LEVITATION AND MAGNETIC PROPERTIES OF MELT PROCESSED HIGH TEMPERATURE SUPERCONDUCTOR CYLINDERS

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ABSTRACT

The high temperature superconductor $YBa_2Cu_3O_x$ (YBCO) is a very promising material for superconducting magnetic bearings due to its good magnetic properties. Large samples with diameters of up to 32 mm and 20 mm thickness were prepared by a modified melt process. Starting from mixtures of YBCO 123 and 211 phase cylinders were cold isostatically pressed and then sintered followed by a partial melt process at 1050 - 1100°C. During the slow cool down from the peritecticum with a cooling rate of 1 - 2°/h large crystals grow with sizes of up to 10 mm. Additions of PtO_2 and 211 to the 123 powder led to higher repulsion forces from a magnet. The influence of the magnetic field distribution of magnets with varying shapes was studied. The temperature dependence was investigated in the range of 18 - 80 K. An operation temperature of 30 K increased the repulsion forces by a factor of 3 in comparison to 77 K. For the first time the levitation properties of melt cast processed $Bi_2Sr_2Ca_1Cu_2O_x$ were compared with YBCO showing similar properties of both materials at low temperatures.

INTRODUCTION

The effect of autostability and the very low friction make magnetic bearings based on high temperature supeconductors (HTSC) very interesting for technical applications [1-8]. Up to now the low magnetic properties of the material in the desired shapes limit the use of this kind of bearing. Therefore the overall quality of large bulk parts of HTSC material has to be optimized. Melt processed YBCO exhibits very large magnetization values and strong repulsion forces from a magnet [9-12]. In this study the influence of different additives (YBCO 211, PtO_2) on the microstructure and on the levitation properties of melt processed YBCO was investigated. The amount of YBCO 211 influences the crystallisation of the superconducting 123 phase at the peritecticum and PtO_2 is known to reduce the size of the 211 precipitates in the 123 matrix [13]. Reducing the operation temperature from 77 K (boiling nitrogen) to 20 K using a closed cycle refrigerator leads to a further improvement of the levitation properties. For the first time the repulsion forces of melt cast processed (MCP) $Bi_2Sr_2Ca_1Cu_2O_x$ was investigated and compared with YBCO. This material can easily be prepared in large bulk shapes but due to low pinning effect, operation at lower temperatures is necessary [14-16].

SAMPLE PREPARATION

The investigated YBCO samples consisted of cylinders with dimensions of 20 - 32 mm diameter and 15 - 20 mm height. They were prepared starting from a powder mixture of YBCO 123 and YBCO 211 reacted by a solid state route. The grain sizes were in the range of d_{50} = 5 - 10 µm (123) and 0.7 - 1.5 µm (211). Different mixtures with 0, 17, 26 and 35 wt.% 211 and with 15 % Ag_2O were intensively mixed for several hours to obtain a good homogenity[12,17,18]. The Ag_2O addition increases the density of the samples and thus the mechanical properties[12]. Pt is known to influence the size of the 211 precipitations during the crystallisation after the melt process[13]. To investigate its effect on the levitation properties a series of samples with 0, 0.6, 1, 1.5, 2 wt.% PtO_2 was prepared with 17 % 211. The cylinders were made by cold isostatic pressing at 2300 bar followed by sintering at 920 °C in air in order to reach a density of 92 %. In a second heat treatment the temperature was raised to 1050 - 1100 °C for a partial melting process. This was followed by fast cooling to 1020 - 990 °C to prevent growing of 211 precipitates and slow cooling at a rate of 1°/h. Further details of the preparation are described in previous papers. Seeding or cooling in a temperature gradient to obtain larger grains was not used in this study. Finally the samples were oxygenated in the temperature range of 630 - 400 °C for 40 - 100 h. Even though the melting temperature of 123 was passed all samples kept their shape due to the formation of the solid 211 phase. After the melt process the density of the cylinders was in the range of 95 - 97 % of the theoretical density.

For comparison the levitation forces of a 40 mm Ø and 20 mm high melt cast processed (MCP) cylinder of $Bi_2Sr_2Ca_1Cu_2O_x$ (BSCCO 2212) were investigated too. With this preparation method large and arbitrarilly shaped bulk parts can be easily prepared[14-16].

EXPERIMENTAL SETUP

Two automated measurement systems were assembled to test the levitation forces between the samples and different permanent magnets (NdFeB, CoSm). For comparing the results one had to take into account that the absolute values of the forces depend not only on the electromagnetic characteristic, the size and shape of the samples but also on the magnetic field distribution of the different magnets. Since we always used the same experimental setup a comparison of the overall quality of the different samples is possible. In system A the YBCO-cylinders were mounted in a small LN_2 dewar and were mechanically moved slowly (13.3 mm/min) towards the magnet and removed. The repulsion or attraction forces were measured by a balance and recorded by a computer. For thermal isolation reasons the nearest distance between magnet and samples was 3 mm. With this setup a fast measurement at 77 K can be obtained, easily varying the shape of the samples and magnets [12]. Three different magnets were used, a disk shaped NdFeB magnet (20 mm diameter, 5 mm high, B (3 mm) = 1600 G), a rod shaped NdFeB magnet (15 mm diameter, 18 mm long, B (3 mm) = 3200 G) and cylindrical CoSm magnet (25 mm diameter, 10 mm high, B (3 mm) = 2900 G).

In system B the levitation force in dependence of the operation temperature was measured between 18K and T_C. For this purpose the superconducting sample was mounted on the cold finger of a two staged Gifford-McMahon Cryocooler (CTI). To improve the thermal conditions a copper shield was fixed on the second cooling stage in the isolating vacuum. A quartz glass window was placed in the vacuum vessel just above the sample to minimize its influence on the flux distribution. By mounting Si-diodes on top and bottom of the samples temperature gradients within the cylinders were determined. Only differences of less than 2 K were observed in the whole temperature range. Magnets of different shapes were fixed on a strain gauge and moved by a computer controlled stepper motor in vertical direction with a precition of 0.05 mm. For this system the minimum distance between magnet and sample was 4.5 mm due to the isolation (vacuum, copper shield, glass window).

MICROSTRUCTURE

Similar to the results of other melt processes on YBCO, the samples exhibit large grains of 123 with up to 10 mm diameter including small precipitates of 211 phase[11,12]. By adding PtO_2 to the mixture the size of the 211 inclusions was reduced to 0.5 - 2 µm and simultaneously a more homogeneous distribution was achieved. During the reaction 211 + Liquid → 123 at the peritecticum the artificially added 211 powder grains are included, so there is no correlation between the starting 211 powder size and the final 211 inclusion in the melt processed samples.

RESULTS AND DISCUSSION

The levitation forces depend on one hand on the value of the magnetic field and its gradient and on the other hand also on the intragrain critical current density and on the grain size. For optimasing the microscopic properties a set of samples with different amounts of 211 addition ranging from 0 - 25 wt% was prepared. The amount of 211 influences the crystallisation properties at the peritecticum and therefore the size of the obtained grains. Fig. 1 shows the increase of the levitation force for an increasing amount of 211 addition to the powder mixture with 15 % Ag_2O and 0.6 % PtO_2. Larger amounts of 211 led to larger grains and a small increase in the intragrain critical current densities. Samples without 211 additions showed grains with sizes less than 1 mm Ø. 211 additions of more than 25 % did not result in larger levitation forces.

The influence of Pt on the size of the 211 precipitates is known from the literature. This addition effects a reduction of the inclusion sizes leading to a higher critical current density

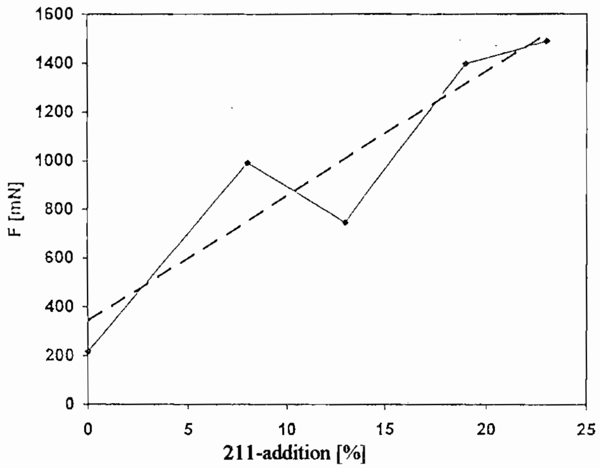

FIGURE 1: Influence of the YBCO 211 addition on the repulsion force of 22 mm Ø YBCO samples from the disk shaped magnet

or to an improved field dependence of the critical current density by improving the pinning effects. In this study we used PtO_2 as addition instead of metallic Pt since it has smaller grain sizes and is more easily dispersible during mixing. In Fig. 2 the variation of the measured levitation forces for mixtures with 26 % 211 and 15 % Ag_2O is shown. The data are for 20 mm Ø samples at 3 mm distance for the disk like NdFeB magnet. The repulsion force increased from 1430 mN 0 % PtO_2 to 2050 mN with 1 wt% PtO_2. A further increase of the PtO_2 amount reduced the levitation forces.

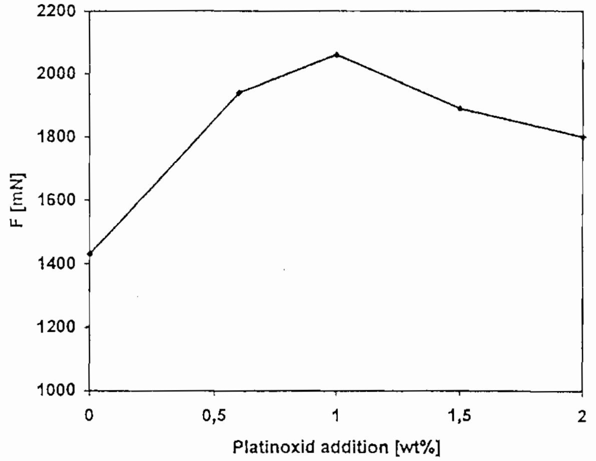

FIGURE 2: Effect of the PtO_2 addition on the repulsion force at 3 mm distance from the disk shaped magnet

As expected the levitation forces depend on the maximum field of the magnets at the nearest distance between magnet and sample. Fig. 3 shows the dependence of the repulsion force from the distance for a 20 mm Ø, 15 mm

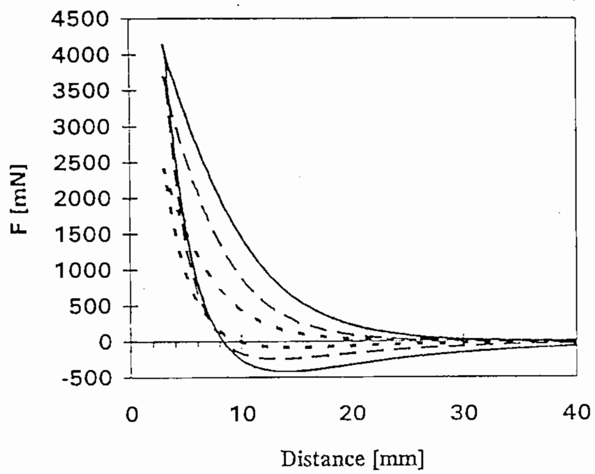

FIGURE 3: Levitation force versus the distance for three different magnets. Details are given in the text

high and 28 g sample with 26 % 211, 15 % Ag_2O and 0.6 % PtO_2. The dotted line is for the disk shaped magnet, the dashed line for the cylindrical CoSm magnet and the solid line for the rod shaped NdFeB magnet. A maximum value of 4200 mN was obtained at 3 mm distance. This corresponds to a repulsion pressure of 134 N/mm². This value is limited by the minimum distance between magnet and sample in our experimental set up. Next to the absolute value of the magnetic field also the flux distribution strongly influences the repulsion properties. As can be seen from the logarithmic diagram of Fig. 4 the resulting forces do not scale with the maximum field at intermediate distances. Even for similar maximum values of 4200 mN (NdFeB rod) or 3900 mN (CoSm cylinder) the levitation forces in the range of 5 - 30 mm were relatively larger for the NdFeB magnet. This is a result of the narrower but longer field distribution of the rodlike magnet. So for obtaining large repulsion forces in a magnetic bearing the shape of the samples and flux distribution of the magnets have to be optimised.

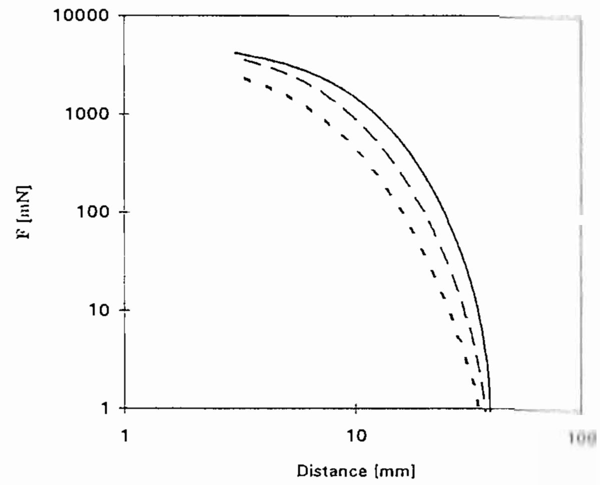

FIGURE 4: Logarithmic diagram of the levitation forces for different magnets showing the effect of the field distribution on the shape of forces vs. distance

The high temperature superconductor material BSCCO 2212 has a similar T_c to YBCO but the electric properties at 77 K in a magnetic field are reduced due to the low pinning effects. Using lower operation temperatures a large improvement of the critical current densities j_c in magnetic fields was observed. While at 77K j_c is depressed to 1 A/cm² at 2000 G from 1000 A/cm² without field, at 20 K only a small field dependence of j_c can be observed. Therefore $j_c > 10^4$ A/cm² at 2000 G can be obtained in MCP-BSCCO 2212 at this temperature. A comparison of the levitation forces of 22 mm Ø, 10 mm high melt processed cylinders of YBCO and BSCCO from the disk shaped magnet is given in Fig. 5. For small distances i.e. high magnetic fields the repulsion forces of BSCCO exceeds those of the YBCO sample.

A comparison of the levitation forces from 20 - 80 K of both materials at 4.5 mm and 9.5 mm is given in Fig.6. For the BSCCO sample the operation temperature had to be lower than 65 K to observe a repulsion effect. Lowering the temperature leds to a fast increase of the force especially at higher fields. This is the result of the nearly constant critical current densities for increasing field at temperatures less than 40 K. For large levitation distances the repulsion force of YBCO from a given magnet is larger in the whole temperature range. For 4.5 mm distance a crossover in the forces was observed at 50 K.

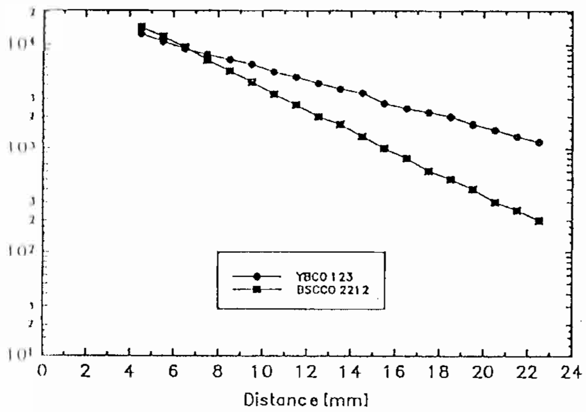

FIGURE 5: Comparison of the levitation forces as a function of the distance at 20 K for a YBCO and a BSCCO cylinder

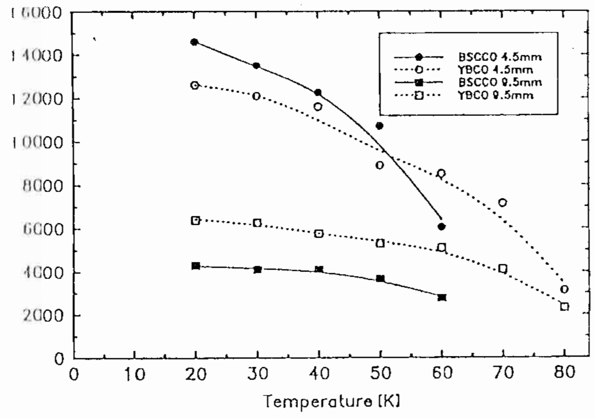

FIGURE 6: Temperature dependence of the levitation forces for a YBCO and a BSCCO sample at 4.5 mm and 9.5 mm distance

SUMMARY

The levitation and magnetic properties of melt processed YBCO and melt cast process BSCCO 2212 cylinders were investigated. Large YBCO samples with diameters of up to 32 mm and 20 mm thickness were prepared by a modified melt process. The addition of 25 % 211 phase improved the crystallisation of large grains and thus increased the repulsion forces by a factor of 7.The addition of PtO_2 to the powder mixture also increased the levitation further. The influence of the magnetic field distribution of magnets with varying shapes was studied. Also the temperature dependence of the levitation forces was investigated and compared with the properties of melt cast processed BSCCO 2212. Due to the low pinning effects BSCCO can only be used at temperatures below 60 K. The operation at 30 K increased the repulsion forces by a factor of 3 in comparison to 77 K for YBCO. The strong temperature dependence of the magnetic properties of BSCCO resulted in similar levitation forces for both materials at 20 K.

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