HIGH-HEAT-FLUX PERFORMANCE OF MONOBLOCK TARGET PREPARED WITH ADVANCED W-K PLATE

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Tungsten materials have been attracting growing interest as a promising candidate for plasma facing materials (PFMs) based on its high melting point, high temperature strength, and good thermal conductivity[1-3]. As early as 2011, the ITER Organization (IO) proposed to use tungsten as the armor material at the vertical target plate of the divertor to replace the carbon fiber composite(CFC) material[4].

Japan and the European Union have done a lot of work on the high heat flux testing of tungsten-based divertors. Japan conducted HHF tests on a small target (armor thickness of 7.7 mm) at IDTF. The performance of the small target met and exceeded the IO requirements (increased by 700 cycles at 20 MW/m^2) [5]. The EU conducted extensive HHF tests on the small-scale test mock-ups of the tungsten monoblock target, including two slow (10 s) overloads at 20 MW/m^2 (up to 2000 pulses) and 25 MW/m^2 (1000 pulses). After the test, except for severe plastic deformation, no serious failure occurred on the tungsten surface [6, 7]. But these tests were carried out under the condition of using pure tungsten as the armor material of the divertor. Compared with pure tungsten, WK material has more excellent thermal stability and mechanical properties [8-12], and these advantages will make the performance of WK material in the high heat flux test more excellent [5, 13]. In fact, WK material is also equivalent to pure tungsten, but ppm-level potassium is added to pure tungsten. In terms of composition, the tungsten content of WK material is higher than 99.99%, which is the same as ITER-grade pure tungsten. Compared to pure tungsten, W-K material has superior thermal stability and mechanical properties[14, 15], which will make it perform better when used in fusion reactors.

In this work, large-size W-K plates were prepared through hydrogen sintering and multi-step hot-rolling processes. During the rolling and low-temperature annealing processes, the large-size potassium bubbles formed during the sintering process will segregate into nano-sized potassium bubbles and strengthen the tungsten matrix. The tensile strength of rolled W-K material at room temperature is 1.1GPa and the recrystallization temperature is 1550°C.

Thermal shock tests were conducted on W-K samples annealed for 1 hour at different temperatures. Absorbed power densities of 0.33, 0.44, 0.55 and 0.66GW/m2 were set to study the cracking regime of rolled W-K at RT with a single-pulse duration of 1 ms for 100 shots. The pulse interval was selected to be 3s to guarantee that the surface temperature of the specimen could be cooled to RT after each individual pulse. The crack formation in the thermal loading areas of all samples is summarized in Fig.1. It can be seen that no cracks were observed in the as-rolled W-K alloy and the samples annealed at 1400°C for 1 hour under all test conditions. Cracks were only found in the samples annealed at 1500°C for 1 hour under the test condition of 0.66 GW/m². Cracks appeared in the samples annealed at 1600°C and 1700°C for 1 hour under the test condition of 0.44 GW/m². Compared with pure tungsten, W-K alloy has excellent thermal conductivity, tensile strength, and low-temperature ductility, as well as a higher recrystallization temperature. These properties endow WK alloy with a much higher crack formation threshold than pure W.

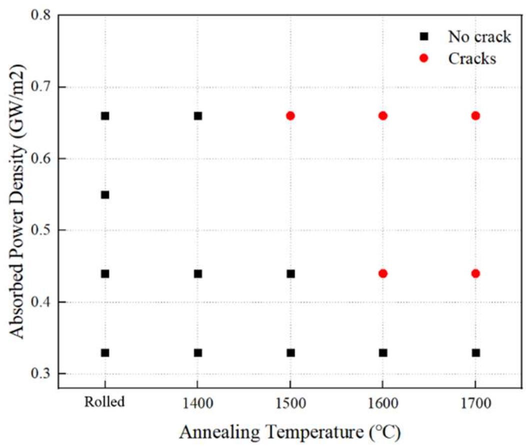

Fig.1 The surface crack formation of all samples in different annealing states under various thermal shock test conditions.

High-heat-flux test monoblock target was prepared using the W-K plates and underwent steady thermal fatigue testing. There were a total of 6 tungsten tiles in the test target, of which 4 were subjected to thermal fatigue testing. The size of the tungsten tile is 28*28*12 mm, and the distance from pure copper layer to loading surface is 5 mm. Three of the tungsten tiles were subjected to thermal loading conditions of 20MW/m^2, with a heating time of 15s and cooling time of 15s. These three tungsten tiles underwent fatigue testing for 500, 1000, and 1500 cycles, respectively. The fourth tungsten tile underwent fatigue testing under a load of 25MW/m^2 for 500 cycles. During the testing process, surface temperature of the tungsten tiles was measured using a two-color pyrometer. After the test, the surface morphology of the loaded tungsten block is shown in Fig.2. It can be seen that no macroscopic cracks were observed on the surface of all four tungsten blocks. Under the load of 20MW/m^2, the initial surface temperature of the tungsten tile was 1590℃, and after 1500 loadings, the surface temperature increased to approximately 1790℃. Under the load of 25MW/m^2, the initial surface temperature of the tungsten tile was 1950℃, and after 500 loadings, the surface temperature increased to approximately 2270℃. SEM observation revealed that only surface roughening and microcracks were observed on the surface of all thermally loaded tungsten tiles, with no major cracks generated.

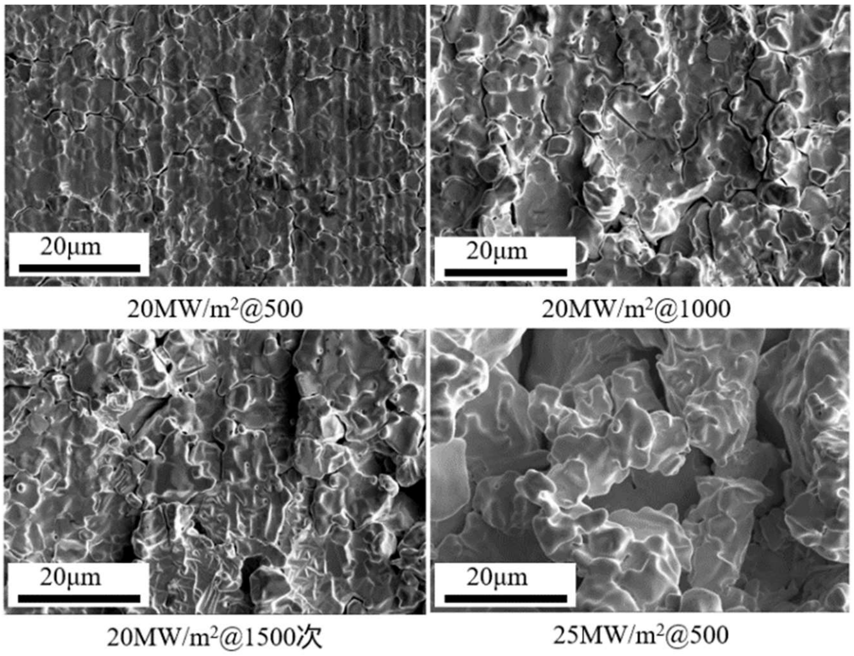

Fig.2 The surface morphology of tungsten blocks under different thermal loading conditions.

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