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Mechanical Characterization of Dissimilar Alloys Joined using Electron Beam Welding: Technical Note

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ABSTRACT:

Electron Beam Welding (EBW) is used in various industrial applications for joining dissimilar metals due to its accuracy and good quality joints. International Thermonuclear Experimental Reactor (ITER) is the first experimental fusion power generating reactor in India. It uses a host of metals and alloys like Ti-6Al-4V, Ni-Al bronze and a special copper alloy (CRZ). This investigation aims to study the metallurgical and mechanical aspects of CRZ alloy and its EBW joint with a dissimilar metal like Nickel and stainless steel. Characterization includes material composition and effect of heat-treatment. The CRZ alloys were solution annealed at the temperature of 980◦C for 15 minutes and then aged at 460-480◦C for 4.5 hrs. The EBW welded joints were fabricated with CRZ-CRZ, CRZ-Ni and Ni-SS combination. The microstructure and mechanical properties were analyzed.

KEYWORDS:

Mechanical properties; Electron beam welding; Microstructure; Annealing; Copper alloy

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1. Introduction

In ITER the copper alloys are used in the regions where high heat flux observed have to be removed using heat sinks due to their excellent thermal conductivity [1]. Precipitation-Hardened (PH) and Dispersion Strengthened (DS) copper alloys are used in thermo nuclear application. In this investigation heat treatment processes such as solution annealing (SA) and solution annealing and aging (SAA) were carried out to improve the hardness of Cu-Cr-Zr samples [2]. In SA, the material has been exposed up to 980°C with the dwell time of 15 minutes and followed by rapid water quenching. In SAA, the samples were heated up to 475°C with the dwell time of 4.5 hours followed by natural cooling [3-4, 8]. After this heat treatment process, the materials have undergone tensile and hardness tests followed by microstructure analysis [5].

2. Experimental Work

Initially the tensile test is conducted on the Cu-Cr-Zr alloy samples at room temperature (RT) around 20°C to 30°C using in UTM with the cross head velocity of 2mm/min [6-7]. In hot tensile testing, the alloy samples are heated in various temperatures ranges such as 200^{o}C, 300^{o}C, 400^{o}C and 500^{o}C soaking time for 20 to 30 minutes. The test results are listed in Table 1. During SA process, the plate samples were heated to 980^{o}C for 15 min and sudden quenching was done in water [9]. The tensile samples are prepared as per ASTM E8M standard. The size of the tensile test specimen is 100mm long, 25mm Gauge length and 6 mm thickness. After SA, the samples are tested for hardness change at a load of 10kg for 10seconds. The results are given in Table 2.

Table 1: Hot tensile test results for Cu-Cr-Zr samples

Heat	Temp. °C	UTS [MPa]	YTS [MPa]	% Elongation
B910	RT	419.31	288.27	23.54
B908	200	393.48	286.25	22.82
B890	300	339.03	255.45	20.56
B911	400	289.57	227.08	21.12
B907	500	240.8	199.62	28.36

The Cu-Cr-Zr tensile test specimens were SAA at the temperature range of 450°C for a period of 4.5 hours and then allowed to cool in ambient condition [10]. The SAA samples are prepared for tensile test as per ASTM E8M standard and also tested for Vickers hardness at a load of 10kg for 10seconds. The results are quoted in Table 3. After tensile test of SA and SAA samples, they are prepared for identifying microstructure as per standard metallurgical procedures [11]. The etchant used is 100ml of distilled water, 6g of K2 Cr2 O7, 8ml of H2 SO4 and 4 drops of HCL. These microstructure images of SA and SAA sample are shown in Figs. 1 & 2 respectively.

Table 2: Tensile test results of SA Cu-Cr-Zr

Heat	UTS [MPa]	YTS [MPa]	% Elongation	ASTM grain size No	Grain size dia.	VHN
B911	228.88	157.35	49.92	5.16	60.07	69.5/71.1
B908	229.67	157.89	55.39	6.04	44.28	75.4/77.2
B907	226.88	155.83	53	4.69	70.7	66.5/64.1
B904	245.62	168.86	48.32	5.44	54.52	63.5/69.2
B909	224.13	154.42	54.48	4.7	70.46	69.5/73.9
B903	234.52	161.23	57.2	5.55	52.48	71.9/73.2

Table 3: Tensile test results of SAA Cu-Cr-Zr

Heat	UTS [MPa]	YTS [MPa]	% Elongation	ASTM grain size No	Grain size dia.	VHN
B911	406.676	279.58	28.88	4.63	72.19	147/147
B908	412.846	283.82	36.64	5.28	57.63	151/144
B907	397.09	272.99	36.39	5.32	56.83	138/134
B904	405.59	278.80	30.88	5.25	58.23	144/141
B909	407.48	280.14	31.88	5.84	47.46	148/152
B903	409.22	281.33	37.28	5.1	61.34	150/144

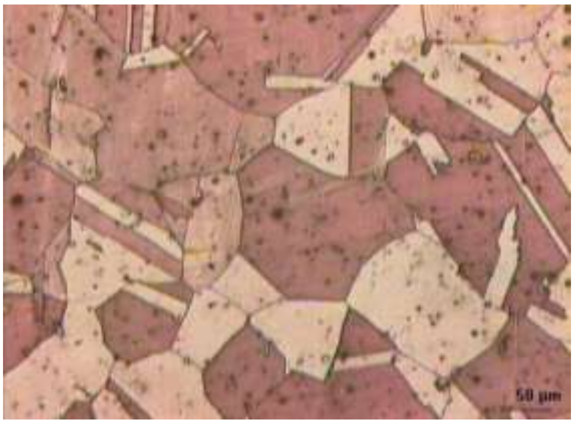

Fig. 1: SA samples microstructure of SA samples

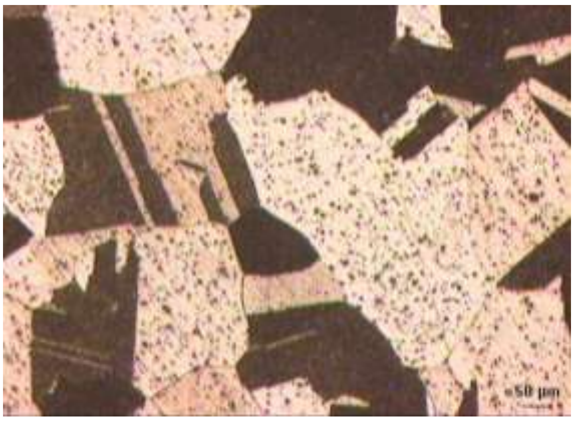

Fig. 2: Microstructure of SAA samples

Fig. 3: EBW Cu-Cr-Zr-Cu-Cr-Zr plate samples

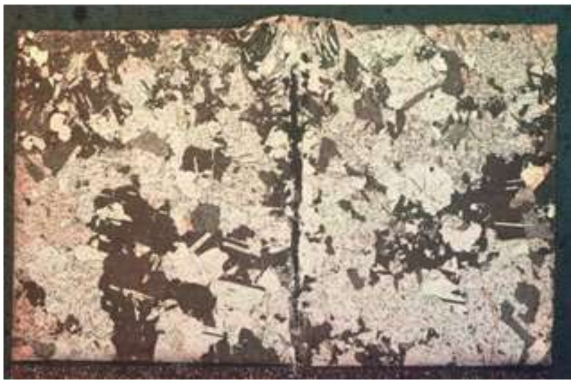

Fig. 4: Microstructure for EBW Cu-Cr-Zr samples

Before EBW, the metal is SA treated at 980°C for 15 min and followed by sudden water quenching to improve the weld ability between Cu-Cr-Zr to Cu-Cr-Zr [12]. The EBW welded Cu-Cr-Zr - Cu-Cr-Zr plates are shown in Fig. 5. The EBW welding Cu-Cr-Zr specimens were subjected to aging at 475°C for 4.5hrs and followed by natural cooling. After that the samples are cut in Electrical Discharge Machine (EDM) as per ASTM E8M standard [13]. The hardness tests were carried out using Vickers hardness machine at the load of 5kg for 10 seconds. The etchant used is 100ml aqueous solution having 6g of K2 Cr2 O7, 8ml of H2 SO4 and 4 drops of HCL. The tensile test results of Cu-Cr-Zr samples are shown in Tables 4 and 5. The EBW welds were subjected to micro hardness survey as shown in Fig. 6.

Table 4: Tensile test results for Cu-Cr-Zr EBW samples – SA

UTS [MPa]	YTS [MPa]	% Elongation
229.073	156.205	35.240
230.665	158.661	35.759
227.118	156.917	55.399

Table 5: Tensile test results for Cu-Cr-Zr EBW samples – SAA

UTS [MPa]	YTS [MPa]	% Elongation
377.939	258.935	28.08
372.799	254.523	27.84
361.880	247.822	31.72
359.513	247.425	26.20
354.543	241.846	35.08

Fig. 5: EBW tensile samples

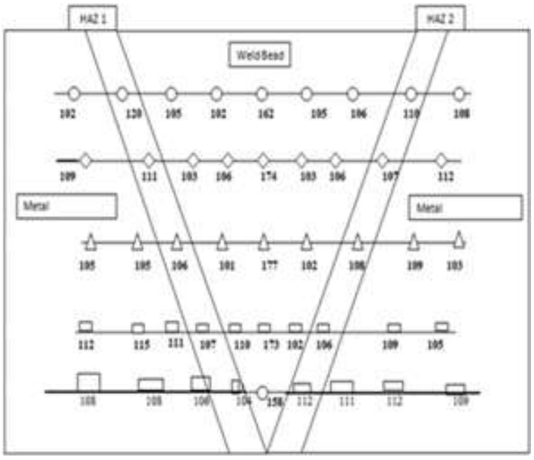

Fig. 6: Hardness survey for Cu-Cr-Zr EBW specimen

3. Discussion

The ultimate and yield tensile strength vs. temperature for various temperatures is shown in Fig. 7. The UTS and YTS decrease when the temperature increases [15]. The VHN results are shown in Fig. 8. It is observed that the smaller size yielded high hardness content. Hardness is found to increase about two folds after ageing [16-18], and decreases after solution annealing, as expected from theory. Decline in grain size also increases the hardness. The average hardness values are:

- SA: 70.54 VHN
- SAA: 146 VHN

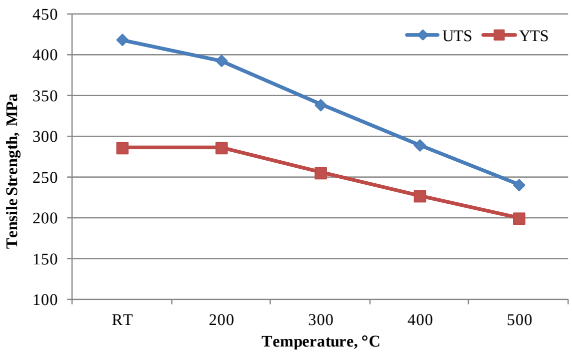

Fig. 7: UTS & YTS vs. Temperature for SAA of Cu-Cr-Zr samples

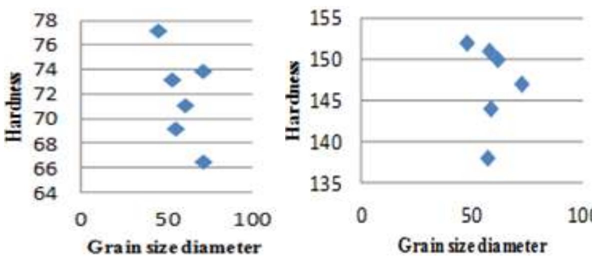

Fig. 8: Grain size diameter vs. Hardness of Cu-Cr-Zr samples, SA (Left) & SAA (Right)

4. Conclusion

This investigation on the Cu-Cr-Zr alloy involves the studies on the Cu-Cr-Zr base material and the effect of heat treatment on Cu-Cr-Zr. The Electron Beam Welding (EBW) was carried out on similar material of Cu-Cr-Zr - Cu-Cr-Zr and the influence of temperature in the tensile strength of the weldment and the influence of grain size on the hardness of the heat treated Cu-Cr-Zr were studied. The tensile test results indicated that the Cu-Cr-Zr which has its application in the high temperature environment is capable to exhibit good hot tensile strength. The weldments showed good tensile strength at room temperature, but some loss of tensile strength occurred at elevated temperatures.

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