Oral | Material, processing, and characterization

Wed. Jul 30, 2025 10:55 AM - 12:15 PM JST | Wed. Jul 30, 2025 1:55 AM - 3:15 AM UTC Convention Hall(300, 3F)

[O10] Sm-based Magnets

Session Chair: Prof. Satoshi Sugimoto (Tohoku University)

Invited

10:55 AM - 11:15 AM JST | 1:55 AM - 2:15 AM UTC

[O10-1]

Phase transition in Sm-Co and its interesting phenomena

*Hubin Luo[1], Zhen Zhao[1], Niuniu Wang[1], Yun Li[1], Lei Liu[1], Yong Ding[1], Renjie Chen[1], Jian Zhang[1], Izabela Szlufarska[2], J. Ping Liu[3], Baogen Shen[4], Aru Yan[1] (1. Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences (China), 2. University of Wisconsin-Madison (United States of America), 3. University of Texas at Arlington (United States of America), 4. Insititute of Physics, Chinese Academy of Sciences (China))

11:15 AM - 11:30 AM JST | 2:15 AM - 2:30 AM UTC

[O10-2]

Composition dependence on magnetic properties and phase changes of $TbCu_7$-type Sm-Fe-Co-Nb-B alloys

*Masashi MATSUURA[1], Shinya SAKURADA[2], Satoshi SUGIMOTO[1] (1. Tohoku University (Japan), 2. Toshiba (Japan))

11:30 AM - 11:45 AM JST | 2:30 AM - 2:45 AM UTC

[O10-3]

Study of magnetization reversal and magnetic hardening in SmCo5 single crystal magnet

*Alex Aubert[1], Hongguo Zhang[1,2], Fernando Maccari[1], Christian Dietz[3], Ming Yue[2], Konstantin Skokov[1], Oliver Gutfleisch[1] (1. Functional Materials, TU Darmstadt (Germany), 2. Faculty of Materials and Manufacturing, Beijing University of Technology (China), 3. Physics of Surfaces, TU Darmstadt (Germany))

11:45 AM - 12:00 PM JST | 2:45 AM - 3:00 AM UTC

[O10-4]

Preparation of magnetically alignable Sm-Co alloy nanoparticles by wet-jet milling

*Kwangjae Park[1], Yusuke Hirayama[1] (1. National Institute of Advanced Industrial Science and Technology (AIST) (Japan))

12:00 PM - 12:15 PM JST | 3:00 AM - 3:15 AM UTC

[O10-5]

Effects of 1:5H-type Cu-rich phase around grain boundary on cell boundary phase and squareness of the demagnetization curve in sintered Sm_2Co_{17}-type magnets

*Chuanghui Dong[1], Lei Liu[1] (1. Ningbo Institute of Materials Technology & Engineering, CAS (China))

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[O10-1] Phase transition in Sm-Co and its interesting phenomena

*Hubin Luo[1], Zhen Zhao[1], Niuniu Wang[1], Yun Li[1], Lei Liu[1], Yong Ding[1], Renjie Chen[1], Jian Zhang[1], Izabela Szlufarska[2], J. Ping Liu[3], Baogen Shen[4], Aru Yan[1] (1. Ningbo Institute of Materials Technology and Engineering, Chinese Academy of Sciences (China), 2. University of Wisconsin-Madison (United States of America), 3. University of Texas at Arlington (United States of America), 4. Insititute of Physics, Chinese Academy of Sciences (China))

Keywords：Sm-Co、Phase transition、Amorphization、Crystallization

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Most of the investigations about Sm-Co have been dedicated to the formation of cellular microstructure due to the phase separation of $SmCo_5$ and Sm_2Co_{17}, which is important for its coercivity. Here, I would like to introduce the phase transition between crystalline and amorphous of Sm-Co and show that the phase transition, by its nature, has profound indications on various materials properties such as mechanical and metallurgical behaviors. We found that the stress-induced amorphization of Sm-Co compounds can accommodate large strain by shear banding, without significant local dilation/contraction that usually serves crack opening within the bands [1-4]. For the crystallization from amorphous state, we reported semicrystalline nucleation when Sm atoms form a lattice but Co atoms are still amorphous between the planes, which renders an ultralow interfacial energy during nucleation [5]. The physics behind these phenomena may be used for future design of materials with good performance.

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[O10-2] Composition dependence on magnetic properties and phase changes of $TbCu_7$-type Sm-Fe-Co-Nb-B alloys

*Masashi MATSUURA[1], Shinya SAKURADA[2], Satoshi SUGIMOTO[1] (1. Tohoku University (Japan), 2. Toshiba (Japan))

Keywords：TbCu7-type Sm-Fe phase、Coercivity、Anisotropy field、phase and microstructural changes

A $TbCu_7$-type Sm-Fe phase in melt-spun ribbons with good magnetic properties, and in 1996, Sakurada et al. [1] prepared a $TbCu_7$-type Sm-Fe-N based compound with high intrinsic magnetic properties of saturation magnetization and anisotropy field of 1.70 T and 6.2 MAm^{-1}, respectively. In 2002, Mochizuki et al. [2] reported that a high coercivity $TbCu_7$-type compound could be obtained with relatively slow roll velocity and without nitriding. Recently, our group also focused on the Sm-Fe-Co-Nb-B alloy system, and achieved a high coercivity of 655 kAm^{-1} with a $TbCu_7$-type phase in $Sm_{6.2}Fe_{68.7}Co_{16.4}Nb_{2.7}B_{8.3}$ by optimizing the annealing conditions [3]. In this work, we investigated the influence of the composition on the magnetic properties including coercivity, magnetization, and anisotropy field, and microstructure of Sm-Fe-Co-Nb-B alloys with the goal of enhancing the coercivity.
$Sm_zFe_{77.4-z}Co_{16.4}Nb_{2.7}B_{8.3}$ (at%) (z=6.1-7.8) alloys were subjected to induction melting followed by melt spinning to obtain amorphous ribbons. The melt-spun ribbons were heat treated at 635 °C for 1–25 h. The magnetic properties were evaluated by VSM with maximum applied field of 1.6 MAm^{-1} after magnetized by a pulsed magnetic field of 6.4 MAm^{-1}. The anisotropy field was estimated using the law of approach to ferromagnetic saturation (LAS) method under applying a maximum magnetic field of 4.8 MAm^{-1}. The crystallization temperature was measured by DSC and the crystal structure was determined by XRD. The annealing time dependence was shown in Fig. 1. For z=6.1 at%, coercivity showed a peak by annealing for 7 h, and it tended to decrease by annealing with extending time. The optimum annealing time for coercivity increased with increasing Sm content to z=7.0 at%, and the optimum annealing time was 17 h for the alloy with z=7.0 at% resulting in 682 kA/m. Further increasing Sm to 7.8 at%, optimum annealing time was short to 13 h, and the maximum coercivity was lower than that of z=7.0 at%. The trend of coercivity changes corresponds to anisotropy field changes. LAS measurement revealed that the anisotropy field tended to increase with increasing Sm content, furthermore, the XRD analysis showed the c/a of $TbCu_7$-type phase tended to be small with increasing Sm content. Therefore, Sm content effects on not only coercivity but also anisotropy field of $TbCu_7$-type phase. The details of microstructure and magnetic

properties will be discussed on the presentation.

[1] S. Sakurada, et al., J. Appl. Phys., 79 (1996) pp. 4611–4613.[2] M. Mochizuki, et al., Proceedings of the Seventeenth International Workshop on Rare Earth Magnets and Their Applications, Newark, Delaware, USA (2002) pp. 401–408.[3] N. Kurokawa, et al., J. Magn. Magn. Mater., 556 (2022) pp. 169414 1-9.
Acknowledgement: This study was supported by New Energy and Industrial Technology Development Organization (NEDO), Japan (JPNP23030).

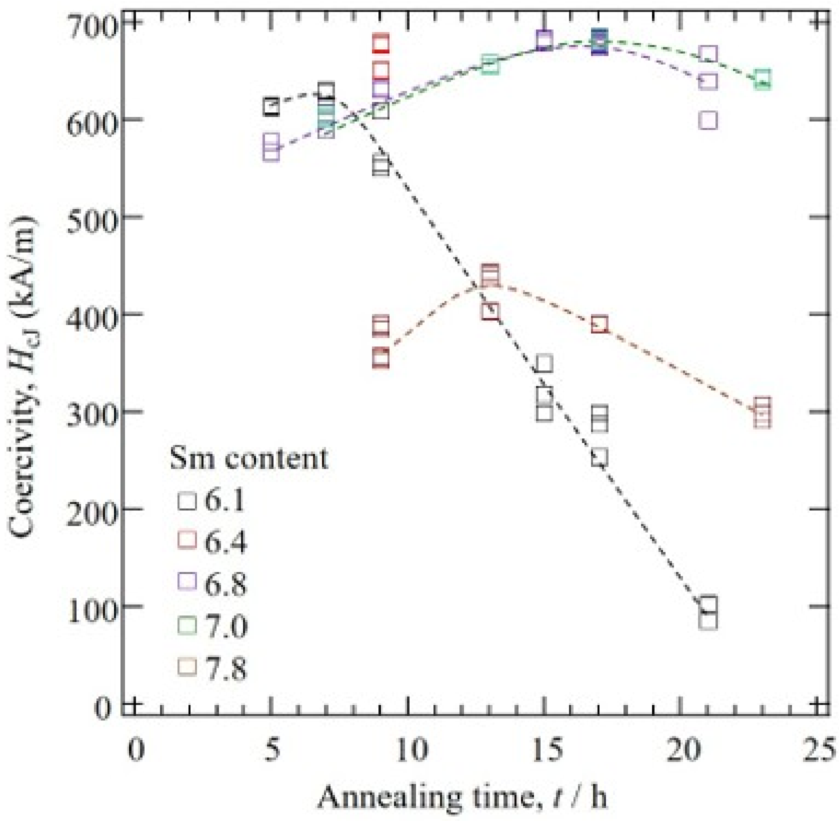

Fig. 1 Annealing time dependence of coercivity of $Sm_zFe_{77.4-z}Co_{16.4}Nb_{2.7}B_{8.3}$ (z=6.1-7.8) alloys.

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[O10-3] Study of magnetization reversal and magnetic hardening in SmCo5 single crystal magnet

*Alex Aubert[1], Hongguo Zhang[1,2], Fernando Maccari[1], Christian Dietz[3], Ming Yue[2], Konstantin Skokov[1], Oliver Gutfleisch[1] (1. Functional Materials, TU Darmstadt (Germany), 2. Faculty of Materials and Manufacturing, Beijing University of Technology (China), 3. Physics of Surfaces, TU Darmstadt (Germany))

Keywords：SmCo5、Single crystal magnets、Magnetization reversal

In permanent magnets, magnetization reversal typically involves two crucial fields: the nucleation field (Hn), which is necessary to introduce a reversal domain into a magnetically saturated crystal, and the (de-)pinning field (Hp), required to release a trapped wall from its pinning sites [1]. However, distinguishing between a true nucleation process and a local "de-pinning" of an existing wall can sometimes be challenging, both experimentally and conceptually. In sintered magnets, the process of magnetization reversal in $Nd_2Fe_{14}B$ or $SmCo_5$ magnets is traditionally attributed to the nucleation of reversal magnetic domains at the surface defects of single crystalline grains. However, recent findings challenge this assertion, primarily based on measurements of the angular dependence of coercivity, which follows a pinning-type Kondorsky model attributed to domain wall pinning at grain boundary interfaces [2]. To clarify this point, a more in-depth understanding of nucleation processes is needed and studying "ideal" objects with minimal defects can provide valuable insights.

In fact, traditional sintered magnets are highly complex objects, often featuring multiple phases, grain boundaries, varied grain sizes and shapes, misaligned grains etc. The magnetization reversal is thus a combination of various effects. The nucleation can arise from high local demagnetizing fields due to surface irregularities, structural defects, secondary phases etc. which can lead to a drastic reduction of the local anisotropy. To properly isolate the effects of nucleation and pinning and better understand their contributions, an ideal experimental system is required. Large, high-quality single crystals provide a good opportunity to study magnetization reversal in the absence of grain boundaries and other microstructural complexities inherent to sintered magnets.

In this study, we synthesis large single-crystal magnets of SmCo5 with high-quality surfaces to investigate their magnetization reversal process. After surface treatment by electro-polishing, the SmCo5 magnets exhibit a significantly increased coercivity reaching values close to 1 T, and are two to ten times larger in size compared to previous reports with similar coercivity (see Figure). We delve into the origin of this large coercivity and examine the detailed influence of surface conditions and different nucleation processes.

We discuss the effect of type-I (local depining) and type-II (true nucleation) nucleus and their impact in magnetization reversal of our objects. Lastly, we explore the angular dependence of coercivity in these ideal objects, assessing the method's applicability for more complex systems like sintered magnets. In summary, we present ideal single crystal permanent magnet of SmCo5 which can help us understand deeper the coercivity mechanism (nucleation, pinning) and the role of surface (im)perfection [3].

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Acknowledgement:
This work was supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), Project ID no. 405553726-TRR 270 and the National Key R&D Program of China (2023YFB3508500).

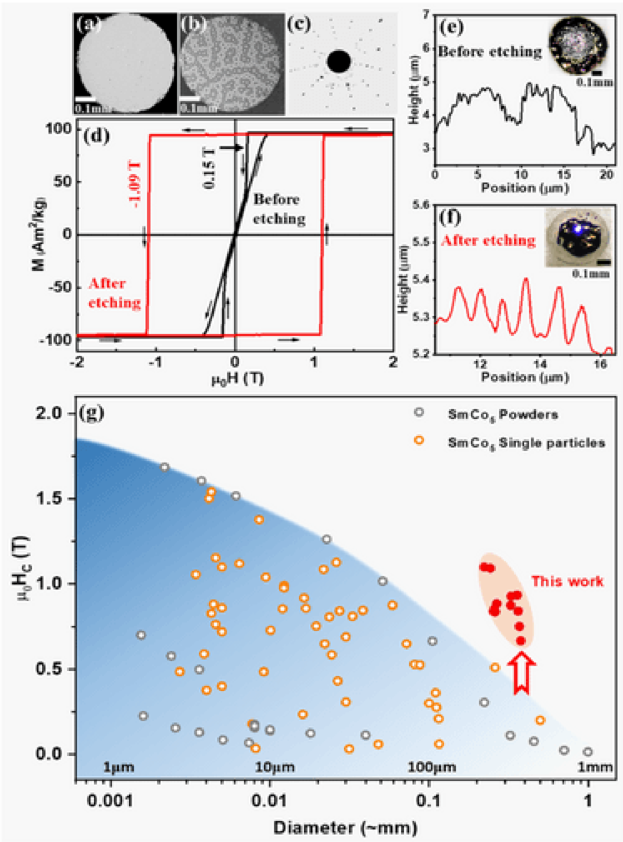

Figure: (a) BSE-SEM micrograph, (b) magnetic domain structure and (c) Laue diffraction pattern of the LSCMs. (d) Representative M(H) curves before and after etching. The profile of morphology defects on the sample's surface (e) before and (f) after etching. (g) Size dependence of coercivity obtained on the etched SmCo5 crystals compared with the data from the literature.

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[O10-4] Preparation of magnetically alignable Sm-Co alloy nanoparticles by wet-jet milling

*Kwangjae Park[1], Yusuke Hirayama[1] (1. National Institute of Advanced Industrial Science and Technology (AIST) (Japan))

Keywords：Sm-Co alloys、nanoparticles、wet-jet milling、crystallographic orientation、anisotropic magnetic behavior

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The anisotropic fine rare-earth alloy particles with high coercivity and high remanent magnetization are promising optimal precursor materials for developing high-performance permanent magnets. In a previous study, we successfully synthesized anisotropic Sm-Co nanopowder with an average particle size of 60 nm using a low-oxygen induction thermal plasma process [1]. The Sm-Co nanopowder consisted of a few types of Sm-Co alloys particles, $SmCo_5$, Sm_2Co_{17}, and $SmCo_3$. The volume fraction of the $SmCo_5$ phase was estimated to be 34 wt% based on X-ray diffraction (XRD) measurements [2].
In order to improve the coercivity of the Sm-Co nanopowder by increasing the volume fraction of $SmCo_5$ phase, we investigated the effect of heat treatment on its magnetic properties [2]. After annealing at 900°C in an Ar atmosphere, the volume fraction of the $SmCo_5$ phase increased to 58 wt%, and the coercivity improved to 1.8 T. However, the heat-treated Sm-Co nanopowder exhibited low crystallographic alignment and weak anisotropic magnetic behavior under an external magnetic field. This was attributed to severe necking between nanoparticles during heat treatment, leading to the formation of isotropic polycrystalline Sm-Co powder.
To enhance the anisotropic magnetic behavior of the heat-treated Sm-Co nanopowder, we employed wet-jet milling, a technique that utilizes a high-speed injection pressure of approximately 200 MPa, to break up the necking between nanoparticles. The heat-treated Sm-Co nanopowder with a coercivity of 3.6 T was pulverized using wet-jet milling. The XRD profiles of magnetically aligned Sm-Co nanopowder revealed a significant increase in the intensity of the $SmCo_5$ (002) peak after wet-jet milling, as shown in Fig. 1a, indicating that the $SmCo_5$ nanoparticles—after necking removal—were sufficiently oriented by the external magnetic field. Furthermore, magnetic measurements demonstrated that the wet-jet milled Sm-Co nanopowder exhibited a higher $M_r/M_{@9T}$ ratio, as shown in Fig. 1b, indicating improved anisotropic magnetic behavior. Based on these results, we conclude that wet-jet milling is an effective method for enhancing the anisotropic magnetic behavior of rare-earth alloy nanoparticles.

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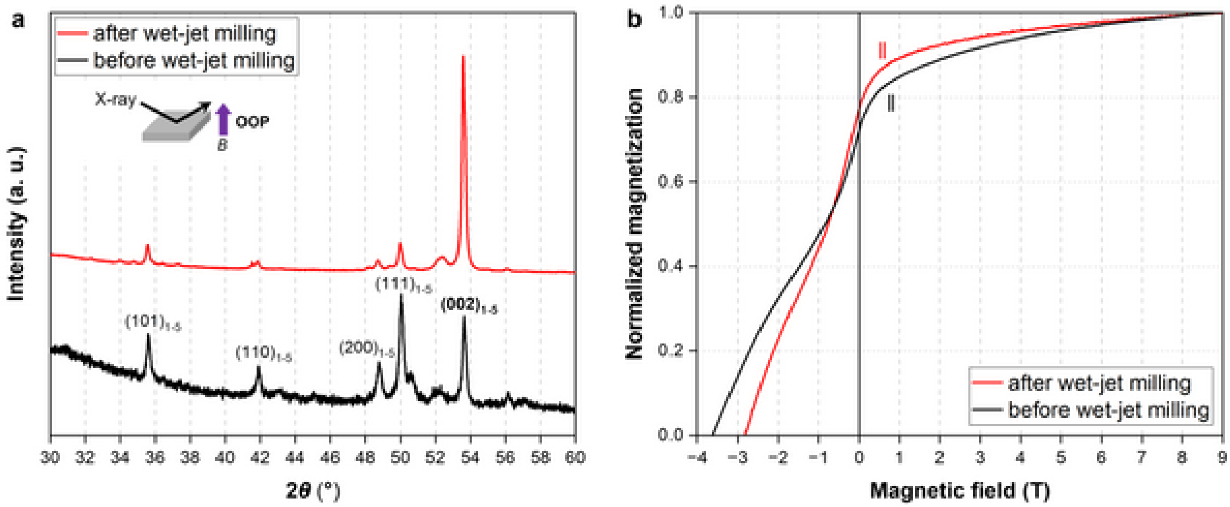

Fig. 1. a) XRD profiles of Sm-Co nanopowders before and after wet-jet milling, measured in the out-of-plane (OOP) configuration. b) Normalized demagnetization curves of Sm-Co nanopowders before and after wet-jet milling, measured parallel to the magnetic alignment direction at 300 K.

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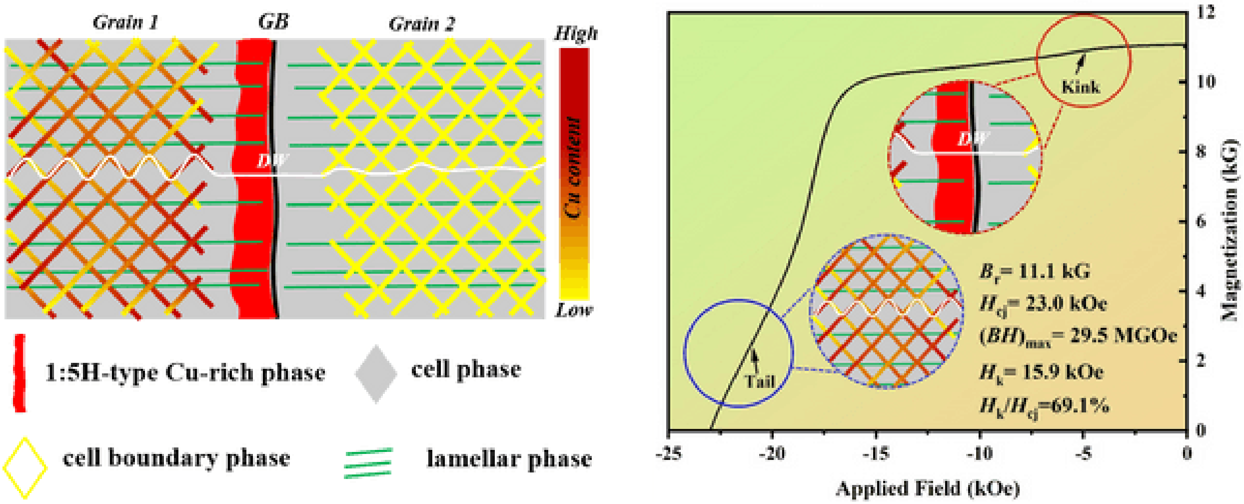
[O10-5] Effects of 1:5H-type Cu-rich phase around grain boundary on cell boundary phase and squareness of the demagnetization curve in sintered Sm_2Co_{17}-type magnets

*Chuanghui Dong[1], Lei Liu[1] (1. Ningbo Institute of Materials Technology & Engineering, CAS (China))

Keywords：Sm2Co17-type magnets、1:5H-type Cu-rich phase、grain boundary、cell boundary phase、demagnetization curve squareness

The unique cellular structure of Sm_2Co_{17}-type magnets is responsible for their outstanding magnetic properties. However, the cell boundary phase around grain boundaries is few, and cannot form a complete cellular structure. This study explores the microstructure and microchemistry of the grain interiors and grain boundary regions in both the solid solution precursor and the final magnet. The Cu-rich phase precipitates around grain boundaries in the solid solution precursor, and it remains present in the final magnet. The Cu-rich phase is not present as a standalone grain boundary phase, rather, it possesses a hexagonal $CaCu_5$-type crystal structure and demonstrates a coherent orientation relationship with the surrounding matrix. The Cu-rich phase inhibits cellular structure formation nearby, while boosting Cu content in the cell boundary phase at the grain boundary regions in the final magnet. The formation of a Cu-rich phase around the grain boundary increases the heterogeneity of the domain wall pinning field in the final magnet, becoming an unfavorable factor for the improvement of the squareness of the demagnetization curve. These discoveries enhance our comprehension of the precipitated phase surrounding the grain boundary and its impact on the cellular structure and magnetic characteristics of the magnet.


Grain 1
GB
Grain 2
High
Cu content
Low
DW
1:5H-type Cu-rich phase
cell phase
cell boundary phase
lamellar phase
Kink
Tail
B_r= 11.1 kG
H_{cj}= 23.0 kOe
$(BH)_{max}$= 29.5 MGOe
H_k= 15.9 kOe
H_k/H_{cj}=69.1%
Magnetization (kG)
Applied Field (kOe)
-25
-20
-15
-10
-5
0
2
4
6
8
10
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