ELECTRON BEAM WELDING OF TUNGSTEN AND ODS ALLOYS

JAN Vít, ČUPERA Jan, HAVLÍK Petr

Brno University of Technology, Institute of Materials Science and Engineering, NETME Centre, Brno, Czech Republic, EU, jan@fme.vutbr.cz

Abstract

The weldability of advanced heat resistant ODS metallic materials in combination with other materials is a prior requirement for their wider use in industry energy production. A special case is formed by the requirements of the International Thermonuclear Experimental Reactor (ITER) construction, where tungsten alloy needs to be incorporated in weld joint.

Due to heating during conventional welding, the microstructure and properties of the resulting weld joints are affected and the joints often become the weakest point of the structure. The electron beam welding with its reduced heat affected zone size may be an answer in this as it is one of the few techniques able to melt tungsten. The presented article is focused on thorough metallographic evaluation of the structure of heterogeneous electron beam welds which combine stabilized tungsten alloy WL10 with MA956 ferritic ODS steel. EB welded joints were evaluated by light and analytical electron microscopy including EDS analyses in the as-welded. Mechanical properties were evaluated by microhardness profiles. Achieving an appropriate structure of such welds and correct welding parameters are crucial aspects for future successful application of similar joints.

Keywords: Electron beam welding, heterogeneous welds, tungsten joining, ODS, diverter first wall

1. INTRODUCTION

The construction of fusion reactor, such as the ITER that still is under development (although not as well publicized as some years ago) does present almost countless number of materials problems among which the joining of different materials forms a specific group [1, 2]. Often the final part that needs to be manufactured using joining has to work under extreme circumstances and so has the prospective joint. One of the most stressed parts of the toroid space of the reactor is going to be the inner wall lining of the diverter part [3]. Apart from carbon-carbon composites, tungsten is usually considered as the material of choice for the first wall tiling. This is because it is able to withstand the extreme heat conditions and also has low activation ratio. The first wall lining needs to be connected to the second wall that will provide effective heat transfer in order to keep the first wall material at bearable temperatures. Very often these heat sinks are expected to be manufactured out of some kind of strengthened copper alloy. However also the possibility of using ODS steel has been proposed [4, 5]. In such case the question of how the tungsten tile should be connected to the ODS steel substrate arises. This has been attempted for example by means of diffusion bonding without any added material or by means of brazing when adding lower temperature melting alloy in between the tungsten tile and ODS steel substrate [6, 7]. The purpose of the experiments presented in this paper was to evaluate the possibility and feasibility of using electron beam welding for joining tungsten alloy and ODS ferritic steel either with or without intermediate layer of material [8, 9].

2. EXPERIMENTAL

The MA956 was used as the ODS ferritic steel representative and the WL10 as the tungsten material. The chemical compositions of each of the materials may be seen in **Table 1**. The MA956 was purchased in the form of extruded bar of diameter of 18 mm; the WL10 was supplied in the form of individual cylinders 6.3 mm wide and 7 mm long.

Table 1 Chemical composition of the materials by EDS analysis - averaged values (wt.%)

Alloy	Fe	Cr	Al	Ti	C	Ni	Y_2O_3	W	La_2O_3
MA 956	bal.	20.0	4.5	0.5	0.05	0.5	0.5	-	-
WL10	-	-	-	-	-	-	-	bal.	1.0

In total, four samples have been manufactured and evaluated. All samples had the geometry of hollow cylinder made of MA956 with the dimensions of outer diameter 18 mm, inner diameter of 6.3 mm and height of 7 mm. In the hole of this piece the WL10 bulk cylinder of 6.3 mm diameter and 7 mm height was fitted and the whole setup was welded using the Universal chamber machine ProBeam K26 with the following parameters summarized in **Table 2**. Samples numbered 1-3 were welded without any added material with different beam properties, and preheating step before the welding step. Preheating was done using de-focussed electron beam moving rapidly over the sample. Sample 4 was composed with added nickel foil in the interphase. Commercially pure Ni of the thickness of 0.05 mm was used.

Table 2 Parameters of EB welding

sample	combination	preheating	EB parameters
1	WL12 - MA956	no	120 kV, 17 mA, speed 15 mm/s, spot 0.35 mm
2	WL12 - MA956	400 °C	120 kV, 10 mA, speed 15 mm/s, spot 0.35 mm
3	WL12 - MA956	900 °C	120 kV, 7 mA, speed 15 mm/s, spot 0.35 mm
4	WL12 -Ni - MA956	no	120 kV, 15 mA, speed 15 mm/s, spot 0.35 mm

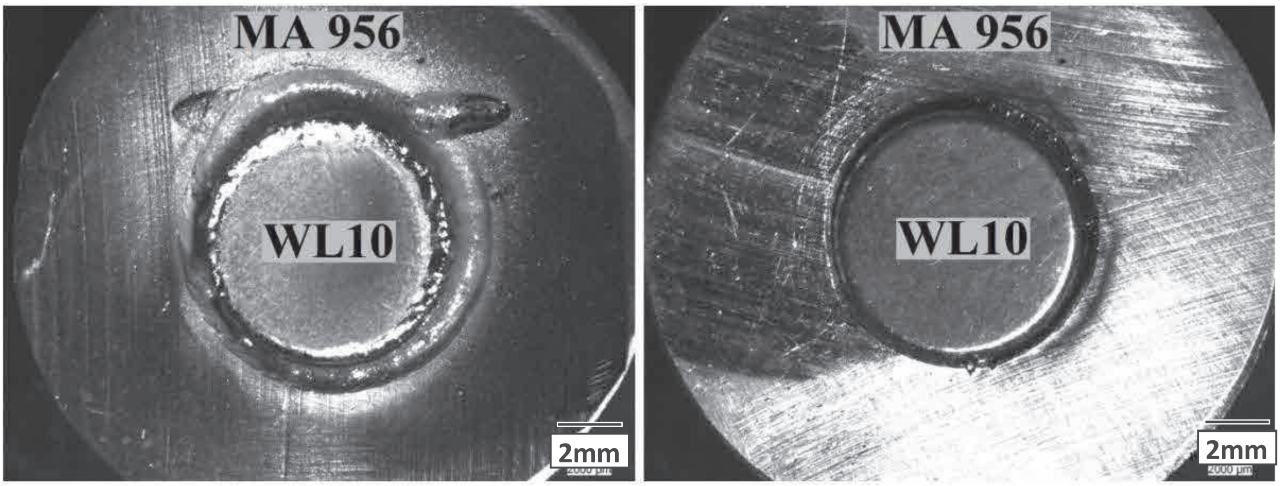

Figure 1 Typical view of the samples from the top (left) and bottom (right) of the joint

After the welding, samples were analysed in the as-welded state. Welds were cut perpendicular to the weld and parallel to the sample axis. Metallographic specimens were prepared and microstructure, microhardness and chemical profiles were evaluated on each of the samples. Microstructures of the whole weld including the base materials were evaluated using light microscopy and scanning electron microscopy. The chemical composition was analysed by means of EDS spectroscope. The alloying elements average concentration was determined and shown in sequences across the welded joints. The Zeiss Axiovert Z1m light microscope and Zeiss UltraPlus SEM with OXFORD analytical complex were used in the analyses.

3. EXPERIMENTS RESULTS

The weld metal of the first three samples was created on the ODS/tungsten interface. While no added material was used, generally the microstructure of the weld metal was homogeneous. The average composition of the weld metal can be seen in **Table 3**. The width of the weld zone was below 1 mm in all of the samples and it usually contained several pores up to 200 µm size. Typical microstructure of the welds samples 1, 2 and 3 without added interlayer may be seen on **Figure 2**. The sample 4 was manufactured with nickel added in the joint. Therefore, the chemical composition of the weld of sample 4 contained nickel and can be seen in **Table 2** too. The microstructure does not differ in macroscale as can be seen when comparing **Figures 2** and **3.**

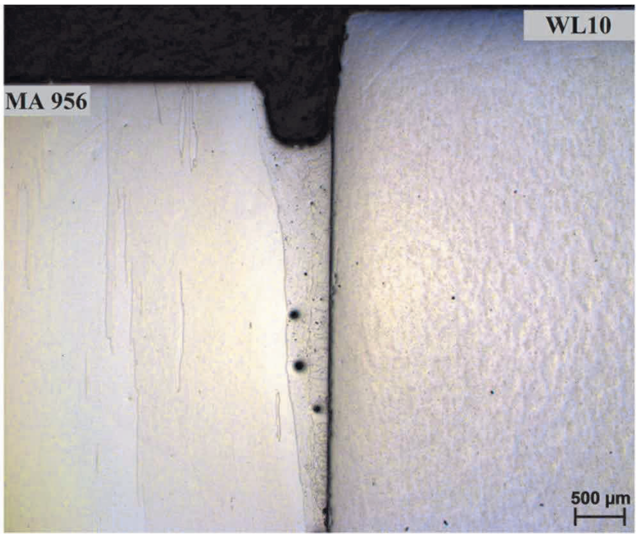

Figure 2 Microstructure of sample 1 (similar to samples 2 and 3 too)

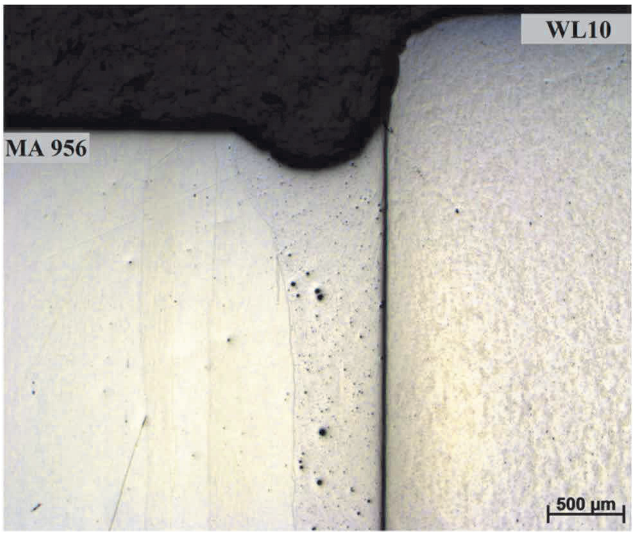

Figure 3 Microstructure of sample 4

Chemical profiles across the welds were measured using line EDX analysis. The resulting profiles show good homogenization of the weld metal across the whole weld. Typical profile valid for samples 1, 2 and 3 can be seen on **Figure 4,** chemical profile of sample 4 is on **Figure 5.** Tungsten has dissolved to certain extent in all cases in the molten metal although this consists by far majority of iron based ODS matrix metal. This indicates that a weld with good metallurgical bond has been created.

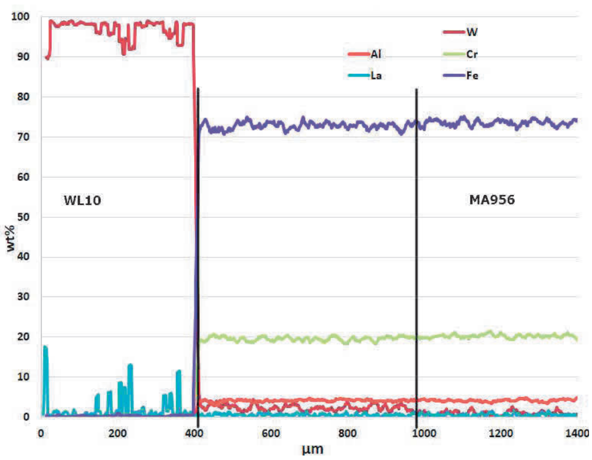

Figure 4 Chemical profile of sample 1 (similar to samples 2 and 3 too)

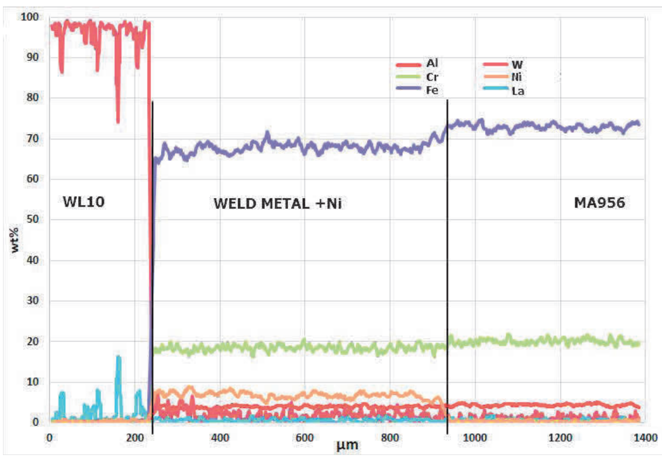

Figure 5 Chemical profile of sample 4

Table 3 Average composition of the weld metals by EDS analysis (wt.%)

Sample No.	Fe	Cr	Al	W	Ni
Sample 1	73	20	4	3	-
Sample 2	73	20	4	3	-
Sample 3	71	19	5	5	-
Sample 4	68	18	4	2	7

The mechanical properties of the weld material were evaluated by means of micro-hardness indentation. Tests measured at HV0.5 showed rather smooth profile of values in case of the three samples without added Ni material in the weld. Also, the hardness profiles did not differ significantly for the three samples with different EB parameters. The hardness of MA956 was below 300 HV0.5 while the weld dropped to 250 HV0.5. The change into 400 HV0.5 region in the WL10 material was gradual and no presence of brittle behaviour was observed at the indents. In sample 4 where Ni was added in the weld, steep increase of hardness was measured reaching 500 HV0.5 however, neither here no brittle behaviour was observed.

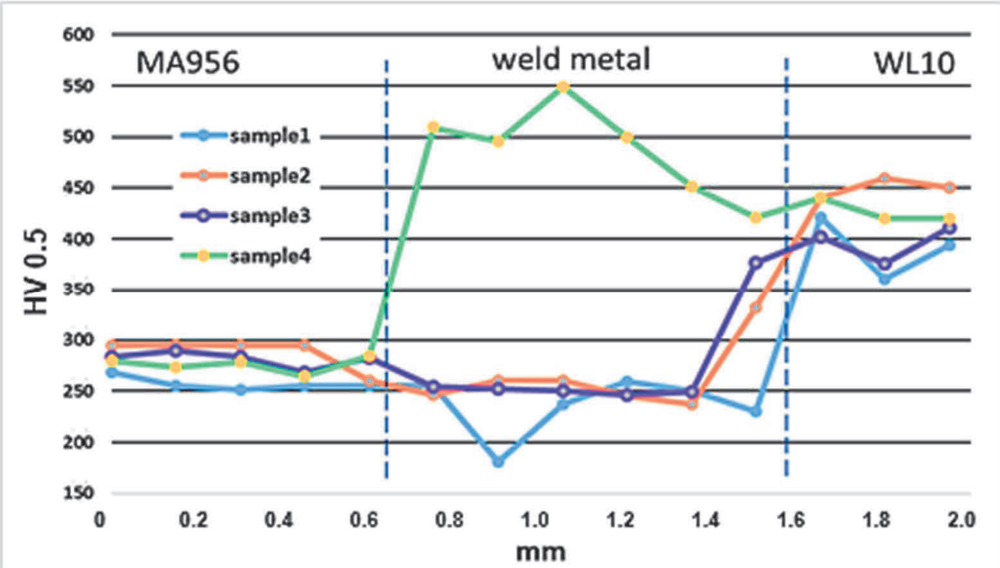

Figure 3 Microhardness of the weld area, weld metal noted by the vertical lines

4. DISCUSSION

In the group of samples where direct contact between ODS and tungsten has been hit with electron beam and welded a homogeneous microstructure with no hardness peak was created. This is promising from the pointy of view of practical usefulness of such joining technique [10]. All joints in this group contained some pores, which is the consequence of non-optimized welding beam parameters. What needs to be still done is the elevated temperature stability evaluation of the weld microstructure [6, 11]. The weld metal consists of majority of the remelted steel material and low content of tungsten originating from minor melted area of the WL10 alloy. The 900°C preheated sample shows the highest content of tungsten in weld metal - 5 wt.%. The sample with added nickel foil shows similar behaviour altered by the nickel presence which resulted in higher hardness values. This may be due to formation of hard phases during relatively fast cooling. Further phase analysis work is planned to understand this behaviour. No effect of the yttrium or lanthanum oxides that are present in the joined materials has been found in the weld metal microstructure. Gradual dissolution of tungsten in the weld metal has been found in all samples in microscale on the weld metal-tungsten alloy interface.

5. CONCLUSIONS

Four samples of ODS steel and tungsten alloy joints have been welded together using electron beam. All samples had formed a weld joint from liquid material combining atoms from the ODS steel and tungsten alloy. Therefore the approach proposed here was proved viable for joining ferritic ODS materials and tungsten alloys, however further evaluation needs to be focused on microstructural stability at high temperatures and general strength of the joints.

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REFERENCES

[1] WURSTER, S. et al. Recent progress in R&D on tungsten alloys for divertor structural and plasma facing materials. *Journal of Nuclear Materials*, 2013, vol. 442, no. 1-3, pp. 181-189.

[2] BOLT, H. et al. Plasma facing and high heat flux materials - needs for ITER and beyond. *Journal of Nuclear Materials*, 2002, vol. 307-311, part 1, pp. 43-52.

[3] NORAJITRA, P. *Divertor Development for a Future Fusion Power Plant*. KIT Scientific Publishing, 2014.

[4] CZYRSKA-FILEMONOVICZ, A., DUBIEL, B. Mechanically alloyed, ferritic oxide dispersion strengthened alloys: structures and properties. *Journal of Materials Processing Technology*, 1997, vol. 64, pp. 53 - 64.

[5] SAROJA, S. et al. Development and characterization of advanced 9Cr ferritic/martensitic steels for fission and fusion reactors. *Journal of Nuclear Materials*, 2011, vol. 409, pp. 131-139.

[6] FILACCHIONNI, G. et al. Structural and mechanical properties of welded joints of reduced activation martensitic steels. *Journal of Nuclear Materials*. 2002, vol. 307-311, pp. 1563-1567.

[7] SUN, Z. et al. The application of electron beam welding for the joining of dissimilar metals: an overview. *Journal of Materials Processing Technology*, 1996, vol. 59, pp. 257-267.

[8] COMMIN, L., et al. "Characterization of ODS (oxide dispersion strengthened) Eurofer/Eurofer dissimilar electron beam welds." *Journal of Nuclear Materials,* 2013, vol. 442, no. 1, pp. 552-556.

[9] RIETH, M. et al. Specific welds for test blanket modules. *Journal of Nuclear Materials*, 2009, vol. 386-388, pp. 471-474.

[10] LINDAU, R. et al. Mechanical and microstructural characterization of electron beam welded reduced activation oxide dispersion strengthened - Eurofer steel. *Journal of Nuclear Materials*, 2011, vol. 416, pp. 22-29.

[11] JAN, V. et al. Microstructure evaluation of heterogeneous electron beam weld between stabilised austenitic and ODS ferritic steel. In: *Materials Science Forum*, Trans Tech Publications, 2017, pp. 185-189.