THE INFLUENCE OF LATTICE STRAIN TO THE CRITICAL CURRENT DENSITY OF YBCO

Engkir Sukirman, Didin S. Winatapura, Wisnu Ari Adi and Yustinus P.
Center for Technology of Nuclear Industry Materials (PTBIN)-BATAN
Kawasan Puspiptek Serpong 15314, Tanggerang

ABSTRACT

THE INFLUENCE OF LATTICE STRAIN TO THE CRITICAL CURRENT DENSITY OF YBCO. The influence of lattice strain to the critical current density of YBCO have been investigated. In this investigation it were prepared the YBCO superconductor samples which made by using a modified melt-textured growth (MMTG) method. The aim of doing this research is to investigate the relation between the critical current density and the lattice strain in YBCO superconductor. The structural and microstructural properties of the samples were characterized by the x-ray diffraction technique. The diffraction data were analyzed by means of a RIETAN software. While, the electrical properties of each samples were characterized by four point probe method. The lattice strains were then determined using the formula: \( <e^2_{hkl}> = \frac{(U - U_0)}{32 \ln 2} \), where \( U \) is the refined FWHM parameters of the broadened peak due to the presence of an inhomogeneous strain field and \( U_0 \) is the one due to the instrumental resolution only. The result of analysis indicate that the critical current densities and the lattice strains in YBCO samples have inversed correlation, i.e. when the lattice strain decreases, critical current increases, and conversely. The melt-process through 12 minutes may have possibly eliminated the weak links. Therefore, the critical current density increases, and the lattice strain decreases.

Key words: YBCO, Rietveld method, Lattice strain, Critical current density

INTRODUCTION

Since the high temperature superconductivity (HTS) discovery in an entirely new class of layered-perovskite, oxygen-sensitive, copper-oxide ceramics by Bednorz and Mueller in early 1986 [1], the research and development on that material still have been going on. There have been many scientific achievements obtained by scientist and technologist throughout the world, including the rigorous application in various field, such as in Sensors, HF Applications, Digital Circuits, Magnets, Power Applications (Power Cable, Fault Current Limiter, Transformers, Generators, Motors, Energy Storage), and Cryocoolers [2]. Oxide superconductors (YBCO [3], BSCCO [4], and TBCCO [5] systems) are among the highly attractive for applications, as they can be made superconductive at liquid nitrogen temperature. For most applications, however, HTS have to fulfill the particular requirements, such as large critical current densities of the order of \( 10^4 \) to \( 10^6 \) A.cm\(^{-2} \) even in the presence of large magnetic fields. Fortunately, critical current density (\( J_c \)) is not an intrinsic property of a superconductor and is strongly dependent on its microstructure. Hence, microstructural control is very important in getting the HTS of having large critical current densities.
The Influence of Lattice Strain to the Critical Current Density of YBCO (Engkir Sukirman)

Although it has been proven that structural control is very difficult in oxide superconductors. Various ways have been performed for the fabrication of bulk HTS, such as sinter and melt processes. Sintering is very common in ceramic processing and has many advantages in making use of conductors. However it has failed in producing high-$J_c$ superconductors [6]. The weak links at grain boundaries are considered as the cause of the low $J_c$ values obtained in sintered bulk samples [7].

Through the melt processes were found that the grains were made to be alignment, and accordingly it reduced the weak links and hence larger $J_c$ values were achieved in YBCO, which is usually called YBa$_2$Cu$_3$O$_{7-x}$ compound or 123-phase [8]. However, the $J_c$ values of melt processed samples reduced to much lower level than the required one when large magnetic fields were applied. In order to increase $J_c$ even in magnetic fields, we need to introduce the pinning centers, which can prevent flux motion against the Lorentz force ($F_L = J \times B$) [9]. The resistive phase, which is commonly called green phase (as the color of this phase is green), or Y$_2$BaCuO$_5$ compound or 211-phase is appropriate to use as the pinning centers [10].

The correlation of $J_c$ and microstructure of YBa$_2$Cu$_3$O$_{7-x}$ compound has been confirmed successfully by our group on the previously research [11]. In that research it was exhibited that the grain boundaries on the samples having a higher $J_c$ are parallel to each other. It means that the grains were made to be alignment. Thus, the critical current density, $J_c$ is strongly dependent on its microstructure. The question now is how the correlation between critical current density, $J_c$ and lattice strain in YBa$_2$Cu$_3$O$_{7-x}$ compound. This physical phenomenon has never been investigated yet, so far. The aim of doing this research is to investigate the relation between the critical current density and the lattice strain in YBCO superconductor.

The microstructure of a crystal is characterized by its grains, i.e., size, shape, and grain-boundaries. The crystallite size is equivalent to the grain size if the individual grains are single crystals. The crystallite of a crystal is formed by the crystal unit cells. In this experiment, the size, shape, grain-boundaries, and grain orientation of a crystallite are changed by melt process. Consequently, the internal stresses and strains should be generated in the melt processed samples. As a hypothesis of this research is that the critical current density, $J_c$ and the lattice strain in YBCO superconductor are inversely correlated, i.e. when the lattice strain decreases, critical current increases, and vice versa. It is because the critical current density, $J_c$ and the weak links at the grain boundaries have an inversely correlation [8], while the lattice strains are directly correlated to the weak links.

**THEORY**

X-ray and neutron diffraction are powerful nondestructive techniques for characterizing latticestrain and/or stress in crystalline materials [12]. When a material is subject to a homogeneous strain field, the angular position of a diffraction peak will shift to lower or higher $2\theta$ values, depending on whether the strain is tensile or compressive. If the matierasl is subject to an inhomogeneous strain field, then in addition to a peak position shift as mentioned above, the diffraction peak profile will also be broadened.

Thus, the shift of a peak measures the average lattice strain along a particular crystallographic direction. While, the peak broadening can be ascribed to either a small particle size or an inhomogeneous strain field, or both. Typically the broadening due to a small particle size appears in the form of a Lorentzian whereas that due the inhomogeneous strain field is described by a Gaussian function.

The profile shape function of a diffraction peak for each phase is a modified pseudo Voigt function, i.e. the sum of a Gauss function and a Lorentz function with unequal peak heights and full-widths at half maximum (FWHM):

$$g(2\theta_i - 2\theta) = \left(\frac{y \gamma^2}{c_0} \right)^{1/2} \left(1 - \gamma\right)\frac{\gamma H_{1\gamma}(G)}{c_0^{1/2}}$$

$$+ \left(1 - \gamma\right)(1 + \frac{c_0^{1/2}}{H_{1\gamma}(G)}\gamma^2)$$

$$\times \exp\left(-\frac{c_0^{1/2}(2\theta_i - 2\theta)^2}{H_{1\gamma}(G)}\right)$$

$$\times \exp\left(-\frac{c_0^{1/2}(2\theta_i - 2\theta)^2}{H_{1\gamma}(G)}\right)$$

$$+ \left(1 - \gamma\right)(1 + \frac{c_0^{1/2}}{H_{1\gamma}(G)}\gamma^2)\delta^2$$

where $2\theta_i$ is the scattering angle at the $i$th step, $\theta_i$ is the Bragg angle for the $k$th reflection, $C_0 = 4\pi h 2$, $C_1 = 4$, $\gamma$ is the Gaussian fraction, $\delta = H_{1\gamma}(G)/H_{1\gamma}(L)$, and $H_{1\gamma}(G)$ and $H_{1\gamma}(L)$ are the FWHMs of the Gaussian and Lorentzian components, respectively. $H_{1\gamma}(G)$ in Equation (1) is given by:

$$H_{1\gamma}(G) = U \tan^2\theta_i + V \tan \theta_i + W$$

where $U$, $V$, and $W$ are the FWHM parameters.

With appropriate choices of $\gamma$, the above profile shape function can vary from Gaussian ($\gamma = 1$) to Lorentzian ($\gamma = 0$). The differences between the pseudo Voigt function [13], and Equation (1) is that the value of $\delta$ is fixed at 1 in the former whereas $\delta$ is a variable parameter in the latter.

The Broadening of a Diffraction Peak Due to the Presence of an Inhomogeneous Strain Field is given by [14]:

$$B^2 = B_0^2 + 2 \tan^2 \theta.e_\omega^2$$
where $B$ is the FWHM of the broadened peak and $B_{ij}$ is the instrumental resolution which varies with $\theta$ according to the Cagliotti equation [15]:

$$B_{ij} = U_o \tan^2 \theta + V_0 \tan \theta + W_0 \quad \text{............... (4)}$$

A simpler approach is taken to obtain an estimate of $<e>$, the average value of the anisotropic rms strains within the composites. Substituting Eq.(4) into Eq.(3), we have

$$B^2 = (U_o + 32 \ln 2 \cdot <e_{iij}^2>) \tan^2 \theta + V_0 \tan \theta + W_0$$

$$= U \tan^2 \theta + V_0 \tan \theta + W_0 \quad \text{............... (5)}$$

where $U = (U_o + 32 \ln 2 \cdot <e_{iij}^2>)$; so from this equation, we have

$$<e_{iij}^2> = \frac{U - U_o}{32 \ln 2} \quad \text{............... (6)}$$

where $U$ is the FWHM parameters of the broadened peak due to the presence of an inhomogeneous strain field and $U_o$ is the one due to the instrumental resolution only.

For precise strain measurements need a high angular resolution x-ray/neutron diffractometer. By using the Rietveld analysis method, the precision of the strain measurements can be further improved. In a Rietveld analysis, structure parameters calculated for every phases in a composite sample can be determined very accurate although there are many overlap reflections. In a Rietveld analysis, the parameters in a structural model, plus necessary instrumental parameters, are adjusted in a computer calculation until the least-squares best fit is obtained between the entire calculated and observed powder patterns. Since a large number of diffraction peaks are fitted simultaneously, the statistical errors introduced in individual peak fitting are largely reduced. Moreover, by fitting to the whole pattern, any effects of preferred orientation, extinction, and other systematic aberrations, if present, will also be minimized [16]. Accordingly, the maximum amount of information can reliably be derived from the observed intensity data. Therefore, this technique has now found wide spread application in the structure determination of compounds which are not available as single crystals.

**EXPERIMENTAL METHOD**

**Sample Preparation**

A solid sintered $Y_{1-x}Ba_xCu_3O_{7-\delta}$ superconductor (123-phase) were prepared in the same way as described in our earlier publication [17-19]. Figure 1 displays the heat treatment patterns followed in the present investigations. At high temperatures above 1200°C, $Y_2O_3$ plus liquid L (L: a mixture of BaO and CuO) are stable. On cooling, these two phases react peritectically to produce $Y_2BaCuO_4$ (211-phase):

$$Y_2O_3 + L(BaO+CuO) \rightarrow Y_2BaCuO_4$$

At around 1000 °C, 211-phase reacts with liquid L to produce 123-phase:

$$Y_2BaCuO_4 + L(3BaCuO_2+2CuO) \rightarrow 2Y_{1-x}Ba_xCu_3O_{7-\delta}$$

As shown at Figure 1, the samples were heated from room temperature (A point) to 1100°C with the rate of 300°C/h and hold at 1100°C (BC segment) for $t$ minute, and then rapidly cooled to 1000°C (CD segment) with the rate of 400°C/h. Subsequently samples were slowly cooled to 960°C with the rate of 10-20°C/h (DE segment), and then finally cooled to room temperature with the rate of 60°C/h (EF segment). In this experiment, $t$ parameters (BC segment) is made in variations, i.e. 1, 6, 12, and 18 minutes, accordingly we get four kinds of sample called YBCO-M1, YBCO-M6, YBCO-M12, and YBCO-M18, respectively, besides the one of sintered $Y_2BaCuO_4$ superconductor that called YBCO-S.

![Figure 1. Schematic of the heat treatment pattern followed in samples preparation](image-url)

**Characterizations**

The qualitatively and quantitatively phases analysis on YBCO-S, YBCO-M1, YBCO-M6, YBCO-M12, and YBCO-M18 samples were carried out by X-rays diffraction technique using the Rietveld method [20]. Rietveld method is the whole pattern fitting of calculated to observed powder patterns through least-squares refinement of model(s) for the structure(s), diffraction optics effects, and instrumental factors. The X-rays diffraction experiments were performed by using a Philips X-Ray Diffractometer, PW170 type. The X-ray intensity data from every point were collected at room temperature with CuKα radiation for 1 sec from 20º to about 80º in 2θ at a step size of 0.020º. Transport $J_\text{c}$ measurements, were carried out by a standard four-probe method. The superconducting critical current density, $J_\text{c}$ were determined using the relation:
$J = 0.318 I_s s^{-2}$, where $s$ = the distance between probe [cm], and $I_s$ = the critical current [A] [21]. All of these experiments were carried out at Technology Centre for Nuclear Industry of Materials, Kawasan Puspiptek, Tangerang, Banten.

RESULT AND DISCUSSION

Figure 2 shows Rietveld refinement of YBCO-S sample. Its space group was assumed to be Pnmmm (No. 47) and structural parameters obtained previously for orthorhombic YBCO [22] were used as initial values. Final crystal-structural parameters are listed in Table 1, and unit cell dimensions are listed in Table 2. In the upper portion of the figure here and elsewhere shows the observed data indicated by the dots; the calculated patterns is shown as the solid line overlying them. The vertical makers in the central portion show positions calculated for $Kα_1$ and $Kα_2$ peaks. The lower portion is plots of $Δ$, the difference between the observed and calculated intensities. On that figure is clearly showed that the full powder pattern calculated from the refined parameters matched the experimental pattern. These results support the ideas that YBCO-S sample does contain only 123-phase with the structural parameters as mentioned above. The YBCO-S sample were then separated into four same portions, and each of it is going to be melted with different melting time.

Figure 3 shows Rietveld refinement of YBCO-M1 (a), YBCO-M6 (b), YBCO-M12 (c), and YBCO-M18 (d), where those samples actually ascribe to YBCO-S sample after being melted on 1100°C for 1, 5, 12, and 18 minutes, respectively. According to the previous investigation [23] and theoretical background which have been mentioned above has been proven that in the melt-processed YBCO contain two phases, i.e. 123 phase and 211 phase. Therefore, Rietveld analysis of those samples were based on two space group; Pnmmm (No. 47) for 123 phase and Pnma, (No. 62) for 211 phase. Structural parameters obtained previously for orthorhombic 123 phase [22] and tetragonal 211 phase [23] were used as initial values.

Table 1. Crystal structural parameters in orthorhombic YBCO (123 phase). Throughout this paper, figures in parentheses are estimated standard deviation referring to the last digit.

<table>
<thead>
<tr>
<th>Atom</th>
<th>Site</th>
<th>$x$</th>
<th>$y$</th>
<th>$z$</th>
<th>$g$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>1.0</td>
</tr>
<tr>
<td>Ba</td>
<td></td>
<td>0.5</td>
<td>0.5</td>
<td>0.145(1)</td>
<td>0.42(2)</td>
</tr>
<tr>
<td>Cu(1)</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Cu(2)</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.316(2)</td>
<td>1.0</td>
</tr>
<tr>
<td>O(1)</td>
<td></td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>1.0</td>
</tr>
<tr>
<td>O(2)</td>
<td></td>
<td>0.0</td>
<td>0.5</td>
<td>0.0</td>
<td>0.01</td>
</tr>
<tr>
<td>O(3)</td>
<td></td>
<td>0.0</td>
<td>0.0</td>
<td>0.070(7)</td>
<td>1.0</td>
</tr>
<tr>
<td>O(4)</td>
<td></td>
<td>0.0</td>
<td>0.5</td>
<td>0.30(1)</td>
<td>1.0</td>
</tr>
<tr>
<td>O(5)</td>
<td></td>
<td>0.5</td>
<td>0.0</td>
<td>0.32(1)</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Table 2. A listing of unit cell dimensions of 123 phase and 211 phase each in YBCO-S, YBCO-M1, YBCO-M6, YBCO-M12, and YBCO-M18 samples.

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>123-phase</th>
<th>211-phase</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$a$ (Å)</td>
<td>$b$ (Å)</td>
</tr>
<tr>
<td>1</td>
<td>YBCO-S</td>
<td>3.888(1)</td>
<td>3.823(1)</td>
</tr>
<tr>
<td>2</td>
<td>YBCO-M1</td>
<td>3.886(3)</td>
<td>3.816(3)</td>
</tr>
<tr>
<td>3</td>
<td>YBCO-M6</td>
<td>3.878(9)</td>
<td>3.815(8)</td>
</tr>
<tr>
<td>4</td>
<td>YBCO-M12</td>
<td>3.880(3)</td>
<td>3.816(3)</td>
</tr>
<tr>
<td>5</td>
<td>YBCO-M18</td>
<td>3.87(1)</td>
<td>3.81(1)</td>
</tr>
</tbody>
</table>
Table 3. Bragg angle (2θ) data, and full width at half maximum (FWHM) of the three highest peaks in YBa$_2$Cu$_3$O$_{x}$ (123 phase) after being corrected by instrumental broadening.

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>Bragg Angle (2θ) [°]</th>
<th>Full Width at Half Maximum (FWHM)[°]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(013) (005) (006)</td>
<td>(013) (006) (103)</td>
</tr>
<tr>
<td>1.</td>
<td>YBCO-S</td>
<td>32.770 38.456 46.556</td>
<td>0.054 0.003 0.055</td>
</tr>
<tr>
<td>2.</td>
<td>YBCO-M1</td>
<td>32.808 38.449 46.547</td>
<td>0.200 0.113 0.202</td>
</tr>
<tr>
<td>3.</td>
<td>YBCO-M6</td>
<td>32.875 38.591 46.723</td>
<td>0.134 0.135 0.134</td>
</tr>
<tr>
<td>4.</td>
<td>YBCO-M12</td>
<td>32.820 38.469 46.572</td>
<td>0.077 0.051 0.077</td>
</tr>
<tr>
<td>5.</td>
<td>YBCO-M18</td>
<td>32.848 38.510 46.623</td>
<td>0.106 0.131 0.106</td>
</tr>
</tbody>
</table>

Table 4. The phase quantity, average crystallite sizes, D, and lattice strains, <εhkl> in YBa$_2$Cu$_3$O$_{x}$ (123 phase).

<table>
<thead>
<tr>
<th>No.</th>
<th>Sample</th>
<th>Phase Quantity [wt%]</th>
<th>Average Crystallite Sizes, D [Å]</th>
<th>Average Lattice Strains, &lt;εhkl&gt; [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>123-phase 211-phase</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.</td>
<td>YBCO-S</td>
<td>100.00 0.00</td>
<td>9652</td>
<td>0.117</td>
</tr>
<tr>
<td>2.</td>
<td>YBCO-M1</td>
<td>83.41 16.59</td>
<td>571</td>
<td>0.103</td>
</tr>
<tr>
<td>3.</td>
<td>YBCO-M6</td>
<td>65.91 34.09</td>
<td>629</td>
<td>0.056</td>
</tr>
<tr>
<td>4.</td>
<td>YBCO-M12</td>
<td>73.83 26.17</td>
<td>1361</td>
<td>0.065</td>
</tr>
<tr>
<td>5.</td>
<td>YBCO-M18</td>
<td>47.64 52.36</td>
<td>729</td>
<td>0.061</td>
</tr>
</tbody>
</table>

As shown in Figure 3, the experimental data are plotted by dots, and the solid curve overlaying the data dots is a diffraction pattern calculated from the final parameters. The Rietveld refinements converged most satisfactorily, giving quite-low S factors (Table 2), where S is the goodness of fitting indicator. It means that the calculated patterns matched the experimental one. These results show that the samples just contain two phases, i.e. 123 phase and 211 phase. There are no other phases which may arise from the melt-process. Final unit cell dimensions are listed in Table 2. It is appeared in that table, that the lattice parameters of the two phases can be refined in such a way that they have an estimated standard deviation until 10^{-4} Å order.

On Table 3 are listed the Bragg angle (2θ) data, and full width at half maximum (FWHM) of the three highest peaks in 123 phase after being corrected by instrumental broadening. It is observed from that table, that the values of the angular position of diffraction peaks of the melt-processed samples shift to higher 2θ values referring to YBCO-S. It means that the melt processed samples undergo a compressive strain. This idea is supported by the fact that the 123 phase unit cell, especially a-, and b lattice, of melt-processed samples have a tendency to shorten referring to that of YBCO-S. While the c-lattice is relatively no change statistically referring to YBCO-S. From this facts be concluded that, the compressive strain occurs on the a-b plane of melt processed samples.

In addition, a little bit broadening of diffraction peak profile referring to that of YBCO-S occur on the melt-processed samples indicated by their FWHM. According to Xun-Li Wang et al. [24], the peak broadening can be ascribed to either a small particle size or an inhomogeneous strain field, or both. In this experiment, the most probable causes of peak broadening on the melt-processed samples are both of small particle size and inhomogeneous strain field. This conclusion is based on data on Table 2 and Table 4. The compressive strain just occurs on the basal plane and not in c-direction (Table 2); so it means that the strain is inhomogeneous. From data on Table 4, we can see that the crystallite sizes of melt-processed samples are getting smaller than the one of YBCO-S, where the crystallite sizes were determined by Scherrer equation [25]. Thus, it means that the particle size were reduced by melt process.

Figure 4 shows voltage-current characteristics on YBCO-S, YBCO-M1, YBCO-M6, YBCO-M12, and YBCO-M18 samples, with the critical current, $I_c$ of 0.5, 10.93, 12.81, 17.02, and 8.53 A, respectively. These data reveal theirs meaning that when a current pass along the sample, then the voltage $V$ develop between the ends varies as the magnitude $I$ of the current is altered. So long as the current is less than the critical value $I_c$ no voltage is observed along the sample, but when the current is increased above $I_c$ a voltage appears which, at currents somewhat greater than $I_c$, approaches a linear increase with increasing current. The critical current densities were obtained through the relation of $J_c = 0.318 I_c s^2$, where $s =$ the distance between probe [cm], and $I_c =$ the critical current [A] as mentioned before [21]. The calculated $J_c$ of YBCO-S, YBCO-M1, YBCO-M6, YBCO-M12, and YBCO-M18 samples are 3.98, 87.02, 101.99, 135.51, and 67.91 A cm$^{-2}$, respectively.

On Table 4 are listed the phase quantity, average crystallite sizes, and lattice strains in YBCO-S, YBCO-M1, YBCO-M6, YBCO-M12, and YBCO-M18 samples. It is observed from that table that, mass fraction of 123 phase in YBCO-S is 100 %. The quantity of
123 phase becomes smaller with increasing melting time. It means that the longer the melting time, the more the quantity of 211 phase formed is, as shown in Figure 5(a). The lattice strains also becomes lower with increasing melting time but in a rather different way as shown in Figure 5(b), that is, in a parabolic curve. However, the lattice strains tend to increase again after the sample being melted for 18 minutes. Thus, there are some stress releases to some extents in YBCO with melt process. Accordingly, the lattice strain decreases with increasing the melting time.

Though, the critical current density, $J_c$ and the lattice strain in YBCO superconductor have an inversed correlation, i.e. when the lattice strain decrease (Figure 6(a)), then critical current increase (Figure 6(b)), and vice versa. It is because the critical current density, $J_c$ and the weak links at the grain boundaries have an inversely correlation [8], where the more the weak links at the grain boundaries reduced, the better the electrical contact among the grains is, and so the $J_c$ value become higher. The more the weak links at the grain boundaries reduced, the better the degree of grains alignment is. The better the degree of grains alignment, the more the lattice strain decreased is.

In this experiment is shown that the critical current densities, $J_c$ continuously increase with increasing melting time until 12 minutes of melt process. The melt process through 12 minutes may have reduced the weak links. Therefore, the critical current density increases, and the lattice strain decreases. This finding is in agreement with the previously result reported by M. Murakami [26], where it was expressed that the melt process may have possibly eliminated the weak links and increases the critical current density.

**CONCLUSIONS**

Using the analysis methods outlined above, the influence of lattice strain to the critical current density of YBCO superconductor have been successfully determined. It have been successfully confirmed that YBCO produced by sintering method contain only 123 phase, and YBCO made by the melt process contain two phases, i.e. 123 phase and 211 phase. The critical current density and the lattice strain in YBCO superconductor are inversely correlated, i.e. when the lattice strain decreases, critical current increases, and vice versa. The critical current density increases or the lattice strain reduces with increasing melting time until 12 minutes of melt process.

This finding has confirmed that critical current density of YBCO superconductor can be increased by reducing the weak link at the grain boundary. Decreasing the weak link can be reached by making the grain alignment better. So, it means that the lattice strain can be decreased by making the grain alignment better.
ACKNOWLEDGEMENTS

We would like to thank to the Head of Technology Centre for Nuclear Industrial Material, Dr. Ridwan for his support of this research, and to the Head of Nuclear Analysis Division, Dr. Setyo Purwanto for his support; also our thanks to all of our colleagues on their helps. This project has been founded by DIPA-BATAN 2006.

REFERENCES

[6]. D.C. LARBALESTIER, Physics Today, 6 (1991) 74
[8]. ENGKIR SUKIRMAN, WISNU ARI ADI, dan SALMAH, Majalah BATAN, XXXIII (1/2) (2000) 31–45
[10]. ENGKIR SUKIRMAN, WISNU ARI ADI, DIDIN S. WINATAPURA dan YUSTINUS, Jurnal Ilmuhan Teknik Mesin, 8 (2) (2006) 79–90
[20]. F. IZUMI, Rigaku J., 6 (1089) 10
[22]. ENGKIR SUKIRMAN, Pengaruh Distribusi Kekosongan Oksigen pada Superkonduktivitas YBa2Cu3O7-x Tesis-S2, Program Studi Materials Science, Fakultas Pascasarjana, Universitas Indonesia, (1991)