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Microstructure and Mechanical Properties of Different EUROFER Welds

In contrast to austenitic steels untreated welded joints of ferritic-martensitic steels like EUROFER suffer from hardening and embrittlement due to uncontrolled martensite formation in the weld and from softening in the vicinity of the heat affecting zones (HAZ). With respect to specific Test Blanket Module (TBM) design and assembly requirements for DEMO there might be a significant discrepancy between the necessary post welding heat treatment and its applicability. Therefore, Tungsten-Inert-Gas (TIG) with EUROFER filler wire, Electron Beam (EB), and Laser welding have been applied to EUROFER plates in the condition as received. The TIG Weld geometry was a one half V-joint with a 1 mm base. For beam welds 0.5 mm x 0.5 mm beam stoppers have been fabricated at the plate roots.

Prior to specimen fabrication the microstructure of the different welds have been investigated. Both TIG welds show coarse grain formation (Fig.1) which is typical for solidification micro structures that form during the welding cycles. Both beam welds don't show this severe grain coarsening. Also typical for TIG welds are the softened regions in the heat affecting zone as can be seen from the hardness profiles (Fig.2). The lateral extensions of the beam welds are significantly smaller and softening in the HAZ cannot be observed here. From these microstructural examinations it is already clear that these TIG welds need a full two-step heat treatment (austenitization plus annealing) in order to recover a uniform distributed fine grain. This was also confirmed by poor charpy test results (Fig.3). But charpy tests on beam welded specimens have shown surprisingly good results, even without post-weld heat treatment. After heat treatment of 700°C/2h the Ductile-to-Brittle-Transition-Temperature (DBTT) of Laser and EB welds is almost comparable to that of the EUROFER base material (Fig.4). While tensile properties of all welds are comparable to those of the base material (fracture always outside the welding zones), the creep properties of TIG welds are worse due to distinct gliding along the softened HAZ (Fig.5).

Although beam welds promise the best mechanical properties even after just annealing at 700 °C, there are anyway some drawbacks. One is the formation of pores and unbonded areas (Fig.6), and the other one comes from potentially remaining beam stoppers (Fig. 1, lower left image). Both are sources for crack initiation which lead to poor fracture toughness values.

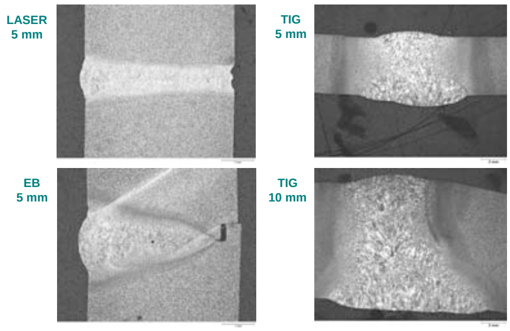

Fig.1: Microstructure of the different welds. It can be seen that the intensity of the EB was too low to for a complete fusion of the beam stopper. Therefore, the V-notch has been placed on this side for fabrication of charpy specimens.

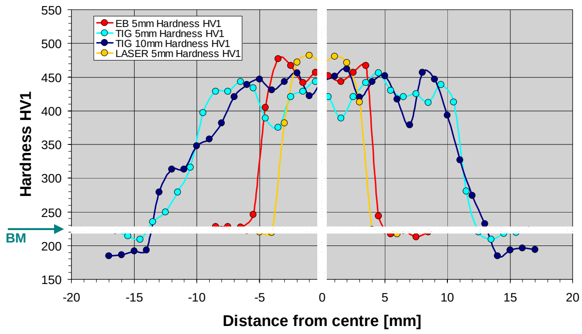

Fig.2: Hardness profile of the different welds. Typical for TIG welds are the softened regions around the HAZ and the broad lateral extensions. The hardness level of the base material is marked with an arrow (BM).

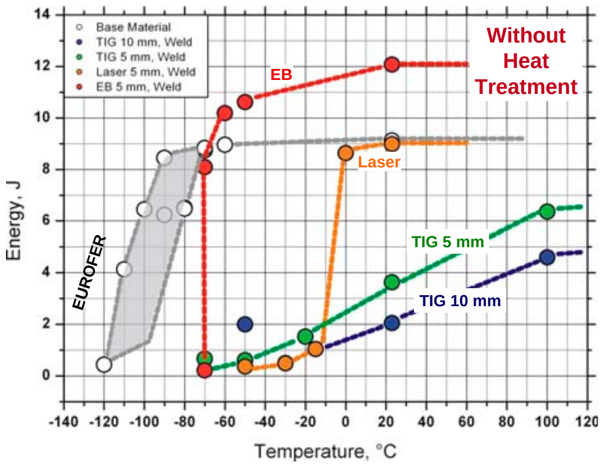

Fig.3: Charpy properties of the different welds without post welding heat treatment. The EB weld is nearly as good as the base material.

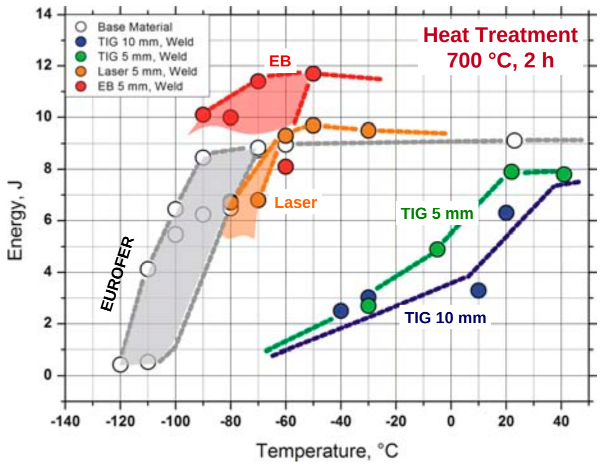

Fig.4: Charpy properties of the different welds after post welding heat treatment of 700°C/2h. DBTT of Laser and EB welds are nearly comparable to the base material.

Fig.5: Creep properties of TIG welds suffer from distinct gliding along softened HAZ. In this example test parameters have been 600 °C, 140 MPa and time to rupture has been 74 h (for comparison, rupture time of the base material is 512 h).

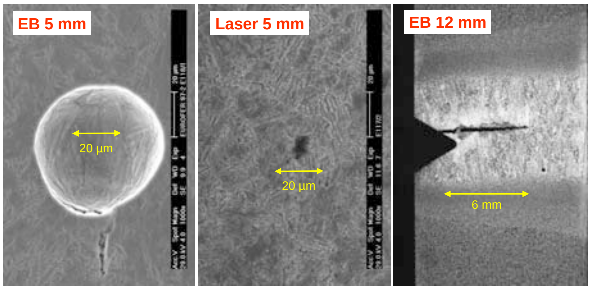

Fig.6: Typical drawbacks of beam welds (especially EB) are pores. In thicker plates even large unbonded areas have been observed (right image).