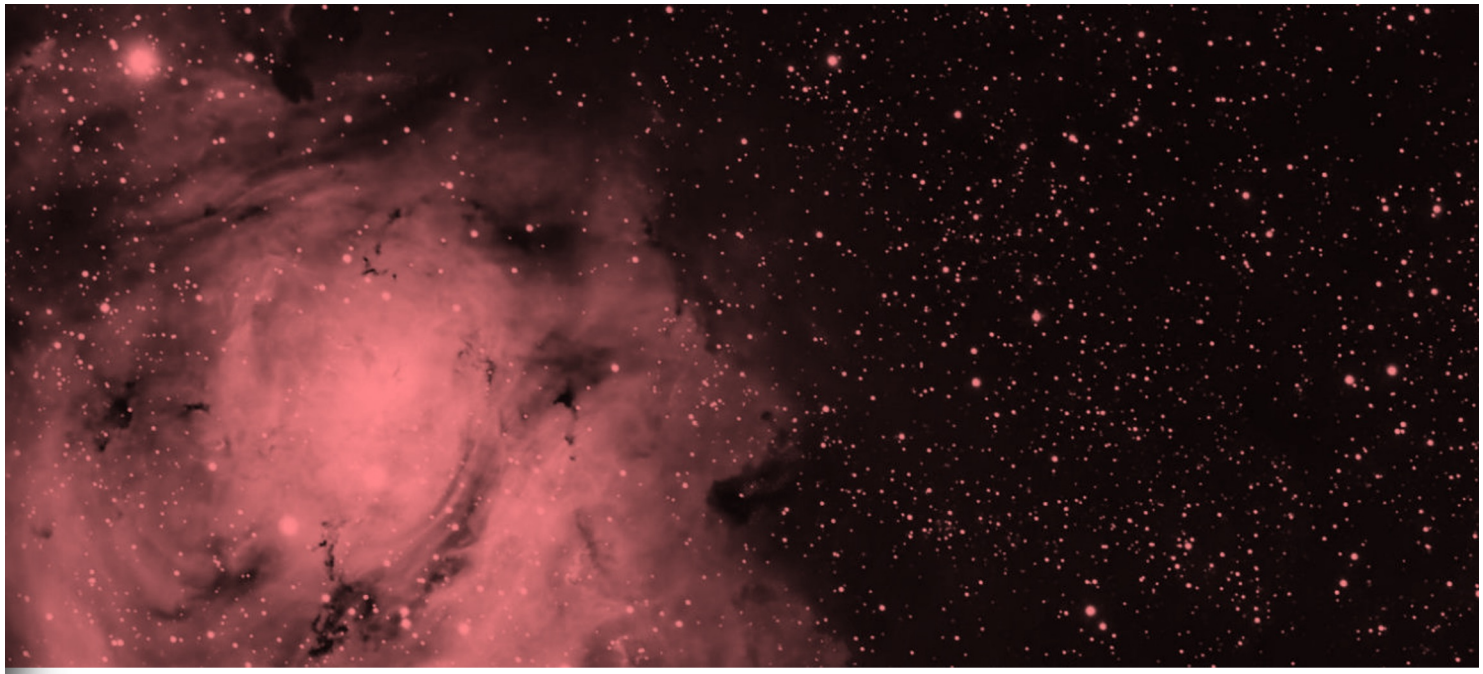

HIP Diffusion Bonding

Bodycote Specialist Technologies Division
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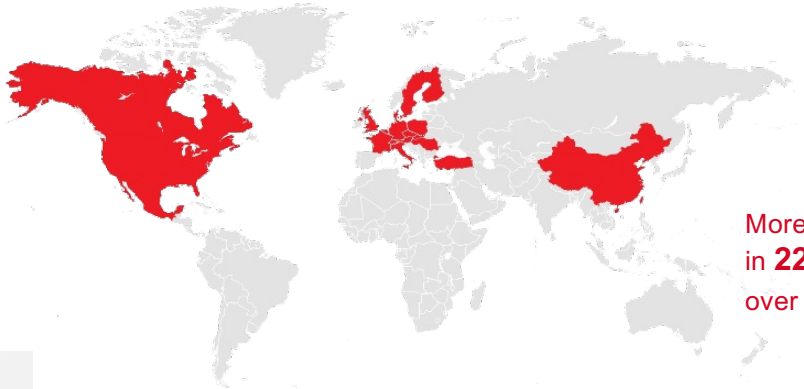
V1.0 06/01/25

Bodycote at a glance

As the world's leading provider of classical heat treatments and specialist technologies, Bodycote provides its customers with value-adding services which improve their components.



Bodycote

More than **165 locations** in **22 countries** serving over **40,000 customers**

Our technologies

Precision Heat Treatments

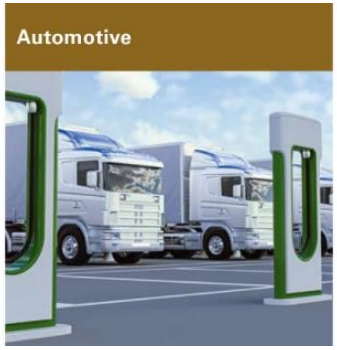
A group of heat treatment processes used to improve the properties of metals and alloys, and metal joining technologies which are used to join and assemble parts.

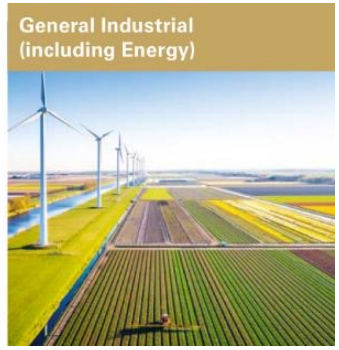
Specialist Technologies

A group of highly differentiated and proprietary technologies which enable our customers to produce unique high value-adding products.

Over **4,800** Engineers, scientists, technicians and support staff

Our Markets





Some of the biggest names in engineering use Bodycote:

PCC · Rolls-Royce · SpaceX · GM · Tesla · GE

BOY Listed on the **London Stock Exchange** since 1972 » Market capitalisation: approx. £1.3b // 2023 revenue: £803m

HIP Diffusion Bonding

The HIP Spa Experience: Diffusion Bonding Edition

1.Meet the Metal Guests
Two metal pieces arrive at the HIP spa. They're not welded, bolted, or glued—just clean, flat, and ready to mingle.

2.Into the Pressure Chamber
The spa chamber is no ordinary sauna. It's a **Hot Isostatic Press (HIP)**—a magical place where heat and pressure come from **all directions** (isostatic = equal pressure everywhere). Think of it like a cozy group hug from all sides.

3.Crank Up the Heat 🔥
The temperature rises to thousands of degrees—hot enough to make atoms jittery and excited, but not so hot that the metal melts. It's like a dance party at the atomic level.

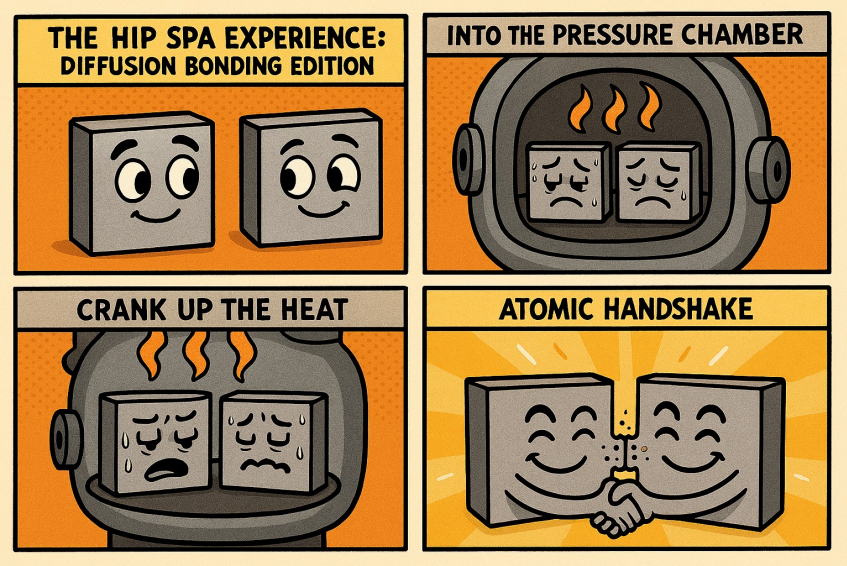
4.Apply the Pressure 💪
Now comes the pressure—up to **2000 bar**! That's like stacking 20,000 elephants on a square meter. This pressure pushes the metal surfaces together so tightly that their atoms start to **diffuse** across the boundary.

5.Atomic Handshake 🤝
The atoms from one piece start mingling with atoms from the other. Over time, the boundary between them disappears. It's not just a bond—it's a **fusion of identities**. They become one solid piece, with no visible seam.

6.Cool Down & Reveal
After the bonding is complete, the spa cools down. The metal emerges stronger, seamless, and ready for action—perfect for aerospace, nuclear, or medical applications.

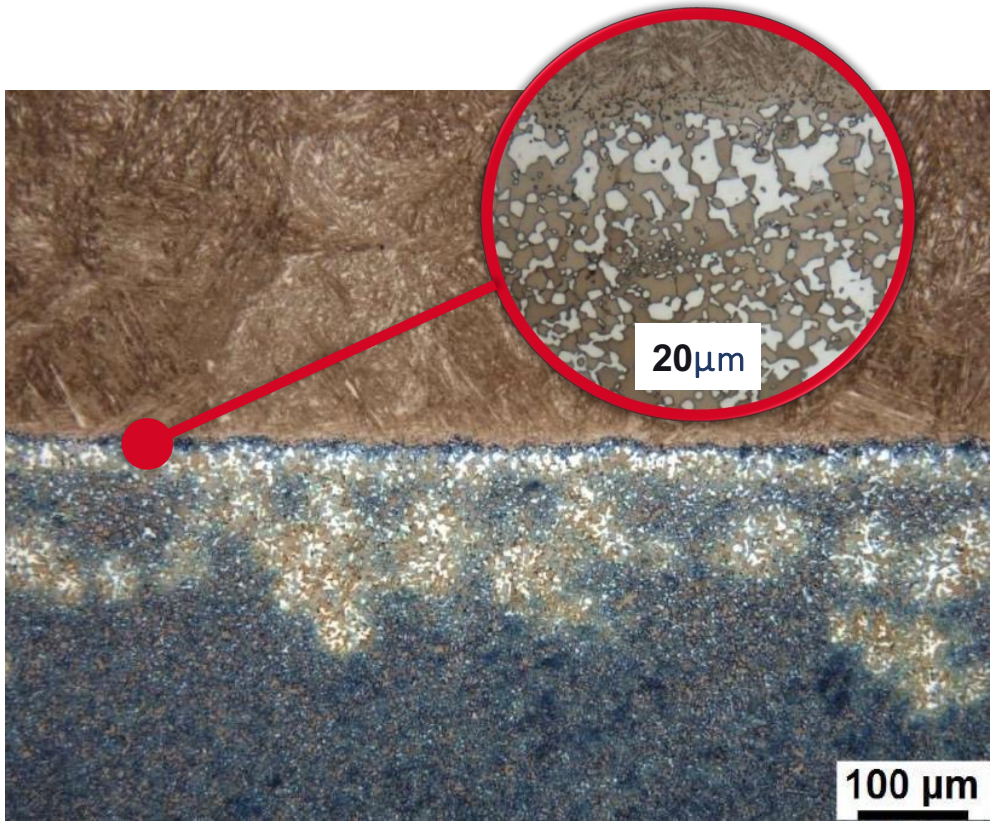
Why It's Cool

- No filler materials or melting.
- Super strong and clean joints.
- Ideal for complex shapes and high-performance parts.



Hot Isostatic Pressing

Bi-Metallic Microstructure



HIP provides a superb diffusion bonding environment

But… this is dependent on material selection

Given the right selection & testing

- Diffusion layer thickness can be controlled
- High interfacial strength can be achieved
- Bonds can be 100% dense
- Where required to reduce residual stress and formation of brittle phases, an interlayer can help

Bi-Metallic Component Design

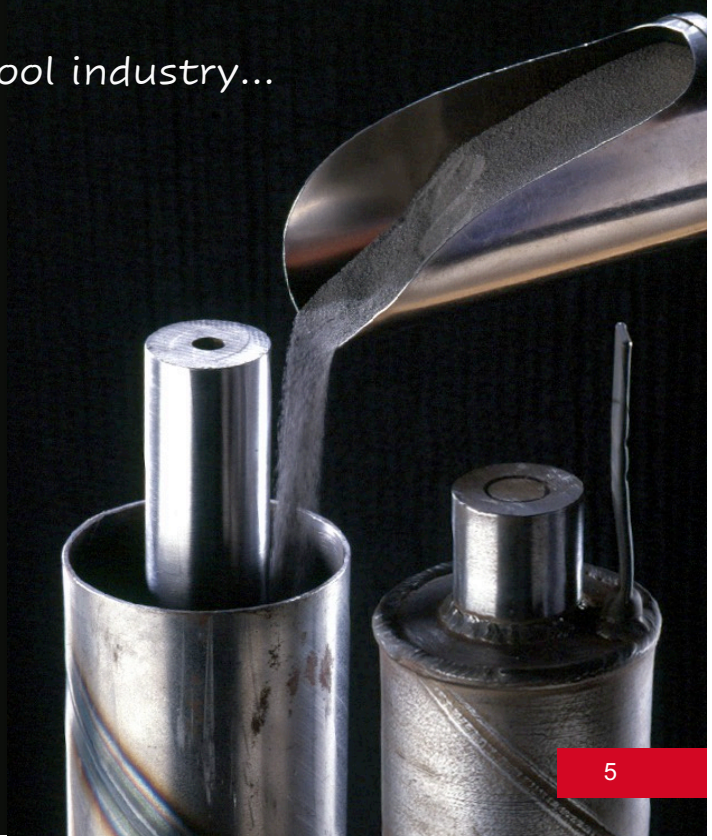
Rather than making an entire part from an expensive alloy, use an alternative material for bulk properties and place a costly wear or corrosion resistant materials only where it is needed

Powder metallurgy allows the use of no more material than is necessary to do the job

Typically, simple shapes for the machine tool industry…

..But we are well experienced in bi-metallic design for special projects such as:

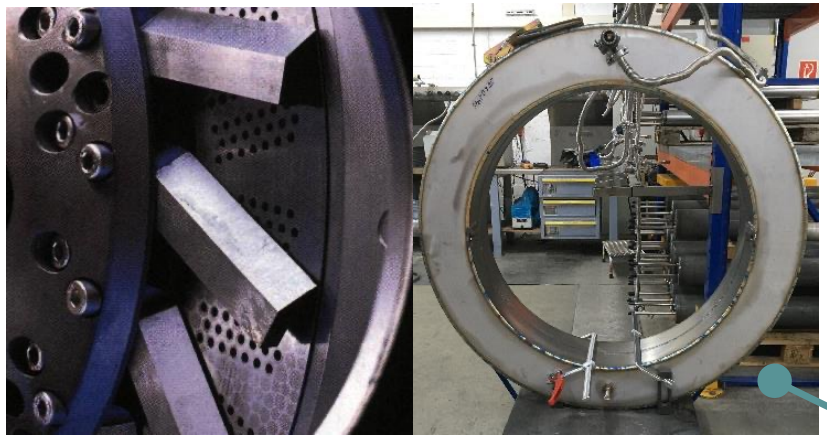
- Diffusion Bonded Wall panels for ITER
- Aluminium Metal Matrix Composite Materials for nuclear fuel cycle
- Wear resistant internals for critical ball valve applications

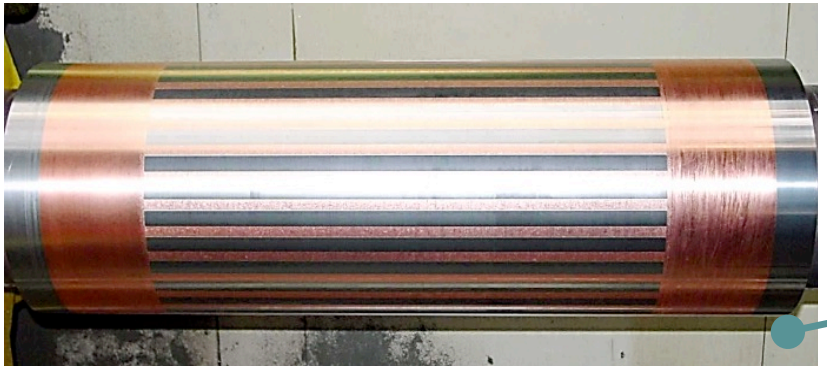


Hot Isostatic Pressing

Bi-Metallic Component Examples

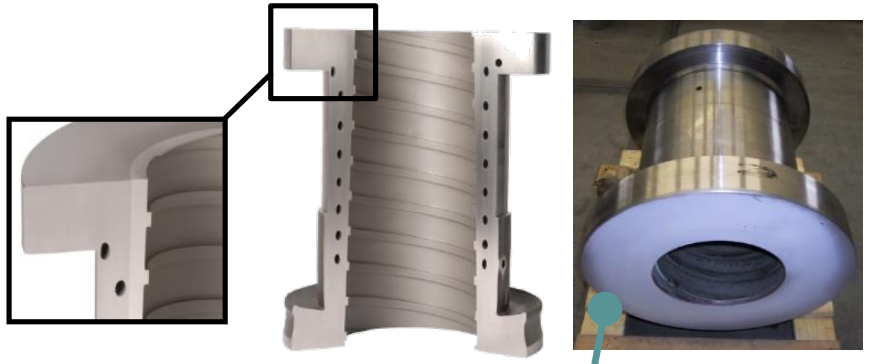
Both Simple & complex near net shapes with bi-metallic arrangements can be created according to customer designs





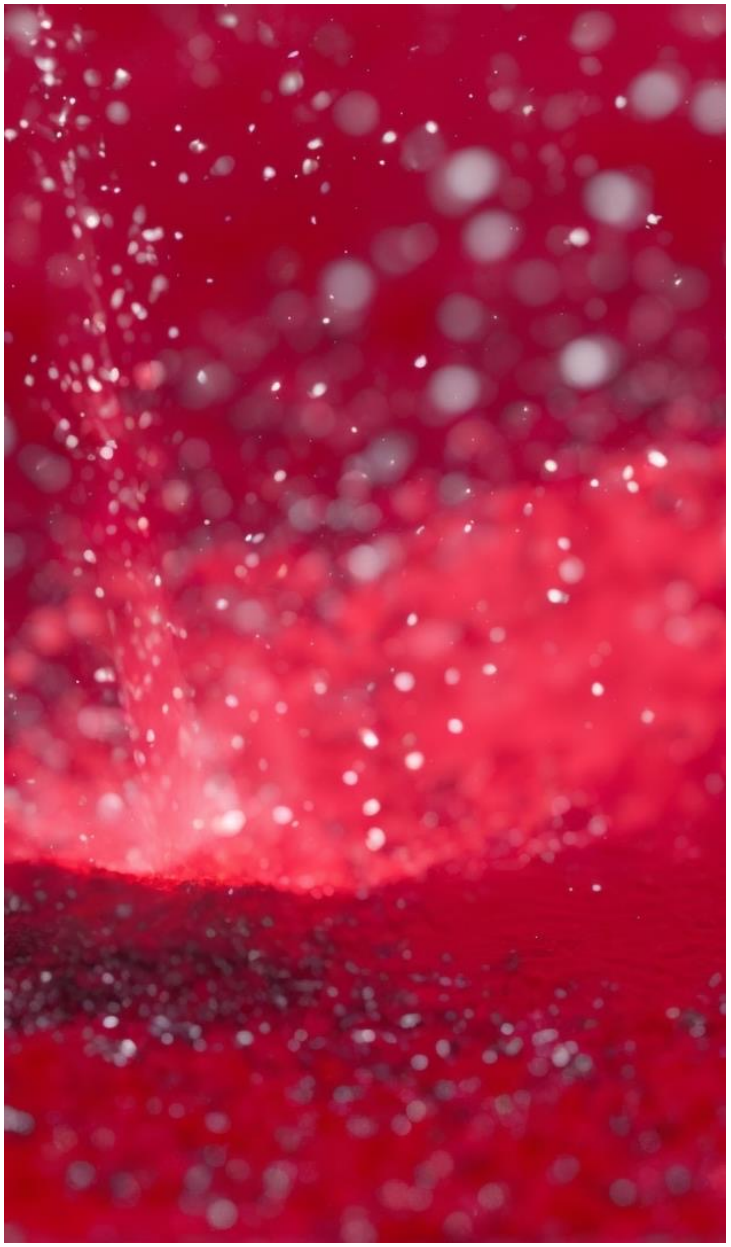
Ferro-Titanit-Segments to steel ring for pelletizer machine

Bonded Steel & Copper for an electromotor rotor



Near-net shape bi-metal component with cooling channels

Bodycote Hot Isostatic Pressing For Nuclear Applications



HIP Product Fabrication

HIP for Nuclear Applications

Bodycote

Nuclear Experience:

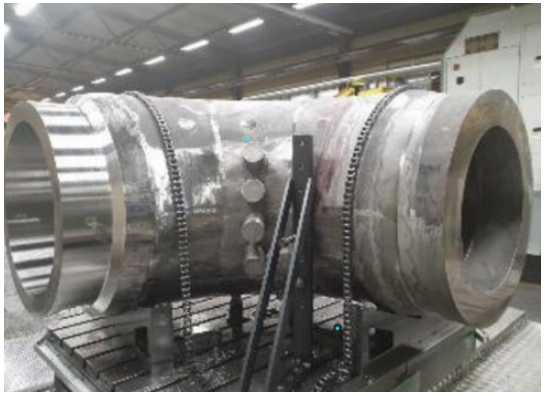
- Raw material and sub-component supplier for Nuclear Submarines
- Delivering innovative diffusion bonded materials for ITER Fusion Reactor
- Working closely with partners on SMR reactor components
- Developed primary circuit pipework demonstrator

Typical Nuclear Materials:

- 304L / 316L & Duplex Stainless Steels (primary components)
- Grade 91 chromium-molybdenum alloy (pressure vessels)
- Cobalt and Nickel based superalloys (bi-metallic cladding)
- Tungsten alloys (plasma facing fusion reactor components)

Hot Isostatic Pressing

Civil Nuclear Applications



Framatome, Primary circuit elbow manufactured via HIP [1]

framatome

Democrite Project

- Process validation for primary circuit pipework manufactured via PM-HIP Process
  - 304L metal powder manufactured in accordance with RCCM code requirements
  - Near net shape mild-steel canister designed, manufactured and filled by Bodycote
  - Powder fully densified to near net shape component using Bodycote Giga-HIP in Sweden
  - Mild steel canister removed via acid pickling and connections machined externally
- Final part displays superior microstructure and mechanical properties vs alternatives

EPRI, SMR Upper Head blank produced via HIP [2]

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

SMR Reactor Pressure Vessel Demonstrator

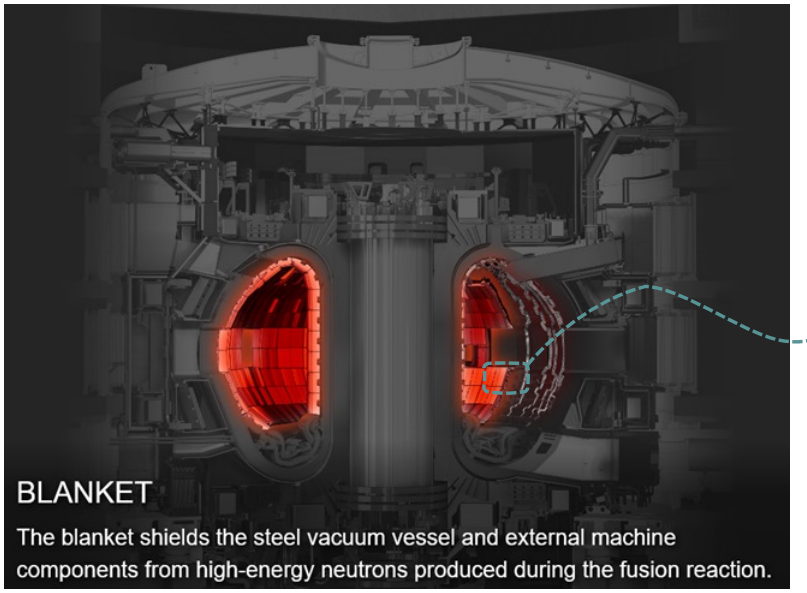
- Demonstration of advanced manufacturing as an enabler for rapid SMR manufacture
  - EPRI, Nuclear AMRC, DOE, NuScale Power funded project
  - 2/3rd Scale RPV Top & Bottom Head manufactured via HIP (HIP Service provided by Bodycote USA)
  - Final assembly used EB welding between HIP components & ring forgings (Sheffield Forgemasters)
- The HIP + Forging + EB manufacture route vastly reduces lead time and risk
- Restriction on HIP vessel size currently available (components up to ~1.6m Dia)

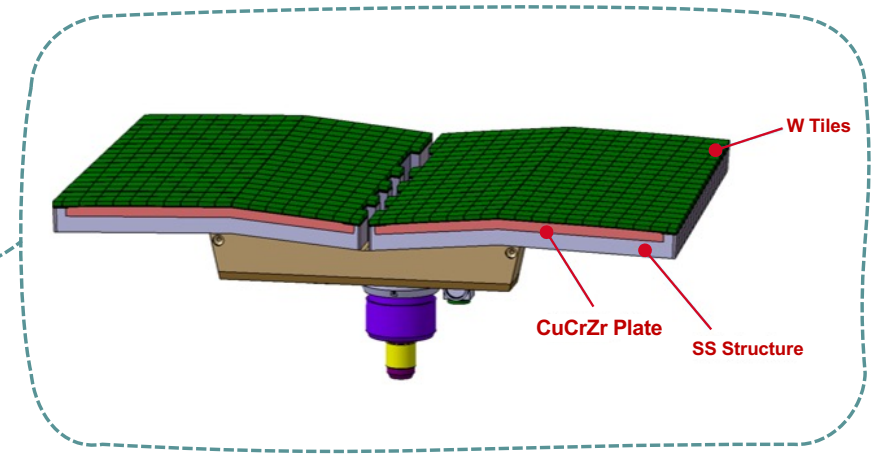
[1] Framatome, Primary circuit elbow manufactured in multi-ton HIP process, Available at: https://www.framatome.com/en/expertise/advanced-additive-manufacturing/ (Accessed 9th December 2024).

[2] Gandy, D. EPRI - Advanced Manufacturing to Enable the Next Generation of Nuclear Plants, Available at: https://www.energy.gov/sites/prod/files/2019/02/f59/ne-amm-gandy-smr-rpv-manufacturing.pdf (Accessed 1st January 2025).

Hot Isostatic Pressing

Fusion Case Study – ITER Blanket first wall panels





THE BLANKET FIRST WALL PANELS:

- Part of the ITER Blanket-Shield system;
  - the innermost part of the reactor
- **Directly exposed to the plasma**
- Provide the main thermal and nuclear shielding.
- EU in-kind delivery consists of 215 first wall panels

Three layers joined by HIP diffusion bonding in 3 stages:

- 40-200 mm thick stainless steel
- 20 mm thick CuCrZr-IG alloy
- 6/12 mm thick tungsten tiles

Disclaimer: The works have been funded by Fusion for Energy under contract F4E-OMF-0900-03. This publication reflects the views only of the author, and Fusion for Energy or Fusion Business Leadership cannot be held responsible for any use which may be made of the information contained therein.

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Thank You