Crimson Publishers
Wings to the Research

Review Article

Overview of Strengthening and Working Technique on Fusion Materials

ISSN: 2576-8840

Hiroyuki Noto[1]* and Eiichi Wakai[2]

[1]National institute for fusion science, Japan

[2]Facility for Rare Isotope Beams, Michigan State University, USA

***Corresponding author:** Hiroyuki Noto, National institute for fusion science, Japan

Submission: October 16, 2024
Published: November 05, 2024

Volume 21 - Issue 1

How to cite this article: Hiroyuki Noto* and Eiichi Wakai. Overview of Strengthening and Working Technique on Fusion Materials. Res Dev Material Sci. 21(1). RDMS. 001004. 2024.
DOI: 10.31031/RDMS.2024.21.001004

Abstract

Materials for blankets and the divertor in fusion reactors are subject to high heat load and high energy radiation. These materials require heat resistance and radiation tolerance, have been continuously evolving since a few decades ago. For the further improvement for high performance fusion materials, author(s) have carried out "Strengthening methods" and "New working technique" based on metallurgical technology in this paper, these studies will be introduced.

Strengthening Methods

Tungsten (W) and Copper (Cu) are applied to severe environment of strike points on fusion diverter, requires superior performance of heat resistance and radiation tolerance than conventional W and C. For overcome such harsh environment, new strengthening technique of "Oxide dispersion strengthening (ODS)" was studied. The ODS method is one of "precipitate strengthening," also includes the elements of "crystal grain refinement" and "dislocation strengthening". On the other hand, new solid solutions that strengthen materials of high entropy alloy is also attractive in the field of fusion materials.

High strength copper applied ODS method [1,2]

In conventional processes for copper alloy, casting processes have been employed in general. In contrast, powder metallurgy of "Oxide dispersion strengthening (ODS)" was applied to production process for copper in our study. The ODS is a unique technique which can disperse strengthening nanoparticles in matrix and crystal grain boundary, have been actively studied in field of fusion and fission. In results of ODS method for Cooper alloy in our study, the dispersion behavior is differed from else base-ODS alloy (Fe ODS, W-ODS and Ni-ODS and the others), which indicates that excess oxygen is needed for process of ODS-Cu.

High toughness tungsten applied ODS method [3-8]

Developed ODS-W showed superior heat resistance in view of stable microstructure than ITER (International Thermonuclear Experimental Reactor) grade pure tungsten. In results of the research, it is revealed that process of mechanical alloying affects the high performance. For research of the effect of stable microstructure on radiation environment, ion irradiation test was carried out for research of irradiation hardening, resulting that the hardness of ODS-W was 6.4±1.2GPa and 6.4±1.4GPa before and after irradiation, respectively, which indicated that the DS-W including matrix in distortions arrangement shows radiation tolerance. These results will affect the study of else type DS-W (W-Y_2O_3 and W-La_2O_3 and others) in the future (Figure 1).

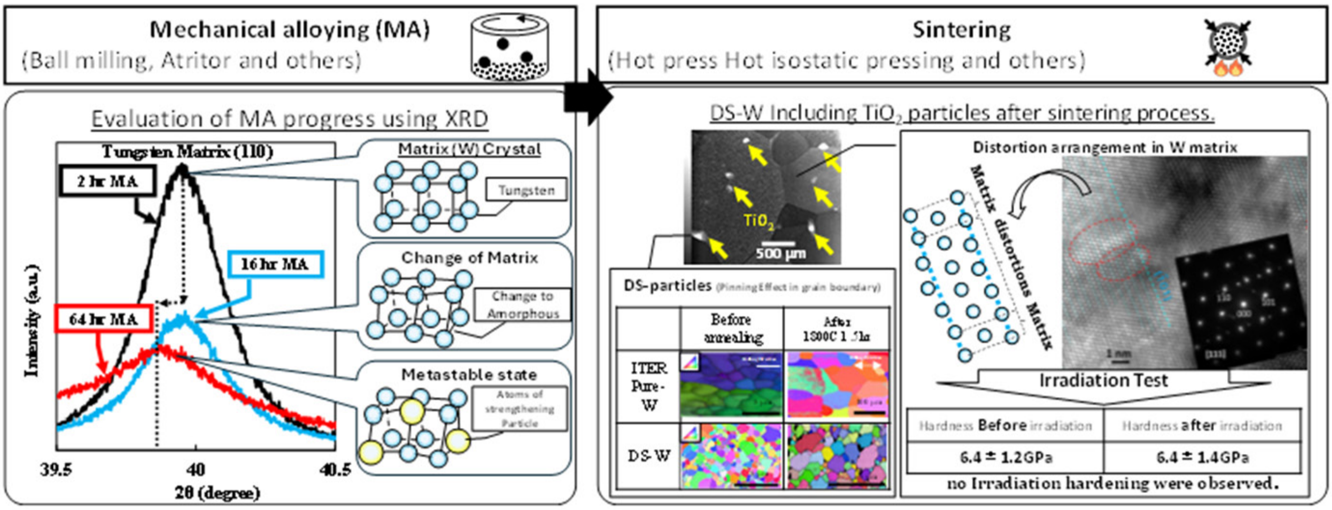

Figure 1: Effect of mechanical alloying on DS-W performance.

Super hardness high entropy tungsten alloy [9]

Recently, solid solution strengthening materials of "high entropy alloy" is attractive attention in a various filed of metallurgy, not only fusion material. Author(s) also have started new tungsten-high entropy alloy(W-HEA) including the characteristics of low activation. The new W-HEA showed mechanical properties of high hardness even though that is solution metal, not ceramics such carbide material, resulting that the hardness overcame conventional carbide material. The hardening mechanism is under research using Ultra-high voltage electron microscope (UHV-EM) or nanoindentation test.

New Working Technique

Bonding method between candidate materials on the blanket and the divertor rest some issue of loss of candidate material performance in case of conventional bonding method. As the solution of issue, new bonding and innovative working techniques were developed in following.

New bonding method for blankets [10,11]

Martensitic oxide dispersion strengthening (9Cr-ODS) steel promising as fusion blanket structural material is known as the degradation of the characterizing properties significantly in welding zone due to discontinuousness of microstructure. Thus, Transient Liquid Phase (TLP) bonding, which is one of the reaction bonding was focused on our study. In this study, author(s) have combined "reaction bonding" and "structural control of oxide metallurgy". The new concept realized the grain refinement in TLP bonding zone, meaning continuousness from matrix (9Cr-ODS steel) to TLP zone. In general, oxide metallurgy is used for welding. However, this study demonstrates a new expansion of oxide metallurgy.

Innovative thermal stress relaxation for fusion divertor [12-15]

On one of fusion divertor designs, tungsten (W) and ODS materials are considered as plasma facing materials and supported structural (heat sink) materials, respectively. Thus, dissimilar bonding between W and ODS materials was needed. On the other hand, it is concerned that thermal stress caused by the dissimilar bonding affects degradation in bonding area. For thermal stress relaxation, author(s) proposed new elastic relaxation and new plastic relaxation. As new elastic relaxation for bonding W and ODS-Cu, two step bonding combined the solid-state diffusion bonding and the TLP bonding using two insert materials of vanadium (V) and the thin Gold (Au) was proposed. As new plastic relaxation for bonding W and ODS steel, Transformation super plasticity materials employed as relaxation insert materials, resulting that thermal stress in tungsten matrix was relaxed, the mechanical properties between W and ODS steel was improved (Figure 2).

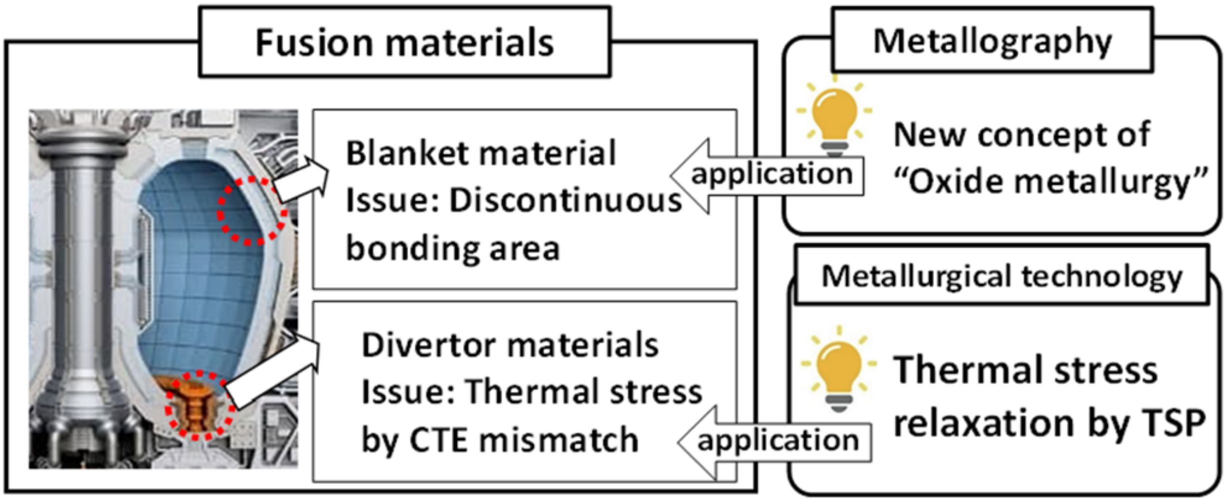

Figure 2: Introduction of fusion materials bonding.

Advanced working technique applied transformation super-plasticity [16]

Reduced activation ferritic-martensitic (RAFM) steel is a promising material as fusion blanket structural material. The development and designing for new RAFM steel have been studying in each country continuously. Although RAFM steels show high mechanical properties at high temperature, low workability caused by high yield strength and low elongation relating conventional steel is concerned. Considering the low workability of RAFM steel, the author started transformation super plasticity on RAFM steel. In the results of our previous study, RAFM exhibited macro elongation (170~200%) on 1/10 load of original yield strength. The results could contribute to the new expansion of metallurgical technology as advanced working technique (Figure 3).

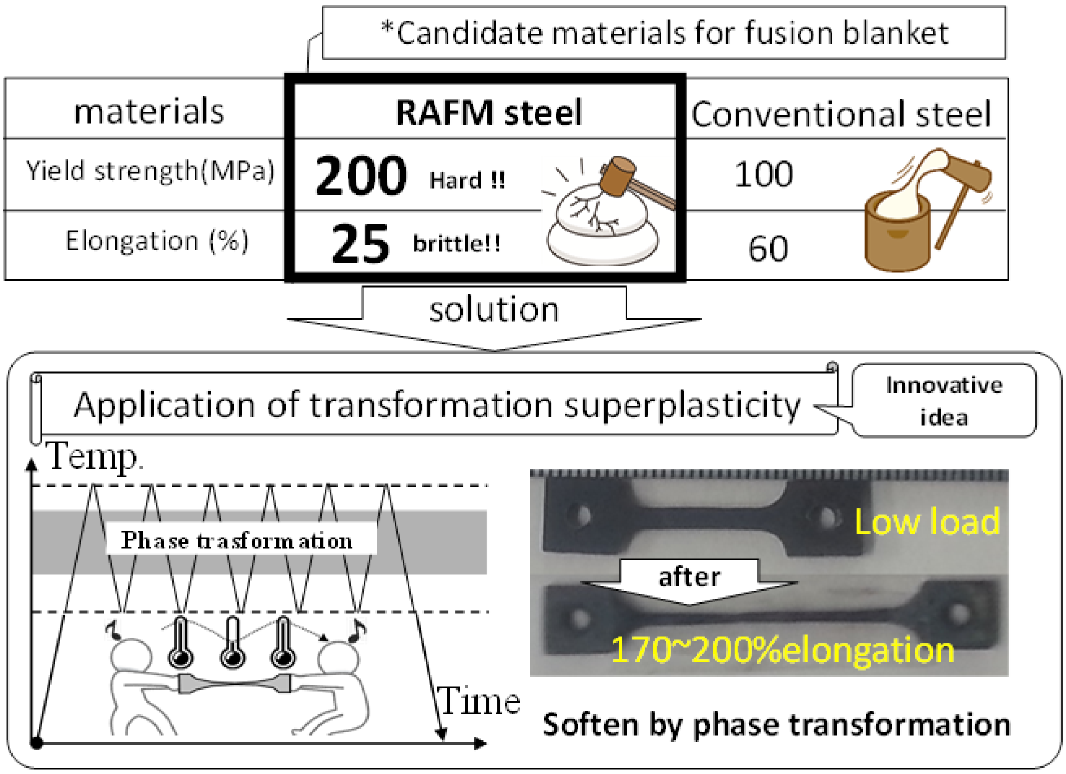

Figure 3: Transformation super-plasticity of RAFM steel.

References

1. Noto H, Yamada T, Hishinuma Y, Muroga T (2016) Development of high strength W/V/Au/ODS-Cu joint using HIP process. Nuclear Materials and Energy 9: 411-415.
2. Noto H, Yamada T, Hishinuma Y, Muroga T (2017) Effect of atmospheric control during MA-HIP process on mechanical properties of oxide dispersion-strengthened Cu alloy. Fusion Engineering and Design 124: 1024-1027.
3. Noto H, Benoki B, Hishinuma Y, Muroga T (2019) Development of W-1.1wt.% TiC using a MA-HIP process. 10th Pacific Rim International Conference on Advance Materials and Processing (PRICM-10) in Xi'an, China Proceedings, pp.158-162.
4. Noto H, Hishinuma Y, Muroga T, Benoki H (2020) Formation mechanism of nano-strengthening particles in dispersion strengthened W-Ti alloys. Plasma and Fusion Research Rapid Communications15: 1205021.
5. Noto H, Hishinuma Y, Muroga T, Benoki H (2020) Microstructure and mechanical properties of dispersion strengthened tungsten by HIP treatment followed by thermal annealing. Results in Materials 7: 100116.
6. Noto H, Hishinuma Y, Muroga T, Tanaka T (2021) Thermal change of microstructure and mechanical properties of dispersion strengthened tungsten. Nuclear Fusion 61: 116001.
7. Noto H, Hishinuma Y, Muroga T (2024) Effect of ball diameter on mechanical alloying process for the production of dispersion strengthened tungsten. Plasma and Fusion Research 19: 1405011.
8. Wakai E, Noto H, Kano S, Makimura S, Ishida T, et al. (2022) Titanium/titanium oxide particle dispersed W-TiC composites for high irradiation applications. Research & Development in Material Science 16: 5.
9. Wakai E, Noto H, Shibayama T, Furuya K, Ando M, et al. (2024) Microstructures and hardness of Bcc phase iron-based high entropy alloy Fe-Mn-Cr-V-Al-C. Materials Characterization 211: 113881.
10. Noto H, Ukai S, Hayashi S (2011) Transient liquid-phase bonding of ODS steels. Journal of Nuclear Materials 417(1-3): 249-252.
11. Noto H, Kasada R, Kimura A, Ukai S (2013) Grain refinement of transient liquid phase bonding zone using ODS insert foil. Journal of Nuclear Materials 442: S567-S571.
12. Noto H, Kimura A, Kurishita H, Matsuo S, Nogami S (2013) Evaluation of feasibility of tungsten/oxide dispersion strengthened steel bonding with vanadium insert. Materials Transactions 54: 451-455.
13. Noto H, Taniguchi S, Kurishita H, Matsuo S, Kimura A (2013) Diffusion bonding of W/ODS steel using pure iron insert for fusion reactor applications. PRICM-8 proceeding with John Wiley & Sons, pp. 129-135.
14. Noto H, Taniguchi S, Kurishita H, Matsuo S, Ukita T, et al. (2014) Effect of grain orientation and heat treatment on mechanical properties of pure W. Journal of Nuclear Materials 455(1-3): 475-479.
15. Noto H, Taniguchi S, Kurishita H, Matsuo S, Kimura A (2016) Development of high strength tungsten/oxide dispersion strengthened ferritic steel joints by innovative thermal stress relaxation technique based on phase-transformation-induced creep deformation. Materials Transactions 57: 1357-1362.
16. Noto H, Hishinuma Y, Muroga T (2019) Transformation super plasticity deformation of reduced activation ferritic/martensitic steel. Fusion Engineering and Design 145: 94-99.

