken and became out of use.

We then decided to use our home-made system again. We re-measured the samples in our laboratory.

CHAPTER 4

4.1 Definition of AC Susceptometer

The sample magnetization is studied using a conventional ac magnetic susceptometer. The susceptometer probe illustrated in Figure 4 includes a primary solenoid that produces a uniform AC magnetic field. Inside the primary coil, there is a secondary coil consisting of two pickup coils that are wound in opposite directions and connected in series. The sample is placed in one of the pickup coils; the other pickup coil is empty. The AC voltage across the secondary coil is due to Faraday's Induction Law;

$$V = -\frac{d\phi_B}{dt}$$

where Φ_B is the net flux through the entire secondary and includes contributions from both the applied field and the field due to the sample magnetization. Because the two pickup coils are wound in opposite direction and connected in series, the net secondary flux due to the applied field will be small. Only causes for this net secondary flux are unevenness of the magnetic field produced by the primary coil and variations in the windings of the pick-up coils.

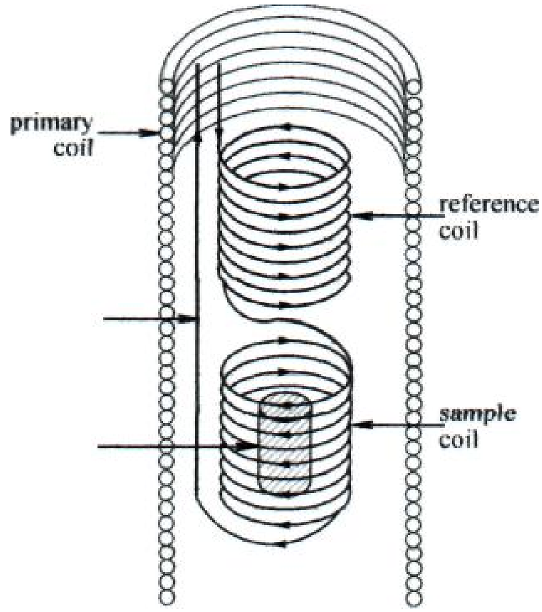

Figure 4: Schematic illustration of primary and secondary coil.

The net secondary flux is not exactly zero because of imperfections in probe construction, and thus, there is some small mismatch in the flux for the sample and reference coils. Of course, the net secondary flux due to the mismatch Φ_{mm} will be proportional to primary field

$$ø_{mm} = \alpha_{mm} B_a \qquad (4.0)$$

α_{mm} is an effective mismatch area, which may be positive or negative depending on winding directions, and whether the sample or reference coil has the larger flux. Consequenty, there will be some secondary signal $V = -dø_{mm} / dt$, which can be written as

$$V = V_{mm} \sin wt \qquad (4.1)$$

Where $V_{mm} = \alpha_{mm}\mu_0 wH_0$ gives the amplitude of the voltage due to mismatch. If a sample is present the magnetic field $\mu_0 M$ associated with the induced magnetization will unbalance the fluxes in the sample and reference coil and there will be large net flux Φ_m in the secondary. We could write

$$ø_m = \alpha_m \mu_0 M \quad (4.2)$$

with the effective area α_m again, the sign of α_m depend on the winding directions and there will be an induced secondary voltage

$$V = V_m(\chi' \text{sinwt} - \chi'' \text{coswt}) \quad (4.3)$$

The lock-in amplifier takes the monitor voltage as the reference input and it takes the secondary voltage as the signal input. Although the amplitude of the reference voltage is relatively unimportant, the origin of time is arbitrary, so the reference voltage can be expressed

$$V_r = V_{r0} \cos wt \quad (4.4)$$

Relative to this reference, an arbitrary signal voltage can be given by

$$V_s = V_{s0} \cos (wt-\delta) \quad (4.5)$$

Where δ is the phase angle by which the signal lags the reference

$$V_s = V_x \text{coswt} + V_y \sin wt \quad (4.6)$$

Where

$$V_x = V_{s0} \cos\delta \text{ and } V_y = V_{s0} \sin\delta \quad (4.7)$$

The lock-in amplifier provides direct measurement of Vx and Vy. Assuming that the monitor voltage is perfectly in phase with the primary field and the secondary voltage is given by the sum of equation

$$V_x = -V_m \chi'' \quad (4.8)$$

$$Vy = V_{mm} + V_m \chi' \quad (4.9)$$

As can be seen, the outputs of lock-in related to imaginary and real susceptibility so it can be accepted that behavior of the susceptibility is the same voltage output of lock-in so can be characterized magnetic behavior of sample by using lock-in output. Note, however, that the lock-in has a reference phase offset adjustment, which allows one to introduce an arbitrary, constant phase shift between the reference and signal voltages. The phase offset is often adjusted when there may be an apparatus-dependent phase shift in the reference and/or the signal, say due to cable lengths or stray impedances. To correct for the unknown phase shift, one needs some condition that can be realized experimentally where the relative phase between the reference and signal is known. If such a condition can be achieved, the lock-in phase adjustment can be set to produce the known phase difference, and as the experimental conditions change to those where the phase relationship is unknown, the results can be interpreted based on this setting.

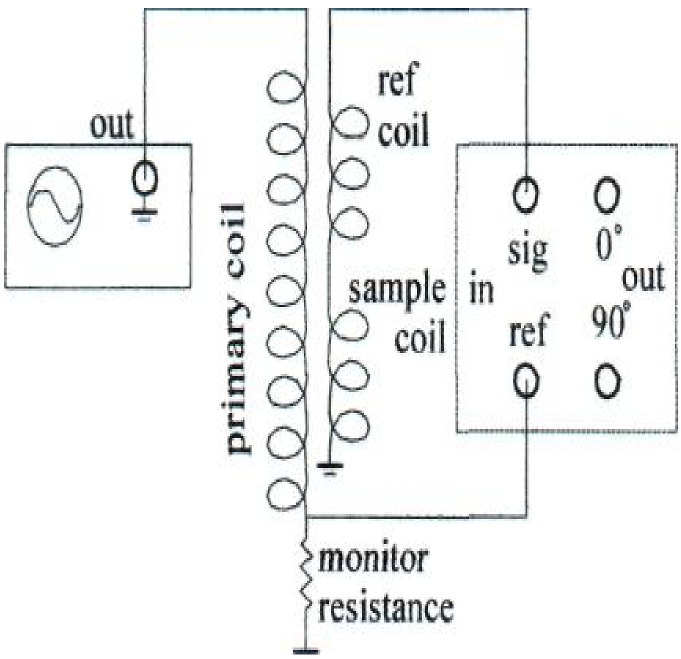

Figure 5: Equivalent circuit for the function generator, susceptometer and lock-in.

Where $V_m = \alpha_m \mu_0 w H_0$ sets the scale for the secondary voltage due to the sample.

CHAPTER 5

5.1 Results and Discussion

Figure 6 shows the AC susceptibility results obtained in Ankara University Solid State Physics Laboratory.

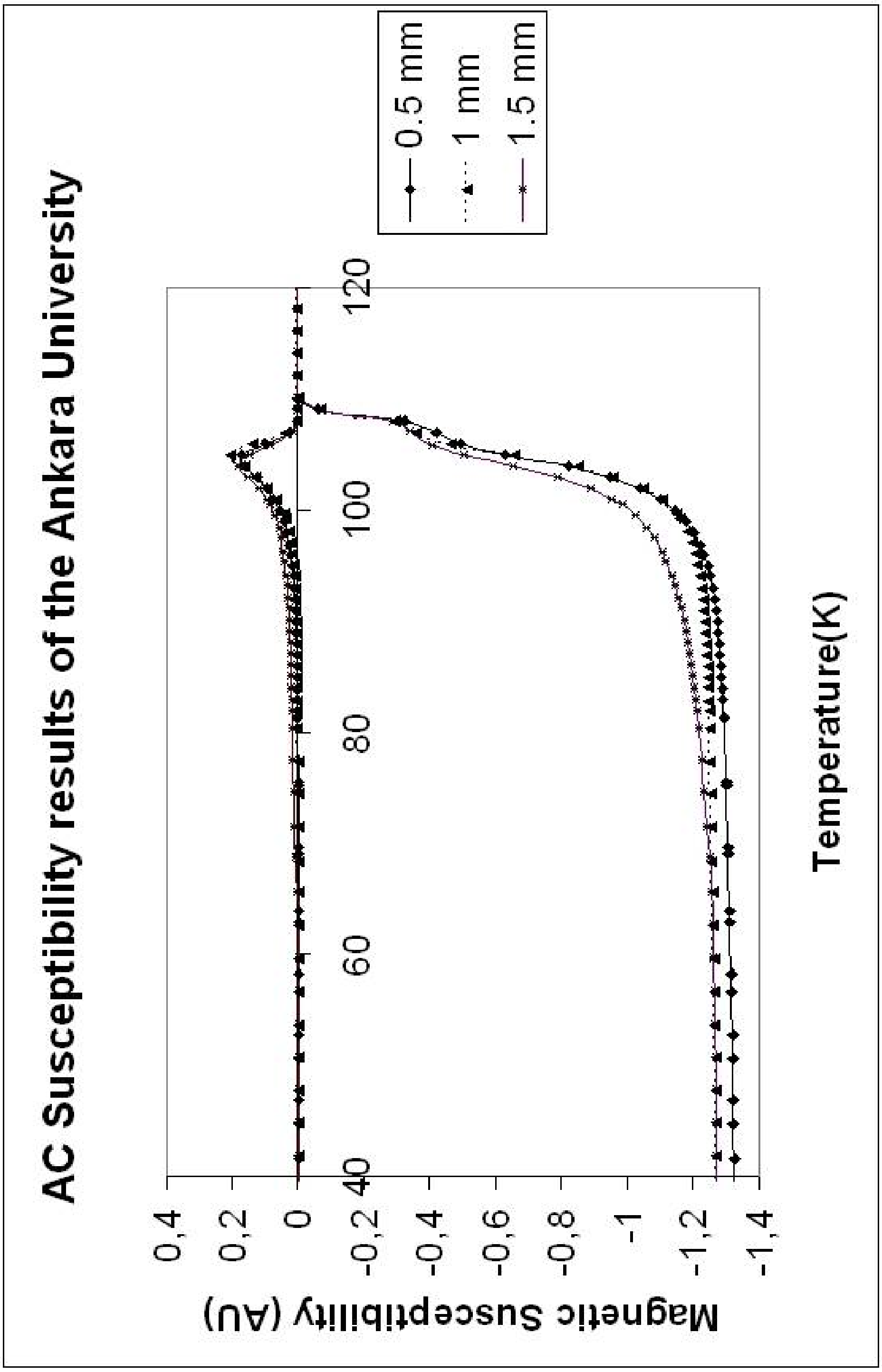

Figure 6: AC susceptibility results from Ankara University.

In this measurements there are data belonging three samples with hole diameters of 0.5mm, 1mm and 1.5mm. The ac loss seems to increase with increasing bore diameter. X'' curves exhibit a slight sliding to the left, towards lower temperatures, indicating poorer inter-grain connectivity in sample with larger bore diameters. The magnetic field applied to the sample during measurement was a very small field, 20 A/m. This has probably resulted in the disappearence of the first ac loss peak which is due to intra-grain effects. The second ac loss peak, which is due to inter-grain effects, is apparent in the curves. This very low field region can not be experimented in our home made system. It would be very useful if it was possible to measure the sample with no bore in Ankara University, but the system could not repaired within the time duration of experimental parts of this study.

Figure 7 shows ac susceptibility results of measurements of 0.5mm hole diameter sample with our home-made system. 1, 2, 3, 4, 5 V potential differences were applied to primary coil of the system, respectively corresponding to applied magnetic fields of 111, 222, 333, 444, 555 A/m. Frequency was 330 Hz. It is seen in the graph that signal obtained from the sample increased with increasing magnetic field magnitude. The temperature, at which the diamagnetic signal starts, increases slightly with increasing magnetic field.

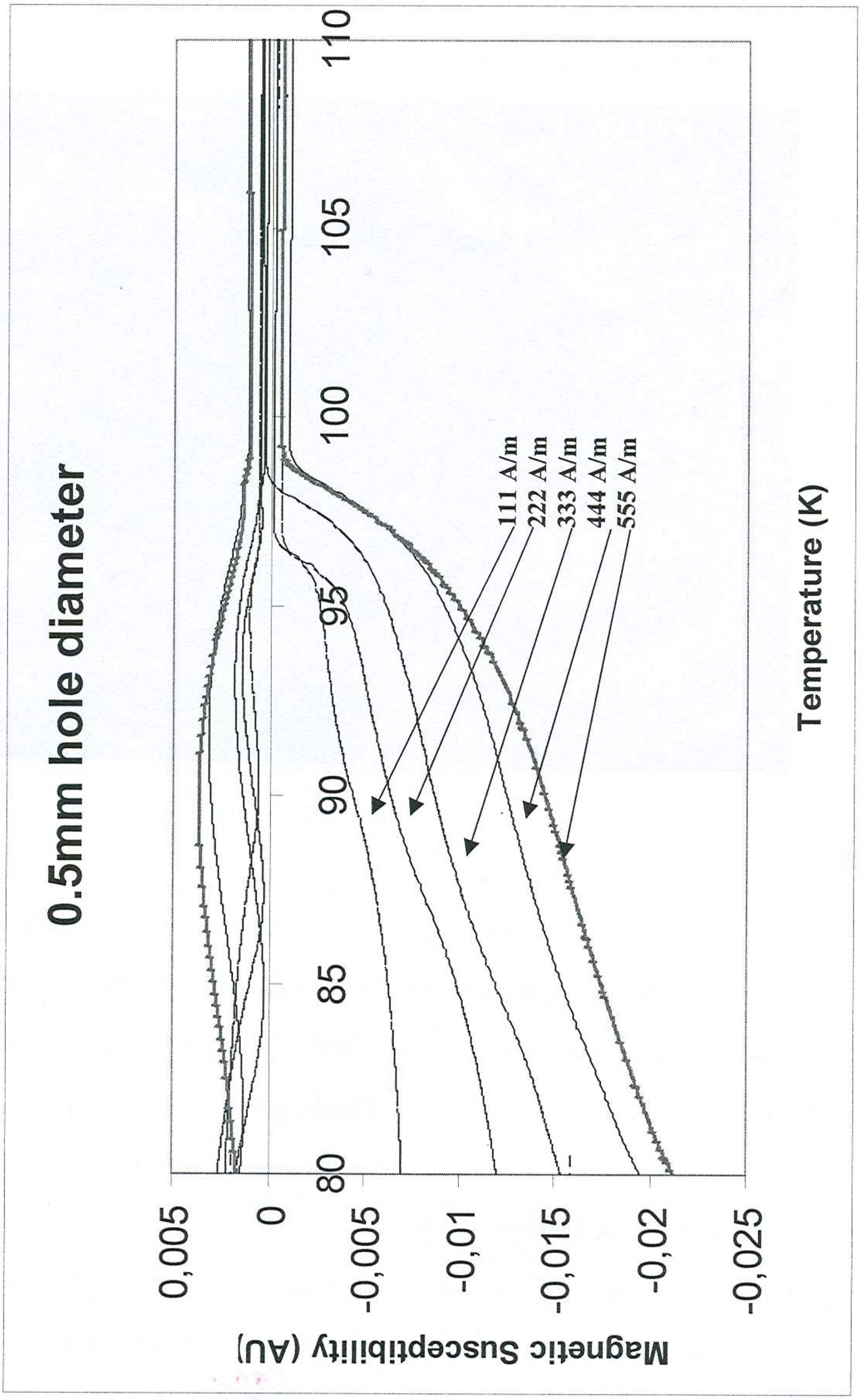

Figure 7: AC susceptibility results of 0.5mm.

This may be related with the sensitivity of the measuring system. Especially at the beginning of the diamagnetic signal, measured potential difference is very small, making the sensitivity of the system important.

Figure 8 shows ac susceptibility curves of the sample with 1mm inner bore. Increasing the magnetic field strength has caused a significant increase in the temperature at which the diamagnetic signal is observed. This temperature is known as magnetic critical temperature. Increase of this magnetic critical temperature for this sample is important because it can not be attributed to receiving more signal since the sample with a larger hole has less material to respond the magnetic induction.

In order to compare the magnetic response of two samples at different applied magnetic field values, we produced ac susceptibility curves of both samples separately for each applied magnetic field strength.

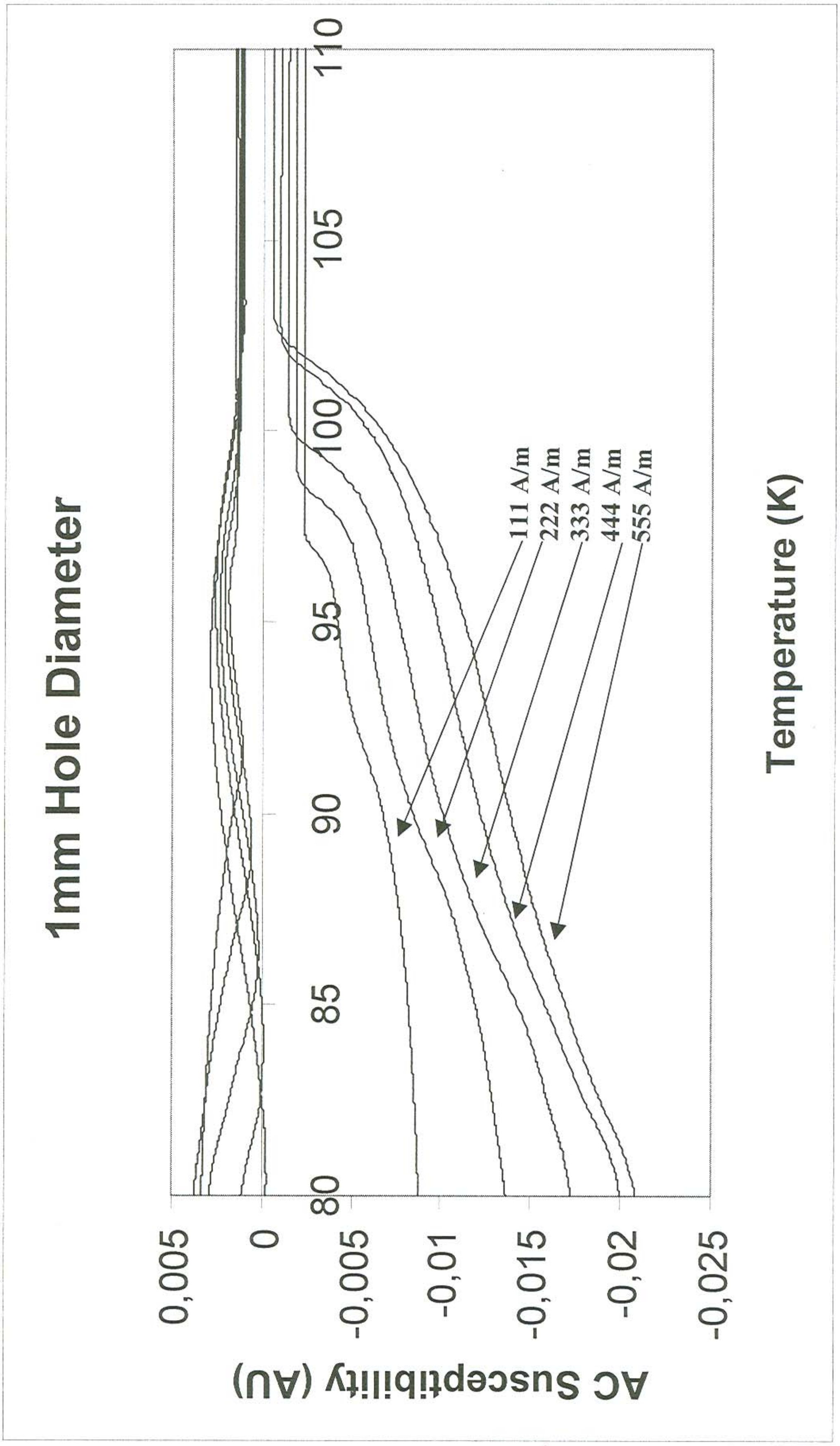

Figure 8: AC Susceptibility results of 1mm.

Figure 9 shows ac susceptibility curves fo 111 A/m magnetic field. There is a difference of 0.7 K between magnetic critical temperatures of the two samples.

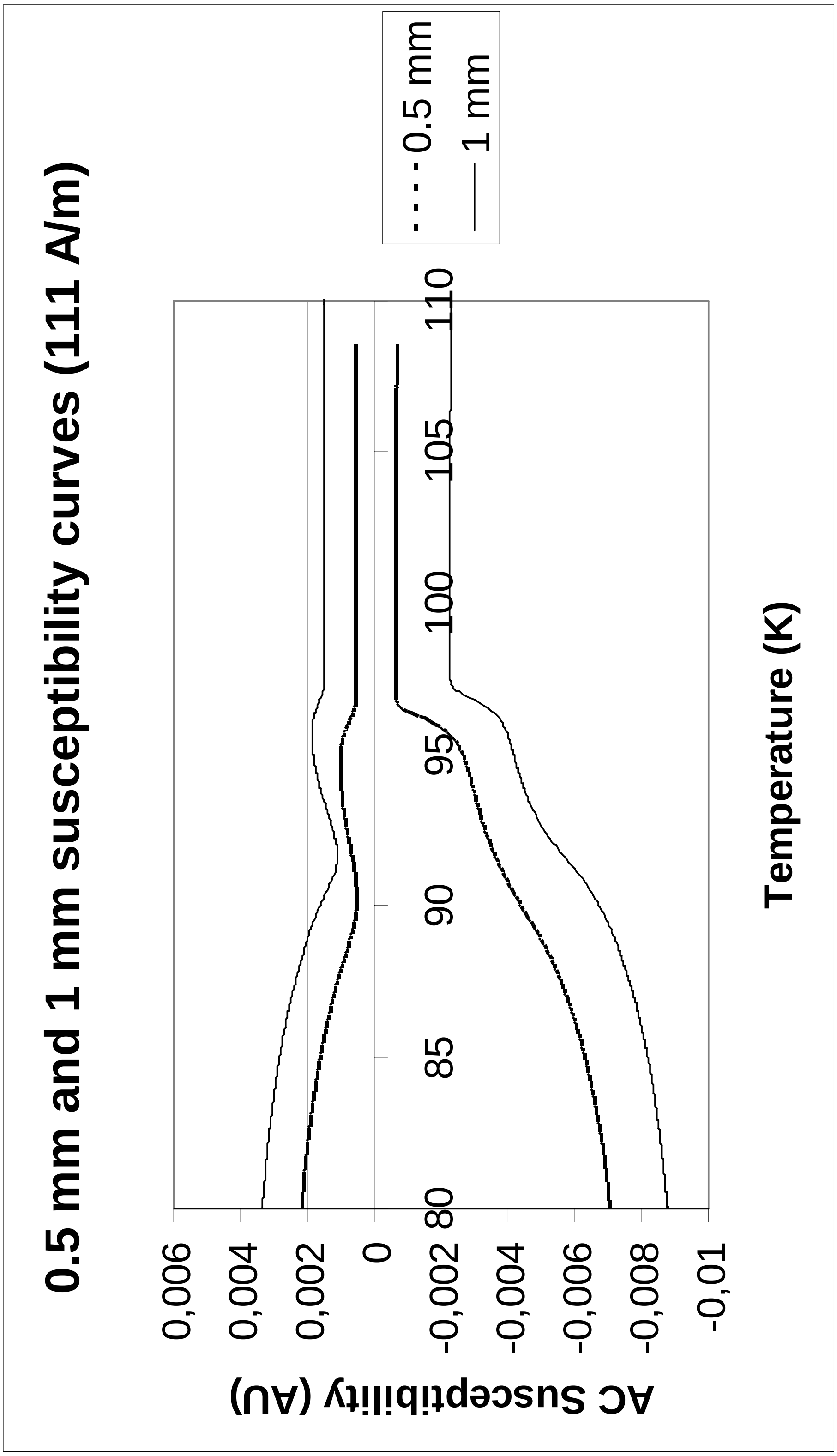

Figure 9: Comparison at 111 A/m.

Two peaks are seen in the X'' curves, first peaks correspond to the intra-grain effects. AC loss peak of the sample with 1mm bore is at a higher temperature. This is an indication of better superconducting properties.

A similar result is seen in Figure 10.

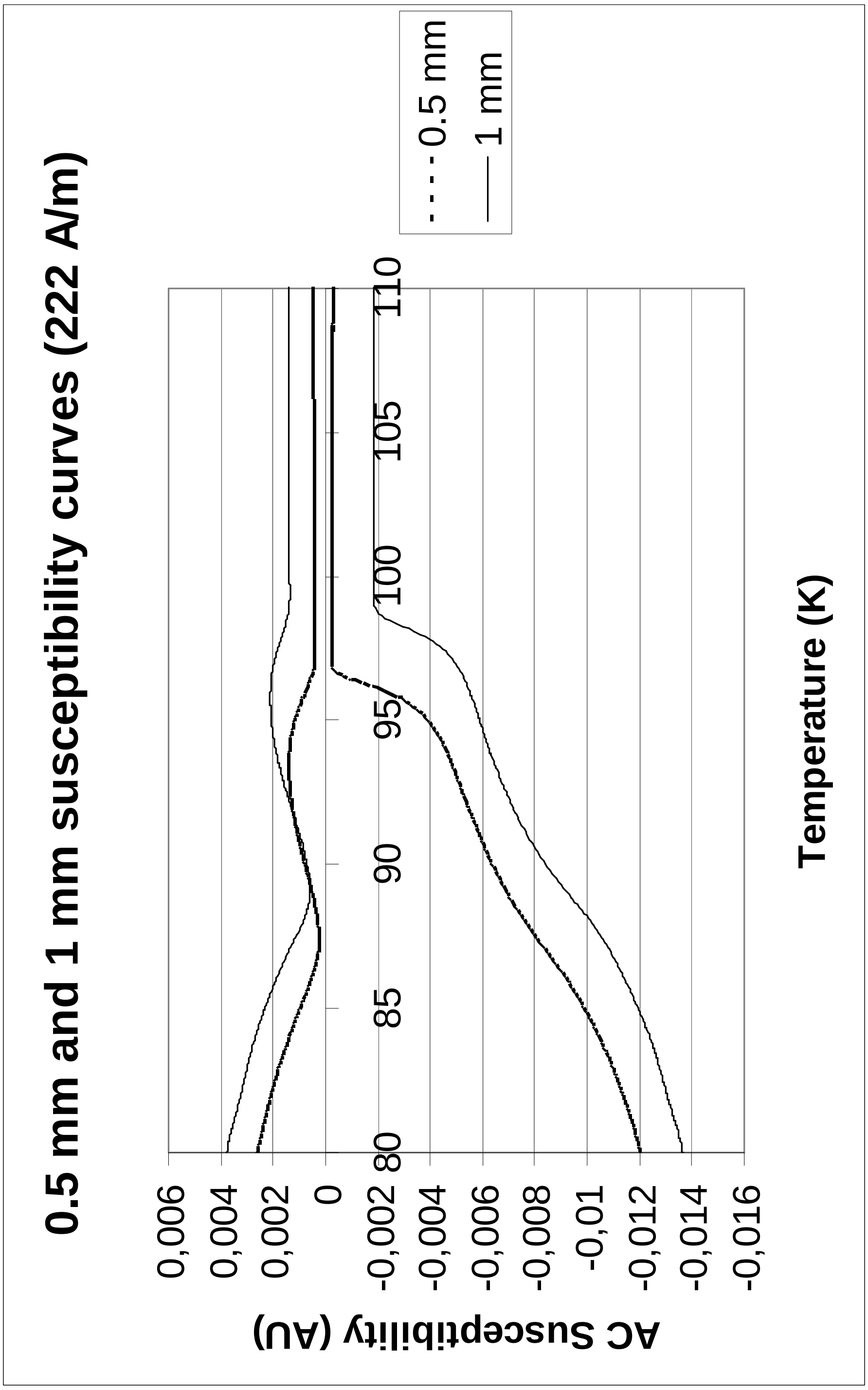

Figure 10: Comparison at 222 A/m.

The difference between ac loss peak temperatures of 0.5mm bore diameter sample and 1mm bore diameter sample is more significant when the applied field strength is increased. In this measurement, the difference between magnetic critical temperatures is increased to 2K.

Figures 11, 12 and 13 exhibit similar properties.

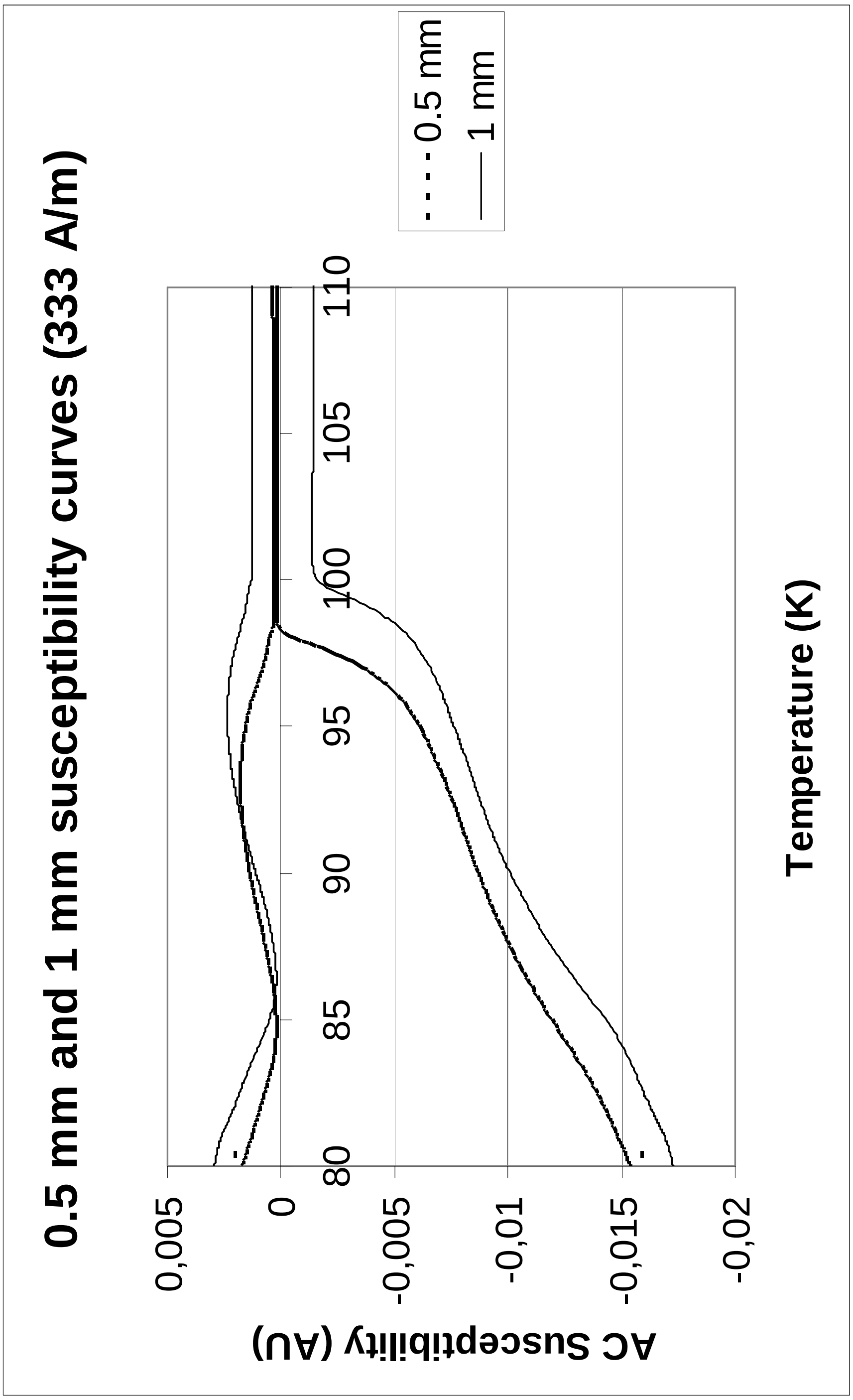

Figure 11: Comparison at 333 A/m.

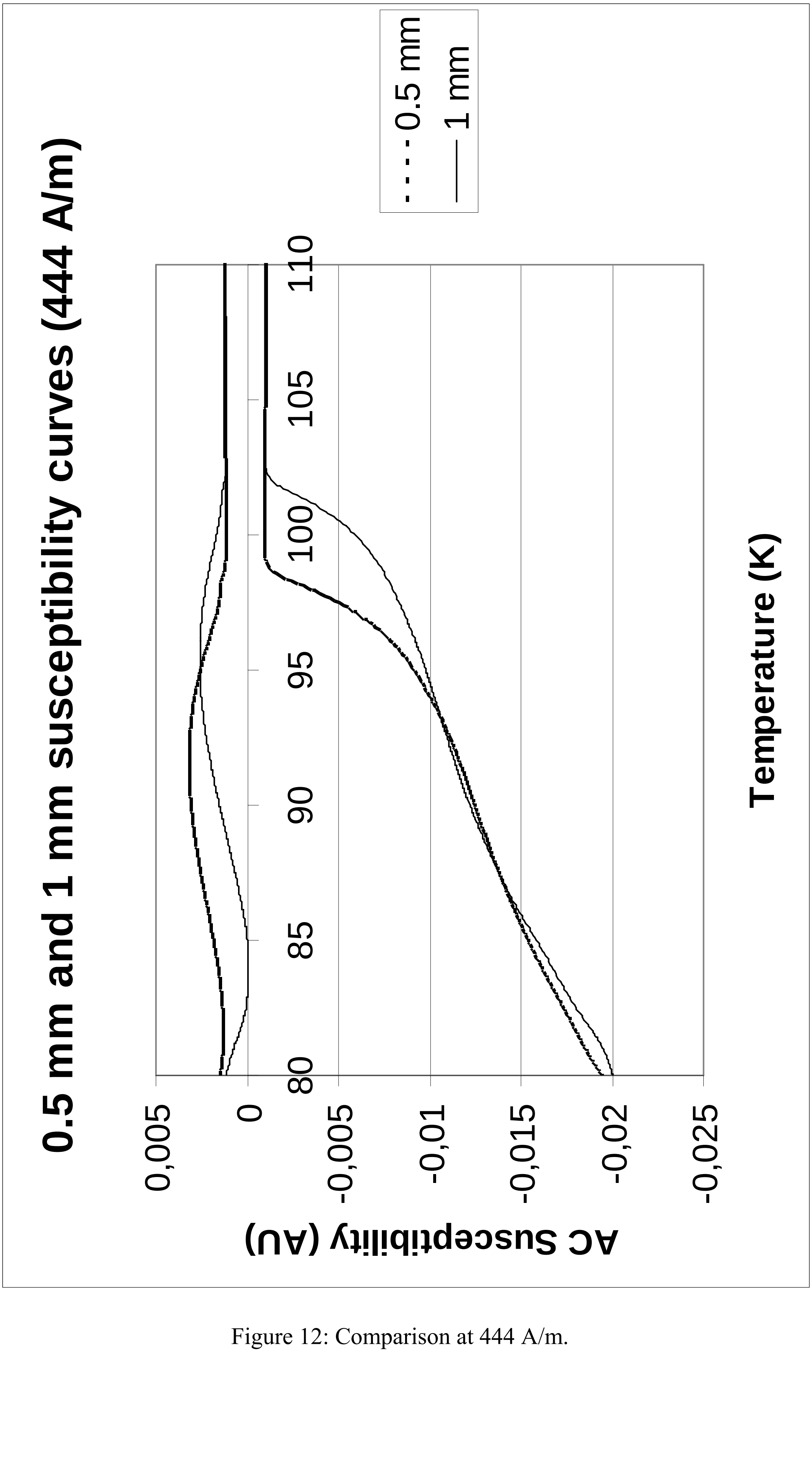

Figure 12: Comparison at 444 A/m.

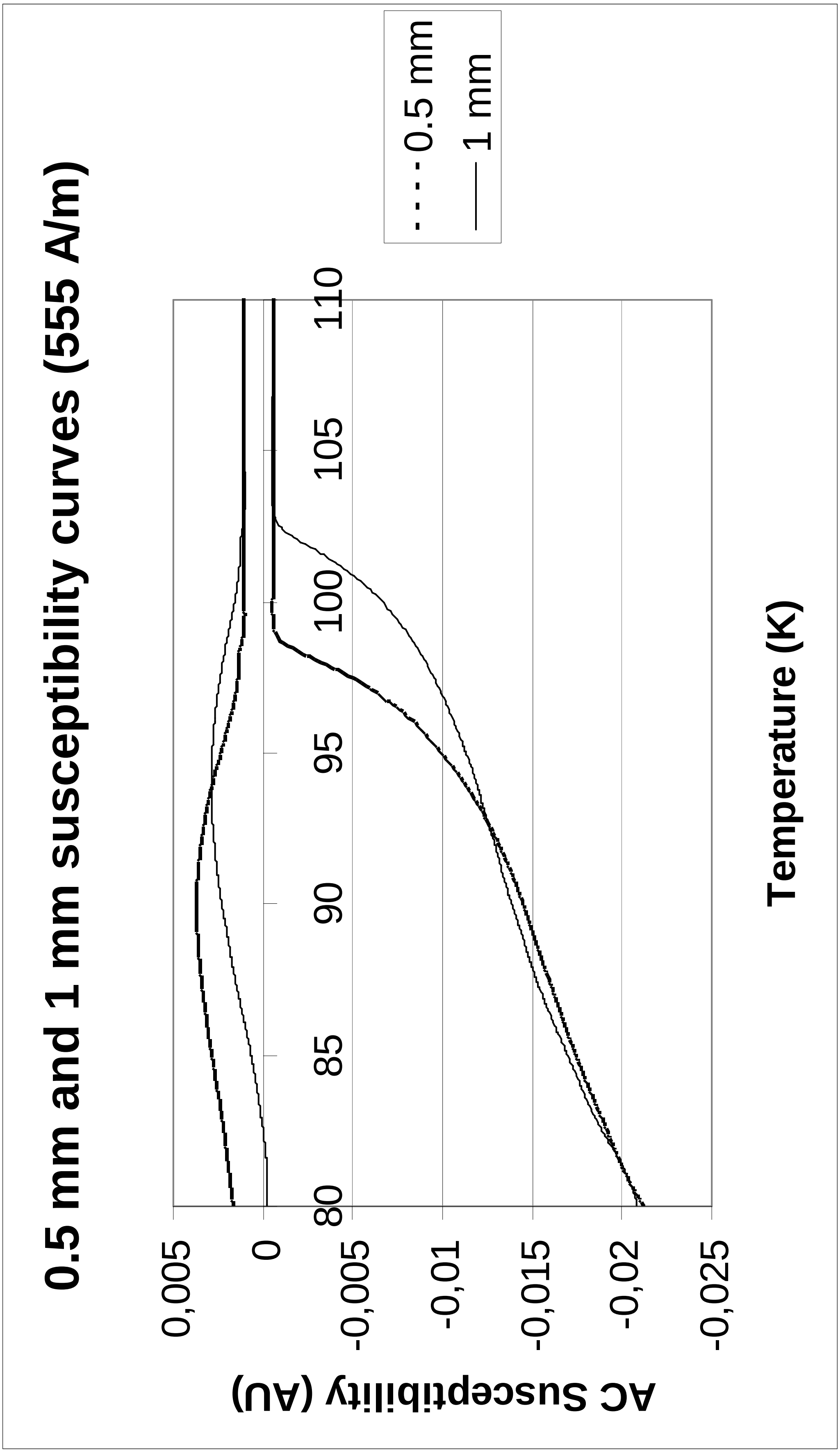

Figure 13: Comparison at 555 A/m.

The difference between critical temperatures continues to increase with increasing magnetic field strength. It is 4 K when the applied magnetic field strength is increased to 555 A/m. This cannot be explained by sensitivity of the system since the sample with 0.5mm diameter bore has more superconducting material to give more diamagnetic response. We could not fully explain this phenomenon. This is a subject of further research. It is worth noting that bulk samples have better crystallinity at the surface. Another possibility is that, since the compaction starts from outer surface, the ceramic material is denser at the surface and it is less dense at the central parts of the cylindrical bar samples.

The temperature dependence of $J_c(T_p)$ is often determined via the temperature dependence of the intergrain maximum in the imaginary part, χ'' (T) of the ac susceptibility using the Bean's Model. $J_c(T_p)$ is calculated for our samples using the relation $J_c(T_p) = H_a/a$ for the cylindrical shaped so $J_c(T_p)$ is the intergranular current density and H_a is the amplitude of applied field at T_p. As seen in Figure. 6 T_p are the 105.5, 105, 104K for 0.5, 1, 1.5mm hole diameter, respectively. When critical current density was calculated for H_a = 20 A/m and a = 0.003m. from Bean's Model, $J_c(T_p)$ was found to be about 666 A/m^2 for our samples.

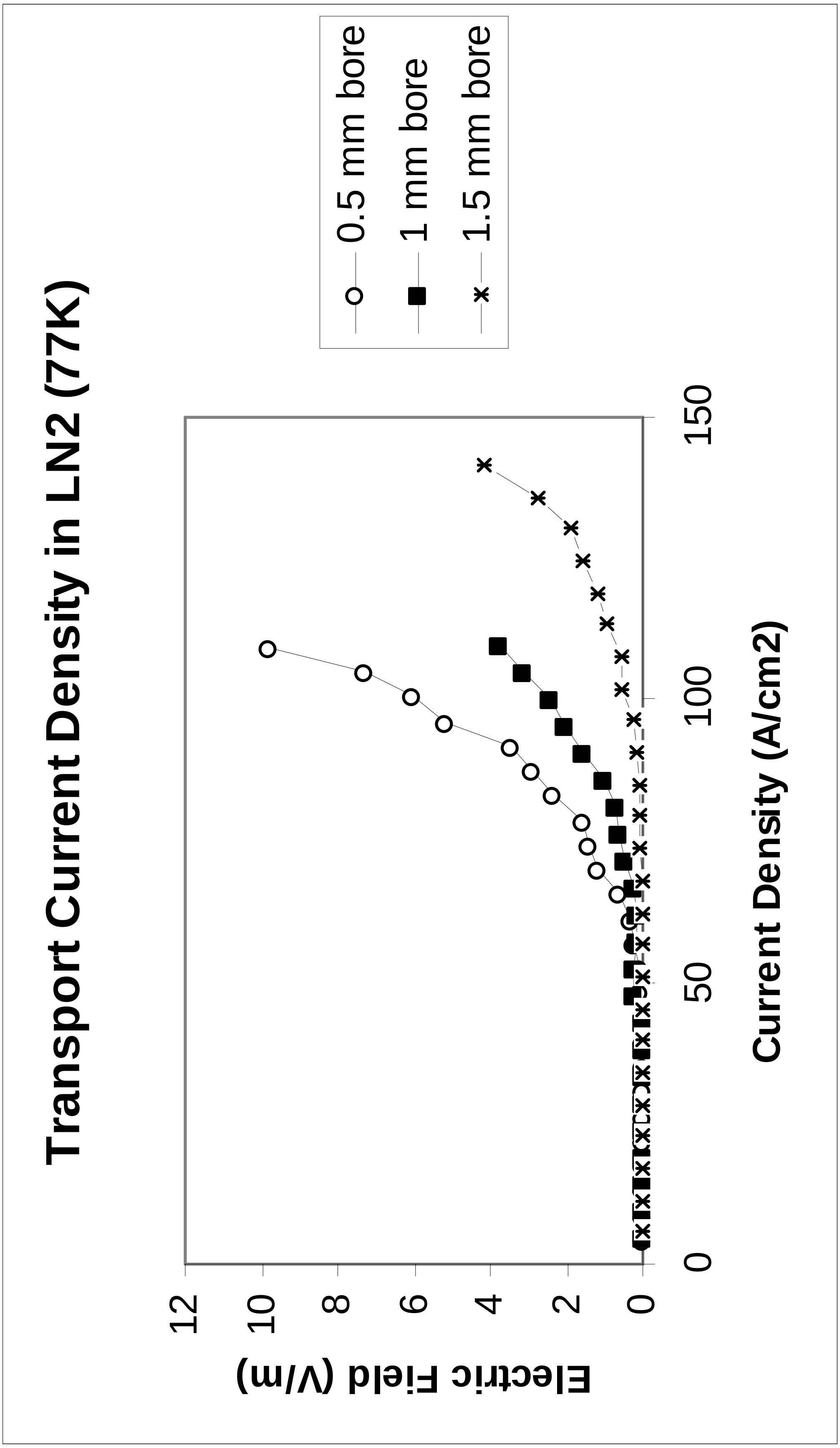

Figure 14: Transport Current Density in LN2 (77K)

We have measured the transport critical temperatures of our samples at 77K in liquid nitrogen. Current connections were made with silver paint. Critical current densities were calculated from these I-V measurements. The sample with 1.5mm diameter bore has the highest critical current density. The sample with 0.5mm inner diameter has the lowest critical current density. The results of these measurements are shown in Fig.14. The difference between the critical currents is in agreement with our ac susceptibility results.

5.2 Conclusions

We have managed to produce bulk samples of solid and hollow cylinders with 0.5mm, 1mm and 1.5mm inner bores. It is more convenient to produce solid cylinders first then to drill holes in them. This process would be easier if the outer diameter was larger. Increasing the applied magnetic field strength has increased the sensitivity of the measuring system. Higher magnetic field has caused the ac loss peaks to the lower temperatures as expected. Cylinders with larger inner bores had higher magnetic critical temperature when measured with our home-made ac susceptibility system. This phenomenon could not be elucidated within this thesis and requires further research.

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