Texture and grain-boundary misorientation distributions in Y123 ceramics deformed by torsion under pressure

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Abstract. Texture and grain-boundary misorientation distributions in different parts of the sample of the high-\(T_c\) superconductor Y123 deformed by torsion under pressure at 1008 °C to a twist angle of 30° were investigated. The average levels of the basal plane texture (the Lotgering factor \(F\)) of undeformed and deformed samples were \(F = 0.25\) and \(0.965\), respectively. In the undeformed sample, the fraction of low-angle grain boundaries (LAGBs) with misorientation angles from 2° to 10° does not exceed 5%. The deformation led to the formation of a strong, but non-uniform texture along the radius of the sample. In the center of the sample, a strong fiber texture is formed with the [001]-axis parallel to the axis of compression / torsion, and the fraction of LAGBs is about 20%. At a distance of 2 mm from the center of the sample there is a ring with a non-basal texture, where the fraction of LAGBs reaches 30%. A biaxial texture is formed at the edge of the sample: the [001] axis is parallel to the axis of compression / torsion, and the [110] axis is oriented along the radius of the sample. The fraction of LAGBs at the edge of the sample is 56%.

1. Introduction
In order to obtain high critical current density (\(J_c\)), high-temperature superconducting (HTSC) ceramics should have a strong crystallographic texture (the angles of the grain boundary misorientation should not exceed 10°) [1]. Among these materials, at present the bulk ceramics \(\text{YBa}_2\text{Cu}_3\text{O}_{7-x}\) (Y123) is the closest one to practical applications. To form a strong texture in Y123, a melt texturing process has been developed, but the properties of the samples obtained by this method are not high enough. For a wide range of practical applications, the value of \(J_c = 10^5\) A/cm\(^2\) in a field of 1 T is required. The best samples of Y123 obtained by the melt texturing technique have a critical current density of the order of \(10^4\) A/cm\(^2\) in 1 T field. When superconductors are used as permanent magnets (with a frozen field), another important parameter is magnetization. The magnetization of a superconductor is proportional to the critical current density \(J_c\) multiplied by the minimum size of the current loop. In a strongly textured sample, the latter is approximately equal to the size of the sample. That is, to obtain high magnetization, superconducting products must be one-piece, rather than multipart ones. At present, melt texturing techniques do not allow producing large billets, therefore large products, for example, superconducting rings in the kinetic storage [2] and rotors of superconducting motors [3], are stacked from small rectangular blocks of Y123. The production of a one-piece ring will increase the size of the current loop and, accordingly, increase the magnetization of the superconductor. In this connection, it is important to develop an alternative method for processing of Y123 ceramics, which makes it possible to obtain a high value of \(J_c\) in a large single axisymmetric
product. As such a method, one can consider hot torsion under quasi-hydrostatic pressure (HTP), which allows deforming brittle ceramics to large strains.

Using this method, a strong texture and high superconducting properties were obtained in ceramics Bi$_2$Sr$_2$CaCu$_2$O$_{8+d}$ [4]. A strong texture can be also obtained by the HTP technique in Y123 ceramics. For the best Y123 sample, the full width at a half maximum of the (002) peak of the rocking curve was 5.2 °, and the Lotgering factor $F$ (basal planes orientation degree) was 0.956 [5]. However, a more detailed study of the local texture on the polished sections which are perpendicular to the axis of the pellet showed that in the deformed Y123 ceramics, the texture along the radius of the samples was not homogeneous [6]. The presence of an annular region with a non-basal texture was found. In the sample with $F = 0.965$, a ring with a non-basal texture is located in the range of 0.7-3.5 mm from the center of the sample. The existence of such a ring is associated with the formation of a wavy (corrugated) structure due to the constraint of deformation during HTP. For a more detailed and accurate determination of the texture, the transverse section of the sample should be studied.

Therefore, the aim of the present paper was to investigate the local texture and distributions of grain-boundary misorientations in different parts of the polished section parallel to the axis of compression / torsion of the sample.

2. Experimental

Y123 powder was pressed to pellets of 10 mm in diameter and 2 mm in height and was sintered in air at 900 °C for 5 hours. The prepared samples were plastically deformed by HTP in the following regimes: temperature $T = 1008$ °C, twist rate $\omega = 4 \times 10^{-4}$ rpm, pressure $P = 10$ MPa, and the twist angle $\alpha$ varied from 0° to 60°. Details of the deformation process, the calculation of the strain, the study of the microstructure and texture are given elsewhere [5-7]. To study the distributions of grain-boundary misorientations, two samples were chosen: one undeformed and one deformed by HTP to $\alpha = 30°$. The diameter of the dense interior of the deformed sample was 14 mm. The degree of basal plane texture (the Lotgering factor) of the undeformed and deformed samples was $F = 0.25$ and 0.965, respectively [5].

The local texture and grain-boundary misorientation distributions were measured on polished sections parallel to the axis of the pellets. In the undeformed sample the measurement was made in the center of the section, and in the deformed sample it was performed at distances $r = 0.5; 2; 4.2$ and 6.3 mm from the center of the sample. The microstructure and grain-boundary misorientation distributions were examined using a TESCAN MIRA 3 scanning electron microscope equipped with an EBSD HKL Oxford attachment. For the analysis and data processing Mambo, Tango, Twist, Salsaprograms, included in the software package CHANNEL-5, were used.

3. Results and discussion

Deformation led to the formation of a strong texture (figures 1a-d). At the center of the deformed sample ($r = 0.5$ mm), the [001] fiber texture (axis [001] is parallel to the compression/torsion axis) is formed as it is evidenced by a diffuse maximum on the inverse pole figure between the poles (010) and (110) (figure 1a). At a distance of 2 mm from the center of the sample there is a ring with a non-basal texture (figure 1b). When moving towards the edge of the sample (figures 1b-d), the texture maximum becomes more and more localized at the pole (110), which indicates that the texture turns into a biaxial type – the axis [001] is parallel to the axis of compression/torsion and the axis [110] is oriented along the radius of the sample (figure 1d). Since the critical current density in superconducting ceramics depends on the grain-boundary misorientation angles [1], the distributions of grain-boundary misorientation has been constructed for a more complete description of the microstructure formed during deformation. The graph in figure 2a shows the distribution of grain-boundary misorientation angles in the undeformed sample. The distribution is uniform in the entire investigated range of angles from 2° to 100°, and it is dominated by high-angle boundaries with misorientations above 35°. The fraction of low-angle grain boundaries (LAGBs) with misorientation angles from 2° to 10° does not exceed 5%. The distributions of grain-boundary misorientation angles
in different places of the deformed sample are shown in figures 2 b-e. The absence of boundaries with misorientation angles more than 50° is characteristic of all parts of the deformed sample, which is expected for a sample with the [001] fiber texture and a cubic crystallographic lattice. At the center of the sample (figure 2 b), the distribution is uniform, the fraction of LAGBs is about 20%. In the area with non-basal texture (figure 2 c) the distribution of misorientation angles is non-uniform, in the intervals of misorientation angles of 5-6° and 31-32° the number of boundaries increases to 6-7%. The fraction of LAGBs reaches 30%. At a distance of 4.2 mm from the center of the sample (figure 2 d), the distribution has one maximum in the angular interval of 2-3°, and then the distribution is uniform. The fraction of LAGBs is 32%. At the edge of the sample (r = 6.3 mm), the fraction of the boundaries in each interval of the range of angles from 20° to 45°, with the exception of a small maximum in the interval of 44-45°, does not exceed 1%, which is noticeably less than in other places of the sample (figure 2 e). About 31% of the grain boundaries fall within the interval of misorientation angles of 2-3°, and this value is the maximum of the entire distribution. The fraction of LAGBs at the edge of the sample is 56%. Thus, the data on the distribution of misorientation angles are consistent with the texture data.

Figure 1. IPF maps and local inverse pole figures taken from the places located at a distance of (a) 0.5 mm, (b) 2 mm, (c) 4.2 mm, (d) 6.3 mm from the center of the deformed Y123 sample.
4. Conclusions
The texture and grain-boundary misorientation distributions in different parts of the sample of the high-$T_c$ superconductor Y123 deformed by torsion under pressure were studied. High critical current density should be expected at the edge of the sample, where a biaxial texture is formed, and the fraction low-angle grain boundaries exceed 50%.

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References
[1] Gross R 2005 Physica C 432 105
[2] Poltavets V, Kovalev K, Ilyasov R, Glazunov A, Maevsky V, Verzbitsky L, Akhmadyshew V and Shikov A 2014 J. Phys.: Conf. Ser. 507 032022
[3] Levin A V, Vasich P S, Dezhin D S, Kovalev L K, Kovalev K L, Poltavets V N and Penkin V T 2012 Phys. Procedia 36 747
[4] Imayev M F, Daminov R R, Reissner M, Steiner W, Makarova M V and Kazin P E 2007 Physica C 467 14
[5] Imayev M F, Kabirova D B and Yakshibayeva R R 2011 Perspektivnye Materialy. Special Issue
No. 12 186 (in Russian)

[6] Imayev M F, Kabirova D B and Pavlova V V 2015 *Russian Phys. J.* **58** 762

[7] Imayev M F, Kabirova D B and Dementyev A V 2008 *New Research on YBCO Superconductors*, ed D M Friedman (NY: NOVA Publishers) pp 235-252