STUDY OF MICROSTRUCTURE AND HARDNESS OF ELECTRON BEAM WELDED COPPER ALLOY

Ben Austin B Alapatt, Neelesh Ashok

Abstract— **This paper reports a novel idea of metallurgical characterization of electron beam welded Copper-Chromium-Zirconium (CRZ) with stainless steel (SS) 316L by using Ni as an intermediate. EBW weldment was placed through a series of tests, and characterization includes; material composition (macroscopic and microscopic) and hardness survey on different test specimens. Prior to welding, CRZ material was solution annealed at 980°C for 15 min. After welding, the material was placed through a conventional post weld heat treatment cycle; i.e aging at 460–480°C for 4.5 hr.Macro and micro-analysis of the EBW weldments exhibited a columnar grain microstructure with the exception of a reduced Heat Affected Zone (HAZ), and less distortion weld. Mechanical hardness properties were evaluated at various metallographic locations, including the substrate, HAZ, and weld filler material.**

Index Terms— **EBW, weldment, solution annealing, aging, HAZ**

I. INTRODUCTION

The precipitation hardened Copper-Chromium-Zirconium (CRZ) material used in thermonuclear fusion machines is selected for its good thermo mechanical properties at high temperatures, associated with the possibility of industrial assembling by electron beam welding (EBW). However, repeated occurrence of micro cracks which may propagate and then reduce lifetime, was observed. Therefore qualification of a crack-free EBW technique for these Copper alloys is a key issue and requires further investigation of the assembling process.

Joining thick copper alloys with SS using Electron beam welding (EBW) has been found to be a suitable and effective joining method for thick metals. These studies have shown that EBW of thick copper is very challenging, and avoiding welding defects is difficult. The typical welding defects in thick copper are porosity, root defects, lack of fusion, blowholes and run outs.

EBW has been developed for many years and is being increasingly implemented in various industrial applications for joining dissimilar metals. EBW has special features of high energy density, accurately controllable beam size and location. It has been an efficient way of joining dissimilar metals [1].

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II. LITERATURE REVIEW

In general, the manufacturing processing of CRZ alloys includes casting, hot rolling, solution treatment, water quenching, cold deformation and aging. Copper and copper alloys are widely used as heat sink material because of their excellent thermal conductivity [2] , outstanding resistance to corrosion, ease of fabrication as well as good strength and fatigue resistance[3,4]. CRZ alloy has attracted considerable interest recently because of its superior combination of high electrical conductivity and high strength. It has been used for many areas such as trolley wire, electrode for resistance welding and leads frame materials The high electrical conductivity is due to the very low solubility of Cr and Zr in Cu [5] whereas the excellent strength is attributed to precipitation and particle-dispersion strengthening mechanisms. Precipitation of Cr and Cu_5Zr in copper matrix [6]. Zirconium plays an additional role of fixing elemental sulphur and suppresses dynamic embrittlement [7].In order to control the microstructure, improve the properties of such alloys and optimize the production techniques, identifying the composition of the phases in the Cu–Cr–Zr alloy is of great value. However, there has no unanimous agreement on the precipitation of the alloy [6]. The solubility of Cr in Cu is approximately 0.55% at 1038°C and less than 0.05% at room temperature. The phase that form during age hardening is almost pure chromium. Chromium coppers can develop a combination of high strength and conductivity. Chromium can form a refractory oxide on the molten weld pool that makes oxy fuel gas welding difficult unless special fluxes are used.

The study of this alloy, after proper thermo-mechanical treatments, revealed that significant gains in tensile properties accrue from small additions of chromium and zirconium. Also, two kinds of second phase particles were observed: (a) coarse particles that formed during solidification of the alloy and dissolved only partially during the solutionising treatment and (b) chromium rich ordered *bcc* precipitates resulting from the decomposition of the supersaturated solid solution. The precipitation was, however, seen to take place through the formation of solute rich clusters that evolve, on further aging, into metastable ordered *fcc* precipitates before attaining their equilibrium status as ordered *bcc* precipitates. A comparison of these results with those on dilute binary Cu-Cr alloys revealed that the addition of Zr to the binary alloy strongly influenced the sequence of precipitation. Because of this, an improvement in the fatigue resistance of the alloy results due to a change in the nature of slip from '*wavy*' in the case of pure Cu to '*planar*' in the case of the ternary alloy [8].

III. OBJECTIVE OF WORK

The main goal of this work is the study of welded component to assure defect free weld in copper alloys.The most important requirement for the weld characterization method will be as follows:

1. To produce welds that should not contain discontinuities that exceeds the acceptance criteria. Examples of discontinuities that can occur are cracks, pores, lack of fusion and incomplete penetration or root defects.
2. Characterization of Weld bead and the heat affected zone (HAZ) in terms of microstructure, and hardness since this should possess promising mechanical properties than parent material to meet the requirements for safe handling.

IV. METHODOLOGY

The experimental procedure consists of material selection, their characterization, welding and parameter optimization and finally mechanical property determination steps. The mechanical and metallurgical properties and their behaviour before and after welding were examined. Characterization include material composition, macroscopic and microscopic. Prior to welding, CRZ material was solution annealed (at 980 °C for 15 min). After welding, the material was placed through a conventional post weld heat treatment cycle, aging (at 460–480 °C for 4.5 hr) heat treatment [9]. Macro and micro-analysis of the EBW weldments exhibited a columnar grain microstructure with the exception of reduced Heat Affected Zone (HAZ), and less distortion weld. Mechanical hardness properties were evaluated at various metallographic locations, including the substrate, HAZ, and weld filler locations.

HEAT TREATMENTS

Solution Annealing (SA)

The process consists of heating the material, CRZ up to a temperature of 980°C for 10 to 15 minutes and followed by sudden water cooling. During this process Chromium and Zirconium materials fully dissolve inside the copper boundaries. Solution annealed material is in its most corrosion-resistant and ductile condition. All samples SA done in resistance coil furnace [10,11].

Aging (SAA)

Aging is a heat treatment technique used to increase the yield strength of malleable materials by heating the material between 450-475°C for 4.5hr followed by natural air cooling. This process is to decompose the supersaturated solid solution into a fine distribution of Cu_3Zr and Cr precipitation [10,11]. Fig.1 is showing the heat treatment of CuCrZr samples.

Figure 1: Heat Treatment of Samples

4.1 WELD MACROSTRUCTURE

All weld samples analyzed through macro scope for getting the weld characteristics like depth of penetration, fusion-zone size and size of heat-affected zone and type and density of weld defects like porosity.Fig.5 is showing the macroscopic view of welding.

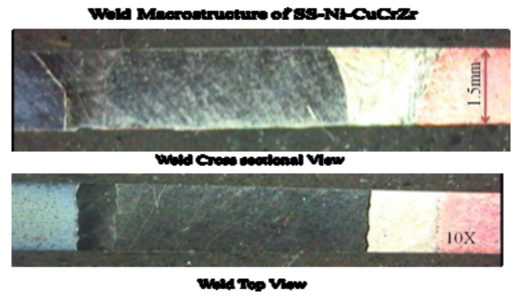

Figure 2: Macroscopic view of weld specimen

4.2 WELD MICROSTURCTURE

The microstructure of the weld zone, parent material and fusion zone of the specimens are shown in Figures. For getting the entire image of weld bead in microscopic view, all images captured in 100X magnification manually and stitched using a software . For each sample 80-100 images have taken for the stitching purpose.

Figure 3: Optical Microscope

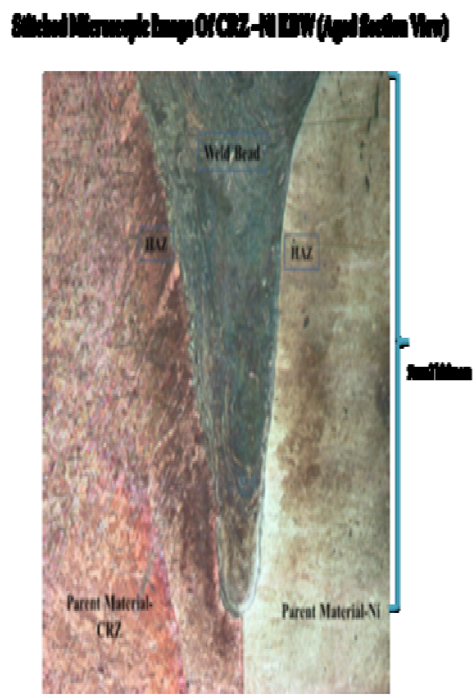

Figure 4: Microscopic view of CRZ-Ni weld specimen

Figure 5: microscopic view of SS-Ni weld specimen

Fig.4 and fig.5 is showing the weld bead cross section of CRZ-Ni and SS-Ni respectively. The portion seeing in the middle of microstructure with conical shape from top to bottom is the weld bead. The spots seen are the inclusions and the carbides. The portion near to weld bead showing small change in color with respect to parent material is the Heat Affected Zone (HAZ).

4.3 HARDNESS SURVEY

All hardness parameters were determined using Vickers hardness method. The Vickers test method uses a diamond shaped indenter pressed into a material using a force of 5000gf for 10 seconds for copper alloys and 10000gf for 10 seconds for Ni and SS. The resulting indentation diagonals are measured, and the hardness number is calculated, by dividing the force by the surface area of the indentation.

Hardness values were measured and Fig.6and fig.7 are showing the variation of the hardness of the specimen at different zone like weld zone, heat affected zone (HAZ) and parent material. The hardness value of the HAZ is greater than the weld zone and parent material, because of the grains in the HAZ is finer than the weld zone and parent material.

But in the case of EBW, total energy is very low and welding velocity is very high because of this, HAZ will be negligible. It shows that, as the energy input to welding speed ratio increases the hardness value of the weld zone is decreasing. The variation implies that as the ratio increases the grain size of the weld zone is increasing. The Q/V ratio and cooling rate is varying inversely. The lower cooling rate infers that the grains will get enough time to grow and form coarser grain and vice versa [12].

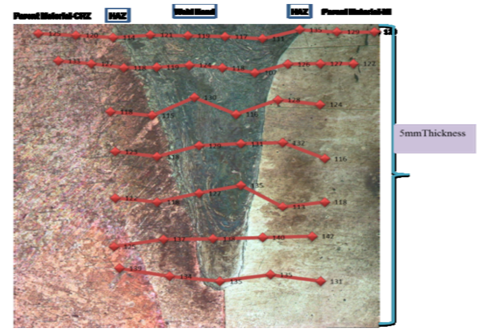

Figure 6: Hardness Profile of CRZ-Ni across the Weld Zone

LAYER	CRZ			WB				Ni		
1	125	120	114	121	119	117	111	135	129	129
2	133	127	118	119	124	118	107	126	127	127
3	-	126	118	115	130	116	128	124	125	-
4	-	-	123	118	129	131	132	116	-	-
5	-	-	122	118	127	135	113	118	-	-
6	-	-	125	137	138	140	142	-	-	-
7	-	-	139	134	135	135	131	-	-	-

Table 5.1. Hardness profile of CRZ-Ni across the weld zone

From table5.1 it is very clear that hardness along the weld bead is coming near to parent material hardness and it is increasing from top to bottom along the cross section. Since the inner portion of weld will cool rapidly compare to outer portion grain elongation will be very less and these small grains will act as barrier for dislocation movement and hardness will get improved.

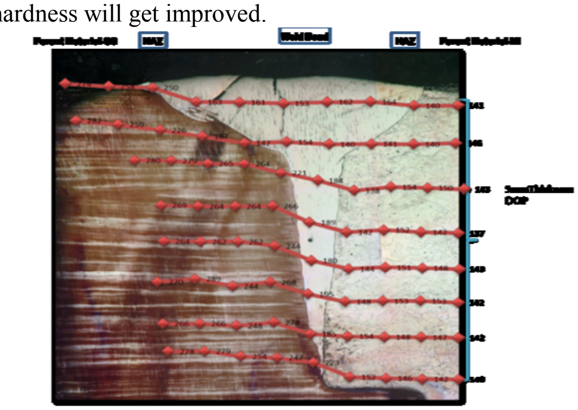

Figure 7: Hardness Profile of SS-Ni across the Weld Zone

LAYER	SS		WB					Ni	
1	258	250	163	161	153	162	164	140	141
2	259	226	187	147	154	140	141	140	146
3	279	265	264	221	184	138	154	150	143
4	274	264	259	233	192	139	149	152	144
5	269	264	264	266	189	142	152	142	137
6	264	262	262	244	180	144	151	148	143
7	270	289	244	268	195	148	153	153	142
8	266	266	248	278	185	154	148	147	142
9	278	279	254	247	223	152	146	142	140

Table 5.2. Hardness Profile of SS-Ni across the Weld Zone

Table5. 2 is showing the increase in hardness value from top to bottom along Weld Bead is because of deceasing size in grain. Grain boundaries will act as barrier for dislocation movement and give more strength with small grain.

SUMMARY AND CONCLUSIONS

CRZ-Ni-SS weld microstructure showed good miscibility throughout the weld. Macro and micro-analysis of the EBW weldments exhibited a columnar grain microstructure with the exception of a reduced Heat Affected Zone (HAZ), and less distortion weld. Hardness survey of Electron Beam Welded samples indicate that the hardness values of weld zone is higher compare to parent material and heat affected zone (HAZ). This clearly distinguishes the weld zone and HAZ; and the in hardness value increase from top to bottom along Weld Bead.

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