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Development of cube textured Ni-W alloy substrates used for coated conductors

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Abstract. It is considered as a challenge for RABiTS route to get cube textured Ni-W alloy substrates with high mechanical and magnetic properties for coated conductors. The works of our group in recent years are summarized about different Ni-W substrates with high W content and composite tapes made by RABiTS technique. The fabrication process and the mechanism of cube texture formation in above different tapes are studied systematically. Compared with commercial Ni-5 at.%W substrate, these alloy substrates show a comparable texture quality and improved mechanical properties as well as reduced or zero magnetization especially in the novel composite substrates.

1. Introduction

Due to the excellent performance, High Temperature Superconductors (HTS) are generally considered the most promising functional materials for many potential applications such as electrical generators and transformers. For the high current purpose in long length coated conductor tapes, highly cube textured metal template tapes are required with not only well mechanical but also lower AC loss. Some works for decreasing magnetic losses are studied in Ni-W substrates [1].

Ni-5 at.%W (Ni5W) alloy tapes, a metallic substrate with highly cube texture, has been fabricated in worldwide [2]. However, it is unsuitable for applications due to the high Curie temperature (~335K) and the low yield strength (~160 MPa) [3]. Increasing the W content leads indeed to a decrease of the Curie temperature and an increase of the yield strength of Ni-W alloys, but also to a prompt decrease of the cube texture unfortunately [4]. Therefore, it is considered as a main challenge for the RABiTS route to obtain a sharp cube textured Ni-W alloy substrates with high W content. Moreover, a kind of composite substrates with sandwich-like structure have been proposed, in which the outer layers possess a sharp cube texture, and the inner layer such as Ni-9.3 at.%W (Ni9.3W) [5] supplies both high mechanical and magnetic properties. By either Powder In Tube (PIT) or co-rolling routes, many groups in the world took more efforts to obtain strong interface bonds between the outer layer and the inner layer as well as a highly cube textured surface on the composite tapes.

This paper summarizes the works about the fabrication process and the mechanism of cube texture formation in different Ni-W alloy substrates prepared by our group in recent years, including both the high W content Ni-W alloy substrates and the composite substrates fabricated by RABiTS technique. A special attention is given to the novel composite substrates made by a "composite ingot" method.

2. Experimental

Ni-7 at.%W (Ni7W) and Ni9.3W alloys were prepared by mixed powders with Ni (99.9%) and W (99.9%), which were pressed under 200~250 MPa by Cold Isostatic Pressing (CIP) after ball milling, then were sintered at around 1100°C for 10 h to obtain the initial Ni-W alloy ingots. Furthermore, the as-obtained ingots underwent heavy cold rolling down to 65 μm thickness with about 3~5% deformation per pass until more than 99% total reduction reached. The optimized multi-step annealing procedures were selected to get the required cube texture in a flowing Ar (4 vol.% H_2) atmosphere [6].

"Composite ingot" method was proposed for the development of multi-layer composite substrates. This kind of composite ingots were made "layer by layer", in which the Ni-W alloy with low W content as an outer layer being in charge of the formation of highly cube texture after rolling and recrystallization annealing processes, meanwhile the one with high W content as an inner layer being responsible for high mechanical and magnetic properties of the whole composite substrate. In this route, composite ingots were designed to different types such as welding type bonding [7] and diffusion type bonding for a good interface joint between the outer layer and the inner layer. After heavy deformation, as-fabricated composite ingots still keep the original sandwich-like structure, and show a good ductility during the following cold rolling process. Optimized heat treatments were performed as same as above-mentioned conditions.

Pole figures, (111) phi-scans and (002) rocking curves were measured by XRD with CuK_α radiation. EBSD was used to analyse the local orientation and obtain GBs information. Besides, the mechanical and magnetic behaviours were tested by mechanical testing machine and PPMS, respectively.

3. Results and discussion

3.1. Textured Ni-W substrates with high W content

3.1.1. Formation of cube texture in Ni7W alloy tape. Compared with one-step annealing process to heat up to final recrystallization temperature directly, in a two-step annealing process, the tapes were held at the initial recrystallization temperature for a certain time prior to full recrystallization at higher temperature. After different heat treatment processes, it was found that the two-step annealing processes are more beneficial to the formation of low angle GBs (LAGBs) and cube texture in Ni7W alloy tapes prepared by powder metallurgical route. The result is similar to that by casting route [4]. A sharp and pure {100}<001> cube texture has been obtained in the Ni7W tape, while the FWHM values of X-ray (111) phi-scan and (002) rocking curve are 6.33° and 4.3°, respectively. Both 99.8% (≤10°) biaxial cube grains and 94.6% LAGBs (2°~10°) are calculated from the EBSD orientation map detected on the surface of Ni7W alloy tape. This is probably due to the rotation of grains from off-cube to cube easily and the merger of annealing twins by cube grains during two-step annealing process. In consideration of influence on the epitaxially deposited superconducting layer, the grains connected with LAGBs will be conducive to transport current in YBCO film [8].

3.1.2. Formation of cube texture in Ni9.3W alloy tape. Due to the lower Stacking Fault Energy (SFE) in Ni9.3W alloy tape, a recovery annealing stage with lower temperature was added prior to the two-step annealing process in order to obtain a sharper cube texture, so-called three-step annealing process. It could be found that both the cube texture content and GBs quality in Ni9.3W alloy tape were improved by this heat treatment method. 88.8% (≤10°) cube texture was obtained in a Ni9.3W alloy tape prepared like Ni7W tapes from EBSD maps of the surface, which is much higher than that in a Ni9.3W alloy tape prepared by melt casting route in our work. Recently a new higher value, 96.0% (≤10°) cube texture in Ni9.5W, is reported by IFW Dresden [9]. In their work, intermediate heat treatments were also introduced many times before the two-step annealing procedure. Therefore, it is necessary to take recovery annealing processes in preparation procedures. However, there are a little of off-cube grains, including annealing twins and rotated cube grains along the rolling direction. More studies on the heat treatment profiles of substrates with high W content should be further optimized.

3.2. Interface characterization and surface texture analysis in composite substrates

3.2.1. Welding type composite substrate. Compared with a single layer substrate, a composite one has advantages combining a sharp cube texture with high mechanical strength as well as low magnetism. Welding type composite tape was prepared from a composite ingot with a total stacking sequence Ni5W/Cu/Ag/Cu/Ni9.3W/Cu/Ag/Cu/Ni5W, where Cu/Ag/Cu layers act as solder between the outer Ni5W layer and the inner Ni9.3W layer. Well welding bonds can be obtained between the interfaces of the tri-layers by forming a CuNi solid solution and AgCu eutectic phases [10] after sintering at 900°C.

The content of cube texture was 98.6% (≤10°) detected by XRD after heat treatment process, and the FWHM values of (111) phi-scan and (002) rocking curve are 7.6° and 6.1°, respectively. The texture relationship between outer layer and inner layer is investigated in an EBSD map of cross section. The outer layer has formed a preferred orientation, while the inner one presents a random orientation with highly misoriented grains. There is no diffusion between each layer from the EDS analysis results. The reason is that the Ag layer prevents the diffusion of W element from the inner to outer layers during the heat treatment process.

3.2.2. Diffusion type composite substrate. Different from welding type composite substrates, diffusion type ones form not a welding bond between the different layers but a W distribution gradient by diffusion from inner layer to outer layer of the composite ingot during the sintering process. Both CIP [11] and Spark Plasma Sintering (SPS) [12] methods can be used to obtain this kind of initial ingots. The details for preparing ingots are given elsewhere [13]. In this part of works, we made Ni12W as the inner layer and chose different Ni-W alloy as the outer layer such as Ni5W, Ni7W, Ni8W and Ni9W.

For example, the Ni5W/Ni12W/Ni5W composite tape has a good connectivity and clear boundaries, with a thickness about 75 μm consisting of a 25 μm/30 μm/20 μm sequence after heavy rolling. But the clear boundary becomes vague due to W gradient diffusion and continuous distribution after heat treatment. The permeation of W results in a broader diffused interface width and a W content slightly higher at the surface. According to a macro-texture measurement, a highly oriented cube texture was obtained on the Ni5W surface, which can also be verified by the ODF section. There is only a little effect on the cube texture formation by the diffusion of W element in the surface of composite tape. To evaluate the local micro-texture, EBSD is employed on the Ni5W surface, and the percentage of cube texture exceeds 98.8% (≤10°). The off-cube grains include a twin grain type and an equiaxial grain type. Equiaxial grains can be eliminated by improving the temperature and prolonging time. The number fraction of cube grains exceeds 67% (≤7°) and the maximum appears at 6°. These results confirm the highly cube texture in the outer layer, despite of W element diffusion from the inner layer.

In the reel-to-reel process, for epitaxial growth of buffer layers and YBCO film at 800°C to 1100°C, the substrate will endure a certain strain. It was reported [14] that the substrate does not withstand strains above 0.2% under tensile stress. Some micro-texture studies were performed by *in-situ* EBSD analysis on the Ni5W surface with tension by a tensile tester accessory at heat temperature. A strain was put along the sample's rolling direction, and the yield strength ($\sigma_{0.2}$) exceeds 240 MPa [15] which can meet the demands for practical applications [1]. The percentage of cube texture is 98.7% (≤10°) at 2% elongation, which is similar as 99.8% (≤10°) at original stage. These results indicate that this kind of composite substrate can be used in the reel-to-reel method with a stable and high quality of cube texture. In addition, it was found that some of the grains have been rotated by a small angle relative to cube grains although the content of cube grains does not change obviously. However, the evolution of misorientation angle is due to complex reasons but not simply related to the increase of elongation.

Similar works were also proceeding on other Ni-W alloy composite substrates. A special attention is given to the Ni8W/Ni12W/Ni8W composite tape especially to its 96.5% cube texture and non-ferromagnetic. The total thickness of this kind of substrate is 80 μm finally and the ratio of thickness in each layer is 1:2:1. Moreover, a detailed optimization for increasing cube texture in Ni8W surface is under study and the results will be reported elsewhere. The key questions are focused on the formation of highly cube texture in the surface of outer Ni-W alloy layers with high W content.

3.3. Magnetic property and yield strength in the as-obtained substrates

Table 1 summarizes the results obtained on cube texture content, mechanical and magnetic properties for different kinds of single component Ni-W alloy tapes and composite tapes. As-obtained substrates combine an excellent cube texture, enhanced mechanical properties and reduced magnetization. Due to the Ni12W inner layer, this kind of composite substrates as alternatives are very competitive to Ni-W alloy ones with single component for the potential applications. Furthermore, the successful deposition of high quality epitaxial $La_2Zr_2O_7$ buffer layer by MOD method directly on several high W content Ni-W alloy substrates and composite substrates, proves that these advanced substrates are appropriate for the further development of the HTS coated conductors [15].

Table 1. Cube texture content, mechanical and magnetic properties of various Ni-W alloy tapes.

Ni-W alloy tapes	Cube texture	$\sigma_{0.2}$ (MPa)	M (emu/g)	Ni-W alloy composite tapes	Cube texture	$\sigma_{0.2}$ (MPa)	M (emu/g)
pure Ni	/	63	57.1	Ni5W/Ni9.3W/Ni5W	98.6%	180	16.7
Ni5W	98.9%	176	24.8	Ni5W/Ni12W/Ni5W	99.0%	240	14.9
Ni7W	99.8%	216	10.7	Ni7W/Ni12W/Ni7W	99.6%	333	5.0
Ni8W	90.2%	/	/	Ni8W/Ni12W/Ni8W	96.5%	/	0
Ni9.3W	88.8%	220	0	Ni9W/Ni12W/Ni9W	72.3%	/	0
commercial Ni5W	98.0%	170	27.5				

4. Conclusions

We have described the development and summarized the properties of various advanced substrates. High W content Ni-W alloy substrates and a series of Ni-W composite substrates have been prepared with a sharp cube texture, high mechanical and magnetic properties. It can be concluded that, by designing innovative configurations and optimizing the preparation parameters, the RABiTS technique can remarkably improve the properties of the substrates. We expect that these advanced Ni-W alloy substrates have a potential for the large scale production of HTS coated conductors in the near future.

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References

[1] Suenaga M, Iwakuma M, Sueyoshi T, et al. 2008 *Phys. C* **468** 1714-1717
[2] Zhao Y, Suo H L, Liu M, et al. 2006 *Phys. C* **440** 10-16
[3] Ijaduola A O, Thompson J R, et al. 2003 *Phys. C* **43** 163-171
[4] Subramanya V S, Eickemeyer J, et al. 2004 *Scripta Mater.* **50** 953-957
[5] Suo H L, Zhao Y, Liu M, et al. 2007 *IEEE T. App. Supercon.* **17** 3420-3423
[6] Zhao Y, Suo H L, Liu M, et al. 2007 *T. Nonferr. Metal. Soc.* **17** 208-211
[7] Zhao Y, Suo H L, Liu M, et al. 2007 *Acta Mater.* **55** 2609-2614
[8] Zhao Y, Suo H L, Zhu Y H, et al. 2009 *Acta Mater.* **57** 773-781
[9] Gaitzsch U, Hänisch J, Hühne R, et al. 2013 *Supercond. Sci. Technol.* **26** 085024
[10] Suo H L, Zhao Y, Liu M, et al. 2008 *Acta Mater.* **56** 23-30
[11] Suo H L, Zhao Y, Liu M, et al. 2008 *Supercond. Sci. Technol.* **21** 025006
[12] Liu M, Suo H L, Zhao Y, et al. 2007 *Scripta Mater.* **56** 129-131
[13] Zhao Y, Suo H L, Liu M, et al. 2008 *Supercond. Sci. Technol.* **21** 075003
[14] Goyal A, Norton D P, Kroeger D M, et al. 1997 *J. Mater. Res.* **12** 2924
[15] Gao M M, Suo H L, Zhao Y, et al. 2010 *Acta Mater.* **58** 1299-1308