ELSEVIER

Journal of Nuclear Materials 283–287 (2000) 1192–1195

journal of nuclear materials

www.elsevier.nl/locate/jnucmat

Effects of thermal aging on the mechanical behavior of F82H weldments

A. Alamo [a,*], A. Castaing [a], A. Fontes [b], P. Wident [a]

[a] Commissariat à l'Energie Atomique, CEA-Saclay, CEREM, SRMA, 91191 Gif-sur-Yvette, France
[b] Commissariat à l'Energie Atomique, CEA-Saclay, CEREM, STA, 91191 Gif-sur-Yvette, France

Abstract

The objective of this work is to characterize the mechanical behavior of F82H weldments, which were produced by tungsten inert gas (TIG) and electron beam (EB) processes. Tensile and impact properties were determined for both types of welds in the as-received condition and after thermal aging for 10 000 h at 400°C and 550°C. The mechanical properties of TIG welds and their evolution during aging is quite similar in the base metal (BM). The main difference was given by the impact energy level (upper shelf energy (USE)) of TIG joints, which is about 60% of the BM. EB welds were delivered without post-weld heat treatment. Very scattered results were obtained, particularly for impact properties.

1. Introduction

One of the objectives of the IEA international collaboration is the qualification of F82H reduced activation martensitic steel for structural components of fusion reactors [1]. For this application, technologies related to component fabrication, like welding processes, are considered as relevant technical issues.

F82H steel was produced as two large-scale heats of several tons each. Plates and weldments of different thickness were manufactured in Japan and distributed by JAERI to participants of IEA program. Weldments were produced by tungsten inert gas (TIG) and electron beam (EB) processes.

The aim of this paper is to characterize tensile and impact properties of TIG and EB welds in the as-received and aged conditions in comparison with the base metal (BM). Thermal aging treatments were performed at 400°C and 550°C for 10 000 h to simulate the eventual modifications that could be induced by in-service temperatures.

2. Materials and weldments

EB and TIG joints examined here were produced from plates of 15 mm thick corresponding to the first (no. 9741) and second (no. 9753) heat of F82H, respectively. Their references are RB802-4-5 and RB802-4-6 for EB joints, KG819-2W5 and KG819-2W3 for TIG welds.

Details about chemical composition, processes, welding conditions and X-ray inspection are reported in [2]. After welding, TIG joints were annealed for 1 h at 720°C, but no information was available about a post-welding anneal of EB welds.

3. Experimental

Samples for optical examination were prepared by polishing and etching in Villela reagent. Vickers hardness measurements were performed with a 10 kg load on the cross-section of different welds. Each value given is the average of 10 indentations.

Specimens for mechanical tests were machined perpendicular to the welding direction. In the case of as-received EB welds, tensile properties were also measured parallel to the welding line. Mechanical properties of weldments are compared to those of a BM plate of 15 mm thickness determined along the transverse direction.

* Corresponding author. Tel.: +33-1 69 08 67 26; fax: +33-1 69 08 71 30.

E-mail address: ana.alamo@cea.fr (A. Alamo).

0022-3115/00/$ - see front matter
PII: S0022-3115(00)00100-8

Cylindrical tensile specimens of 2 mm in diameter and 12 mm gauge length were machined in such a way that the weld joint was located in the center of the gauge length with interfaces between the welded zone (WZ) and the BM perpendicular to the tensile axis. The strain rate used was 7×10^4 s^{-1} and the test temperature ranged from 20°C to 650°C.

Impact specimens, also machined perpendicular to the welding line, were Charpy V notch samples 55 mm long, 10 mm wide and 2.5 mm thick. The initial cross-sectional area is 8×2.5 mm^2. In all cases, the notch was centered in the weld metal. Charpy tests were conducted over the temperature range −200°C to +400°C, to produce full transition curves. The ductile–brittle transition temperature (DBTT) was defined as midway between the upper and lower shelves of the transition curves. The accuracy of DBTT values was about ±10°C, except for EB welds that displayed very scattered values of impact energy.

4. Metallurgical characterization

Fig. 1 shows the cross-sections of TIG and EB weldments of 15 mm thickness. The width of the WZ and the heat affected zone (HAZ), measured at mid-thickness, are respectively: about 10 and 4 mm wide in the case of TIG, 2 and 1 mm wide for EB welds.

Both types of welds exhibit a martensitic structure of WZ and HAZ. In the case of TIG joints, the size of prior austenite grains increases from the root (50–70 μm) to the weld cap where very coarse grains (>200 μm) are detected. The welded region of EB joints exhibits uniform grain structure constituted by coarse grains (about 200 μm) in the whole thickness. Regions containing δ-ferrite of variable size (2–20 μm) are observed, especially in the cap of both types of welds.

Hardness measurements (see Table 1), performed in the WZ, HAZ and the BM, show quite similar values in all regions of TIG joints corresponding to the hardness level of the tempered martensite. However, in the case of EB, values measured in the WZ and HAZ are typical of the as-quenched martensite [3] and confirmed that a post-welding anneal was not performed in EB welds.

5. Tensile properties

Table 2 presents the tensile properties measured at 20°C for TIG and EB welds in the as-received condition, compared to the first and second heats of F82H BM, which are the references for EB and TIG joints. The second heat of F82H BM is essentially characterized by higher strength values in the range 20–500°C.

Related to the reference, higher tensile strength and slightly lower elongation values were obtained for TIG joints in the as-received condition. EB joints display lower values of elongation and reduction in area. This point is confirmed by tests performed along the welding line, which showed very high strength (950–1180 MPa) and lower ductility, i.e., 55–60% reduction in area at 20°C and 600°C.

Tensile properties measured after aging at 400°C and 550°C for 10 000 h are shown in Table 2. Compared to the unaged condition, yield stress and UTS values of aged TIG joints are slightly lower showing that some further recovery has occurred during aging. No changes in the tensile strength are observed on aged EB welds. For both types of welds, no significant modifications in the total and uniform elongations are detected, but the reduction in area values tend to decrease after aging at 550°C, as observed in the base metal aged in the same condition [4].

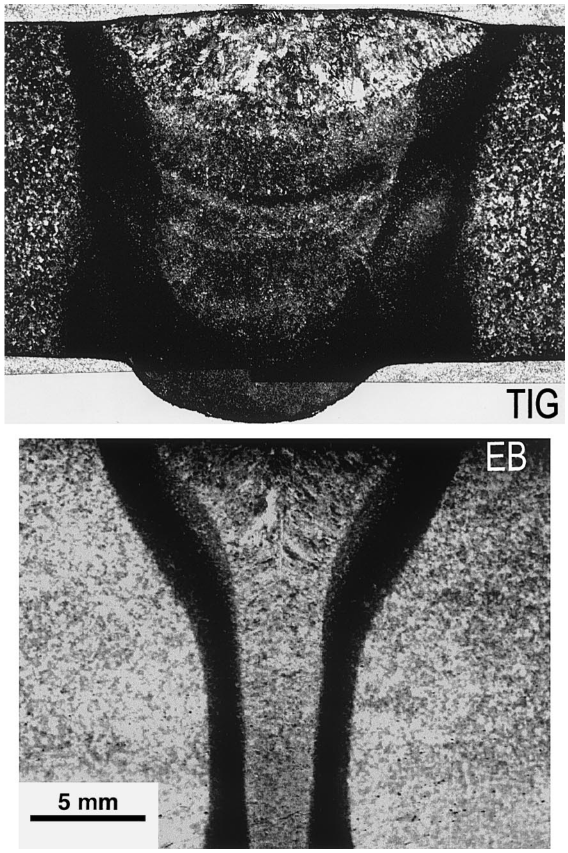

Fig. 1. F82H weldments. Cross-sections of TIG and EB joints.

Table 1
Vickers hardness values (HV10)

Welds	Weld metal	Heat affected zone	Base metal
TIG	220	225	210
EB	390	400	215

Table 2
Tensile properties of the BM, TIG and EB welds determined at 20°C

	0.2% PS (MPa)	UTS (MPa)	Total elongation (%)	Uniform elongation (%)	Reduction in area (%)
As-received					
BM – heat no. 9741	530	629	19	6.0	83
BM – heat no. 9753	581	661–669	18–19	5.0–5.5	83
TIG	621–653	685–709	16–16.5	3.5	83–84
EB	541–549	621–637	12.5–13	2.5–3.0	81
EB (LD)[a]	947–979	1162–1178	11–14	4.0	55–75
Thermal aged					
TIG – 400°C	564–611	655–678	15.5–16.5	4.0	82
TIG – 550°C	558–601	657–680	14–16	4.0	74–76
EB – 400°C	530–546	641–655	12–15	2.5–4.0	80–83
EB – 550°C	516–601	629–637	11.5–17	2–5	76

[a] All values were obtained along the transverse direction of welds and BM, except for EB(LD) where they were measured along the welding line.

The width of the TIG welded zone (about 10 mm) is comparable to the gauge length (12 mm) of tensile specimens. Thus, these tensile tests adequately characterize the TIG welds and their evolution. In the case of EB joints, their width (about 4 mm), represents 30% of the gauge length. Due to the major contribution of the BM, the type of specimens used here are not appropriate to study the evolution of EB tensile properties after thermal aging.

6. Impact properties

Charpy V specimens were obtained from welds and the BM perpendicular to the rolling direction, that is with TL orientation. Several specimens were machined from the cross-sections of welds with the notch centered in the weld metal.

Fig. 2 shows the impact transition curves determined for the BM and both types of welds in the as-received condition. Compared to the former, TIG joints exhibit lower upper shelf energy (USE) and lower values of DBTT.

In the case of EB welds, a great number of tests were performed because of the significant scatter in results obtained throughout the temperature range. As shown in Fig. 2, the impact energy spreads out from 10 to 65 J at room temperature and reaches higher values in the range 100–200°C. This scattered behavior could be directly related to the high hardness level (400 HV) exhibited by EB joints due to the lack of post-weld annealing. Consequently, it was not possible to determine the typical parameters, DBTT and USE, to characterize this type of welds. Nevertheless, it seems evident that the DBTT should be greater than or equal to room temperature.

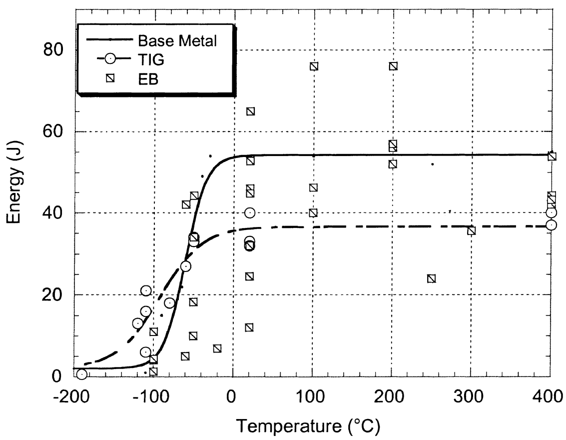

Fig. 2. Impact properties of TIG and EB welds in the as-received condition compared to the F82H BM.

Fig. 3 shows the behavior of TIG welds after aging. They showed a similar evolution as the BM [4], that is, no significant modifications were observed after aging at 400°C, but at 550°C, a shift of DBTT and a decrease in the USE level from 37 to 30 J was detected. Compared to F82H, the main difference of TIG joints is their lower USE level which reaches only about 60% of the USE values corresponding to the BM. The main results are summarized in Table 3 for the BM and weld joints.

EB welds present a quite different behavior after aging. At 400°C, very scattered energy values were obtained as in the case of as-received EB joints. In contrast, after aging at 550°C for 10 000 h a regular transition curve is obtained having a DBTT of −50°C and USE level of 38 J as shown in Table 3. This condition of aging certainly induces a recovery of the EB weld structure producing a higher USE level with the same DBTT compared to TIG welds.

Table 3
Impact properties of TIG and EB welds compared to the F82H BM

	As-received		Aged 10 000 h at 400°C		Aged 10 000 h at 550°C	
	DBTT (°C)	USE (J)	DBTT (°C)	USE (J)	DBTT (°C)	USE (J)
Base metal	−60	55	−50	55	−30	50
TIG	−90	37	−85	35	−50	30
EB	⩾ 20	–	20/70	–	−50	38

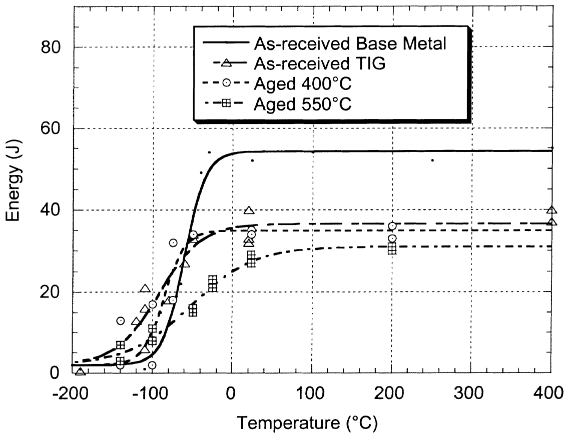

Fig. 3. Impact properties of TIG welds thermal aged for 10 000 h at 400°C and 550°C compared to the as-received condition and the as-received F82H BM.

7. Conclusions

The mechanical behavior of F82H weldments in the as-received and thermal aged conditions were characterized by hardness measurements, tensile and impact tests. Welds were produced by TIG and EB processes from F82H plates of 15 mm thickness. The main results are summarized as follows:

- TIG welds were delivered in the post-weld heat treated condition. In contrast, hardness values showed that no post-weld annealing was performed for EB.
- Compared to the BM, TIG welds were characterized by:
  - Similar tensile strength and slightly lower ductility values before and after aging. A decrease in the reduction in area of TIG specimens was observed after aging at 550°C.
  - Lower DBTT values and lower USE levels in both as-received and aged conditions. No significant changes were induced on impact properties by aging at 400°C, but a small shift of the DBTT and a decrease of USE was detected after aging at 550°C. USE level of TIG welds reaches 60–65% of the USE level corresponding to the base metal for all cases considered here.
- EB welds presented lower ductility and very scattered impact properties, which were related to the lack of recovery of the as-welded structure.

References

[1] A. Kohyama, A. Hishinuma, D.S. Gelles, R.L. Klueh, W. Dietz, K. Ehrlich, J. Nucl. Mater. 233–237 (1996) 138.
[2] K. Shiba, in: Proceedings of the IEA Working Group Meeting on Ferritic/Martensitic Steels, 19–20 September 1995, Baden, Switzerland, Report ORNL/M-4939.
[3] A. Alamo, J.C. Brachet, A. Castaing, C. Lepottevin, F. Barcelo, J. Nucl. Mater. 258–263 (1998) 1228.
[4] Y. de Carlan, A. Alamo, M.H. Mathon, G. Geoffroy, A. Castaing, these Proceedings, p. 672.