Joining of Bulk High Temperature Superconductors

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Abstract. The joining of bulk high temperature superconductors (HTSs) with good transport properties has been investigated. The join is achieved by using a ‘solder’ that is predominately HTS with a slightly lower peritectic temperature than the parent material, in this study YBa2Cu3O7- . This technique results in the formation of a superconducting seam with a critical current density and varying degrees of micro-structural defects. Solder reagents used were YbBa2Cu3O7- , Yb2Ba1Cu1O5, and Y1Ba2Cu3O7- /Ag, which resulted in a total of eight different superconducting ‘solders’. Micro-structural analyses using a scanning electron microscope was conducted on each sample as well as transport measurements. It was found that silver doping lowered the peritectic temperature of YbBa2Cu3O7- resulting in a solder that gave best joins.

1. Introduction
Large single domain high temperature superconductors (HTSs) cannot be easily manufactured due to the difficulties experienced during the growth process. Problems such as twinning and grain-boundaries act as weak-links to supercurrents. This has direct implications on magnetic levitation applications such as flywheel energy storage systems. In these applications, the levitation force is directly proportional to the bearing size hence the importance of creating larger superconducting bearings. Bearings may comprise a number of single domain HTSs joined together with superconducting ‘solder’ with good connectivity.

The joining process attempts to produce a seam between two superconducting domains that have similar microstructure and transport qualities to that of the parent. Typically a good join should comprise few voids, pores and trapped secondary phases. There are a number of different joining techniques with and without a solder agent. It is commonly found that although the joined sample is superconducting a reduction in the critical current density ($J_c$) is experienced. One such method uses a superconducting solder made up of superconducting powders that have lower peritectic temperatures than the parent material [1-3].

2. Experimental
The parent material consisted of bulk “single domain” YBa2Cu3O7- , which was fabricated using the top seeded melt texturing process. The bulk material was cut into pieces using a diamond saw to dimension of $4 \times 2.5 \times 2$ mm$^3$.

The following were considered as possible reagents in the development of different solder compounds: YBa2Cu3O7- (Y123), YbBa2Cu3O7- (Yb123), Yb2Ba1Cu1O5 (Yb211) and AgO2. Yb123 was chosen as it is a HTS with a $T_c$ and crystalline structure similar to Y123 and has a lower peritectic temperature (approximately 925 °C) compared to Y123 (approximately 1010 °C).
Often when Yb123 is used as a solder, Yb211 is used as well [1, 2]. The addition of Yb211 as part of the “reagent list” is based on the ‘Y-diffusion controlled’ model [4] which explains the growth mechanism of the Y123 phase. Here the knowledge of the Y123 system was used to understand the growth of Yb123. According to the model, when Y123 is heated above 1010 °C, it melts into Y211 solid and a Ba-Cu rich liquid phase. After the Y123 has decomposed completely, the semisolid melt is slowly cooled past the peritectic temperature to minimise the number of Y123 nuclei and maintain a stable growth front. Once a single grain has nucleated, it can grow rapidly in the ab [110] direction but this requires a constant supply of Yttrium (in our case Ytterbium). It is believed that this is provided by the dissolution of the Y211 particles in the liquid ahead of the growing interface. This will continue to occur until the Y211 particles are engulfed by the Y123 phase. The inclusion of silver, in the form of AgO2, was due to the fact that it lowers the peritectic temperature of Y123 by approximately 50 °C. Thus the joining of Y123 parent material with Ag-doped Y123 enables a join below the peritectic temperature of Y123. Table 1 shows the solders that were used to join Y123.

Table 1. List of various solders investigated.

| Sample | Solder Mixture | Group Allocation |
|--------|----------------|------------------|
| 1-A    | Yb123          | \( x \)          |
| 1-B    | 0.6 Yb123 + 0.4 Yb211 | \( y \)          |
| 1-C    | 0.75 Yb123 + 0.25 Yb211 | \( z \)          |
| 2-A    | 0.95 \( x \) + 0.05 Ag2O | Group 2          |
| 2-B    | 0.95 \( y \) + 0.05 Ag2O |                   |
| 2-C    | 0.95 \( z \) + 0.05 Ag2O |                   |
| 3-A    | 0.95 Y123 + 0.05 Ag2O | Group 3          |
| 3-B    | 0.9 Y123 + 0.1 Ag2O |                   |

Group 1 set of solders was an investigation of the optimum ratio of Yb123:Yb211 as both ratios, 60:40 and 75:25, have been documented [1, 5]. Group 2 investigated the effects of Ag in joining Y123 when Yb123 is used as solder. The following has been associated with Ag-doping: reduces the melting point of HTS, cleans grain boundaries where it acts as a scavenger and improves mechanical strength [6]. Group 3 was a similar investigation as Group 2 but here the solder was Y123.

Glycerine was used as a wetting agent to allow for easy application of the solder. Once the solder was applied and samples assembled, a jig maintained a constant 5 kPa of pressure on the join. Samples were placed in a furnace with a oxygen atmosphere at a temperature of 980°C for 1 hour and cooled at a rate of 5°C per hour. The cross sectional area of the joined samples was reducing to 4 x 2.5 x 0.2 mm³ by use of a sanding wheel thus reducing the required current to make the joins normal. Silver contacts were fixed to samples for standard 4-wire resistance measurements.

3. Results and discussion

SEM images were used to examine the microstructure of the joins. Typical joins such as Sample 1-A and Sample 1-B, are shown in the Figure 1. Sample 1-A had the most homogenous join out of Group 1, but not the best transport measurements, as shown in Figure 4.
Figure 1. SEM images at magnification x 650 (a) Sample 1-A and (b) Sample 1-B

Figure 2 shows SEM images of Group 2 solder joins at x 6500 magnification. Sample 2-A had the best transport measurements out of all groups as shown in Figure 4. A possible reason for this result may be due to a decrease Yb123’s peritectic temperature due to the presence of silver in the solder. Other solders in this group, where Yb211 was included, have a greater number of non-superconducting constituents this may explain the decrease in $J_c$.

Figure 2. SEM images at magnification x 6500 (a) Sample 2-A and (b) Sample 2-B

Figure 3 shows a typical join of Group 3 solders, which were porous compared to the other groups. This group gave the worst transport measurements as shown in Figure 4.

Figure 3. SEM image at magnification x 53 of Sample 3-A

Figures 4 shows the transport measurements of Group 1, 2 and 3 solders, a 1μV potential decrease across a join indicated the critical current.
4. Conclusion

SEM images are useful in indicating a potential good join but ultimately transport measurements must be used. In this investigation the solder of choice for joining Y123 is Yb123 with 5% Ag-doping by weight. Heat treatment profiles need to be optimised depending on the type of solder.

References

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