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Recent Progress of Dissimilar Material Bonding Technique with Spark Plasma Sintering Method for High heat Load Plasma Facing Components in Reactor-relevant Devices

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ABSTRACT

- In NIFS, dissimilar material bonding technique using Spark Plasma Sintering (SPS) method has been developed for divertor components
- Tungsten (W) has been tried to bond to various heat sink materials, i.e., copper ally (CuCrZr), molybdenum alloy (TZM), stainless steel (SS), graphite or carbon fiber reinforced composite (C/CFC)
- W-CuCrZr bonded divertor tile for LHD succeeded in the heat load test with e-beam of 23 MW/m^2, quasi steady-state (10 minutes) and of 15 MW/m^2, 10 sec, 100 cycles of irradiation (duty cycle = 50 %)
- Diagnostics with SEM, shear stress test performed

BACKGROUND

- In ITER and DEMO, W is the first candidate material for high heat load PFCs, e.g., divertor tile, blanket wall. On the other hand, effective heat removal from the armor to the heat sink made of copper or copper alloy, is crucial.
- To realize such ideal PFCs, it is necessary to join the armor to the heat sink securely with high heat conductivity.
- In LHD, W coated graphite tiles and bulk molybdenum plates have been utilized for the divertor component and the ECH/NBI protection system.
- Recently in NIFS, actively cooled divertor target plates with bulk W armor have been developed.
- To join the W armor to CuCrZr heat sink, advanced multi-step brazing technique has been developed.
- In parallel with the brazing, SPS has also been developed.

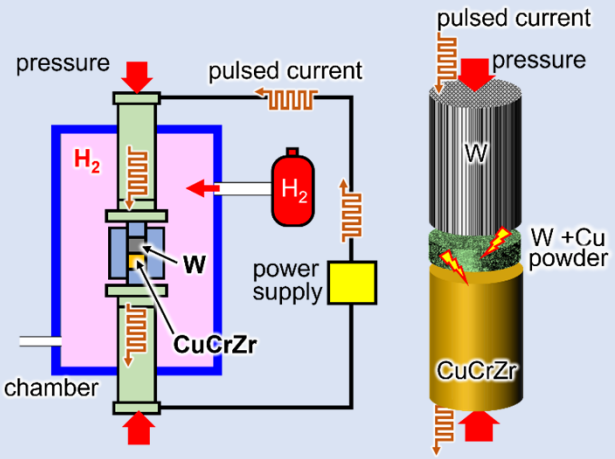
SPARK PLASMA SINTERING (SPS)

Procedure

- In vacuum chamber, apply high one-dimensional pressure of several tens MPa, high frequency pulsed current of several kA
- Joule heating and the periodic electric field move ions and electrons, which results in the stiff bonding
- Hydrogen gas is introduced to avoid oxidization of tungsten
- Interlayer made of metallic powder inserted (Patent)

Advantages

- Process at relatively low temperatures
- Simple procedure, reducing time and cost in mass production

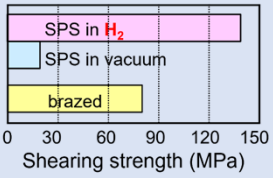


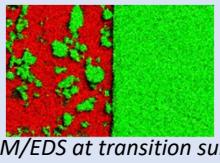
SPS process chamber and external setups. Bonding area is enlarged

OUTCOME

Mechanical and Microscopic Inspections

- SPS bonding is about 1.7 times higher than that of brazing
- In SPS, deoxidization by hydrogen is more effective than evacuation
- WO_3 not detected, no diffused atom neither in W-side nor CuCrZr-side.

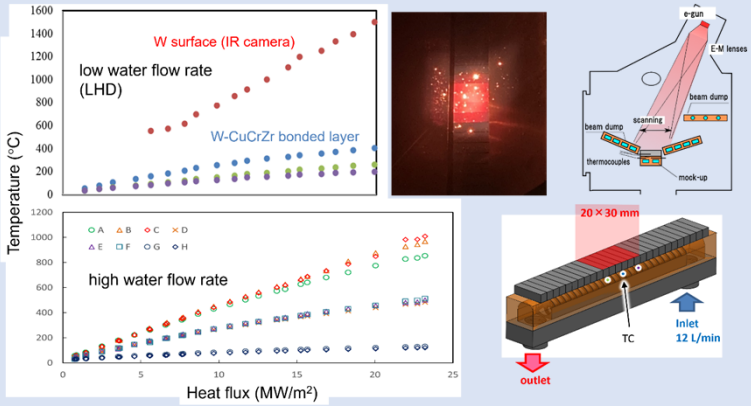




SEM/EDS at transition surface between Cu/W-interlayer and W

e-beam Irradiation Test

- Water cooled divertor element (20Wx150L, 5t W-CuCrZr) for LHD
- High, steady-state, cyclic heat load test performed, as is shown in table
- Combinations of various material tested (see table)



W surface and heat sink temperature vs heat flux in ACT-2 irradiation test

PRESENT STATUS OF R&D FOR SPS BONDING IN NIFS

Target	Divertor LHD	Divertor JT60-SA	Divertor JT60-SA	Divertor JT60-SA	NB target JT60-SA	Divertor LHD	First wall QUEST
Heat flux	high	high	high	high	high	low	quite low
Armor	W	W	W	C	CFC / C	W	W
Heat sink	CuCrZr	CuCrZr	CuCrZr	TZM	CuCrZr	C	SS
Base	SS	SS	-	SS	SS/-	-	-
Cooling	active	active	active	active	active	inertial	inertial
Shear strength	120MPa	120MPa	120MPa	10MPa	1.2MPa	-	-
Heat load (pulse)	23MW/m^2 600sec	15MW/m^2 100sec	15MW/m^2 100sec	not yet	not yet	-	-
Heat load (cyclic)	15MW/m^2 10s x 100	not yet	15MW/m^2 10s x 100	not yet	not yet	-	-

CONCLUSION

- Performance of Spark Plasma Sintering (SPS) method for dissimilar material bonding was tested, which was found to be applicable to high heat load components in fusion devices.
- Another option of e-beam irradiation test in HADES is expected to confirm SPS bonding performance for JT-60SA divertor

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