



Study the Effect of Changing Applied Voltage in CDW for Welding Dissimilar Materials

Assit. Prof. Dr. Baha .S Mahdi¹, Yasir S. Obaid²
Dept. of Production Engineering and Metallurgy,
University of Technology, Baghdad, Iraq

Abstract: The aim of this paper is to study the effect of changing applied voltage in the capacitor discharge welding process on the metallurgical and mechanical properties carried out by joining two dis-similar materials, low carbon steel (C10) type and brass alloy (60-40) by changing the welding applied voltage from 40 to 90 volt and capacitance bank of (120000) μf . The pin head conical pin head tip configurations of (30 degree) with fixed other variables. To evaluate the joints quality the tests done for the specimens includes tensile strength and stereoscopic images for the fractured surfaces and metallurgical testing by using optical and scanning electron microscope assisted with energy dispersive detector and finally X-Ray diffraction to reveal the generated phases in welding process and comparing this results with local micro-chemical analysis by energy dispersive spectrophotometer. Micro hardness tests were also performed on selected points across the joints section.

Keywords: CDW, Dis-similar welding, stud welding.

I. Introduction

Welding processes are not precisely separated; capacitor discharge welding (CDW) can be considered as one of unconventional welding process used in specific situations [1]. One of those specific appliances, among large amount of others, is welding of wires on different metal structures[2]. Capacitor discharge welding can be regarded as welding process that used both heat and pressures. In all these welding processes it is necessary to be achieved certain proportion of heat input (temperature) and pressure to result a welded joint, considering that it is needed to be applied lower pressure at larger degree heating [3]. The igniter tips, fused into plasma state by Joule's effect and getting narrow melt layers of base metals at the joining surface region, to achieve the final welded joint with the forging forces [7], [8]. The advantage of Capacitor Discharge Welding CDW is regarded as a rapid solidification joining process capable to reach cooling rates up to 10^6 K/s [4] and provides a severe reduction of the heat-affected zone and excellent, geometrical integrity accompanied with lower residual stresses. As well no filler material is needed for the welding process. At capacitor discharge welding it is occurred partial heating of parent material which is melted by heating with electrical arc or in some other cases with electrical resistance. Heating with electrical resistance, material is melting on both sides of parts to be joined, in anode and cathode zone. After this, both components melted in this way, are joining using certain amount of pressure. The geometrical and technological factors are combined to improve the welding efficiency, mainly in terms of mechanical strength. The melt point of two different metals must be in equilibrium in order to control the melting and solidification of joint area, in this work focused on the efficiency of joining different metals by CDW and achieves high mechanical and metallurgical properties [9],[11].

II. Capacitor discharge welding (CDW):

Capacitor discharge welding (CDW) is a high power-density welding Process that its use energy generated from the capacitor [12]. CDW uses heat came from electrical resistance and pressure to create a welded joint between two parts. CD welding can be done in one of the following three different ways: initial contact method, drawn arc method, and initial gap method. The process is initiated by dropping the cathode onto the anode from a pre-determined height. The capacitor bank discharges as a tip on the cathode makes contact with the anode. The tip presents a high resistance to the discharge current and is heated. It disintegrates and generates plasma that melts the surfaces to be joined. The actual welding process takes from 1 to 3 MS. In the initial gap method, there is a gap between the two electrodes with the open-circuit voltage applied. One of the electrodes is then brought into contact with the other (by gravity drop), causing a high flash of current. The initial gap method has been found to be the fastest of the three methods in terms of the actual weld time [4]. Because electrical energy stored in the capacitor is utilized to generate the arc used to melt material, the capacitor discharge welding has significant advantages such as short welding time and small distortions of workpiece. The process include a narrow heat

affected zone, thin weld zones, CDW is a rapid solidification process that provides good weld strength. A fine-grained structure can be formed due to its rapid cooling rate. Filler is not required in this process, so the strength is not changed due to the composite material. CDW can be used for joining dissimilar materials [13]. CDW has limitations as well. The size of part to be welded is a limitation because of the finite energy contained in the capacitor bank. The process can be only applied to electrically conductive materials. Energy stored on capacitors, depends on capacity and voltage be calculated by the following equation [14].

$$E = \frac{1}{2} CV^2 \quad (1)$$

Where: E is the energy of stored capacitance (J), C is regarded a capacitance (F) and V represented the applied voltage (v).

III. Experimental procedure:

Welding of two far properties metals is regard a difficult joint, welding of brass to steel is very difficult process by others traditional welding methods as brazing and cause a lot of welding defects as heat affected zone (HAZ) and irregular welding shape [5]. Capacitor discharge welding process could satisfactory needed of welding specific thickness with very fast cooling rate. The base material used were low carbon steel alloys (C10) and brass wire where the chemical analysis of two metals shown in table (3-1).

Table (1): The Chemical composition of the steel alloys (base material).

Chemical composition of low carbon steel C10 (wt%)								
C%	Si%	Cu %	Mn%	P %	Mo%	Cr%	Ni%	Fe%
0.0476	0.0175	0.0319	0.199	0.0130	0.0038	0.0153	0.0104	remain
Chemical composition of brass wire (wt%)								
Cu%	Zn%	Fe%	Mn%	P %	Sn%	Pb%	Ni%	
58.2	38.8	0.40	0.321	0.132	0.530	0.53	0.310	

The pin materials used in this work is a brass wire traditionally known as 60Cu40Zn as it is chemical composition explained in table (1).The pin brass was a wire with diameter of 3mm. Its end fabricated as conical shape with angle of (30 degree). And the low Carbone steel prepared in a rectangular shape of (60x10x1 mm). Figure (2) show pin head (a) and the steel sheet (b).

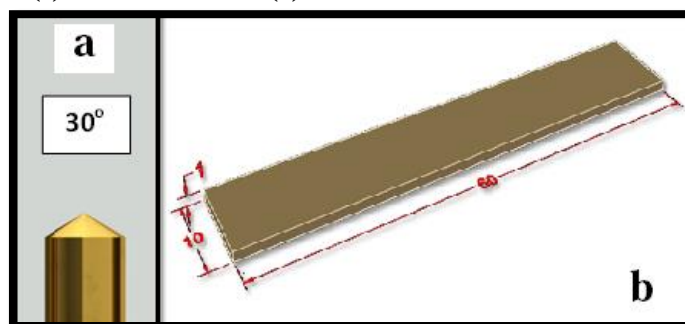


Figure (2) shown;(a) the pin head shape. (b) the steel sheet.

To weld the two dissimilar materials by capacitor discharge welding process there is need welding system. And for this purpose, a machine was assembled from (Variac power supply, series of capacitors, diodes bridge, and voltage digital readers and electrical connectors) used as shown in figure (3). Welding power carried by building a power system contains total capacity of 120,000 μ f. These capacitors supplied with power by a direct current power supply vary from zero to 275 volt but the maximum used voltage was 90 volt because the maximum surge voltage for the capacitors was 100 volt. A power diodes bridge transfers the alternative current to direct current and there is no need for refining the signal because the power capacitors do that perfectly. The pin of brass connected to free guided weight which fixed on 1.5 Newton and the contact done by gravity where the free fall distance is 2 inch and the contact speed was 0.98 m/sec.

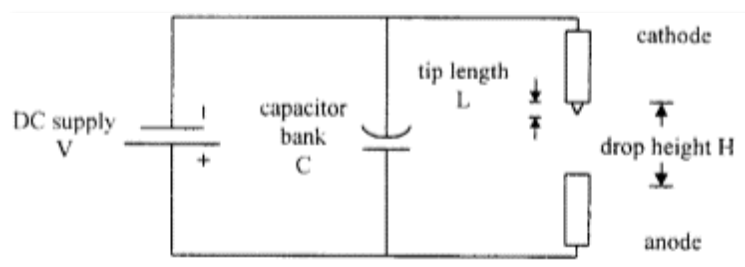


Figure (3): The schematic diagram of the capacitor discharge welding system [14].

The Most important welding variables taken in consideration in this work were three variables: Voltage of welding process in rang (40-90) volt, Capacity of the capacitance bank in the (120000, 105000, 90000, 75000, 60000) microfarads. The other variables had been fixing like welding environment, dead weight of pin housing, speed of shout, the pressure of welding. After welding every joint was prepared for metallurgical tests as microharness and microstructure examination. Welding joint slised near to pin side across steel sheet weld joints were side normally with respect to joint plain and parallel to pin axis. The specimens were mounted using acrylic for easily handling during the preparation processes. Test samples dimensions were (60 × 10 × 1) mm. then samples sliced face grinded using different grades of emery papers from (320 to200) PPI grade Polishing was performed with diamond paste of 0.3 µm grain size on a polishing wheel covered with polishing cloth. Etching was done by immersion for 10 seconds in solution 2% concentration of nitric acid in alcohol. After etching, the joints were washed by tap water and finally by distilled water. Specimen preparations were done according to the ASM Metals Handbook [6]. The weld joints were tensile examined by prepare and fabricate a clamp connected to universal tensile test machine because the welded specimens shown in figure (4) need a special configuration to be tested for tensile test truly. The fractured specimens surfaces were inspected by a stereoscope microscope as shown in figure (5) EDS with X-Ray were used to study the metallurgy of welding in joint layer



Figure (4), joining of pin in 30 degree head shape to plate in rang (40-90) volt.

IV. Results and Discussion:

The results discuss the effect of variables on the welding quality also study the microstructure for the joints layers, Tensile test is the best method for examine the joint quality for mechanical performance perspective, Effect of Welding applied Voltage on Tensile Strength, Table (2) showing fracture tensile strength for specimens at applied voltages from 40 to 90 volt

Voltage	Fracture Tensile Strength (MPa) at 120,000 µf
40	215.0
50	203.7
60	202.3
70	189.6
80	237.7
90	227.8

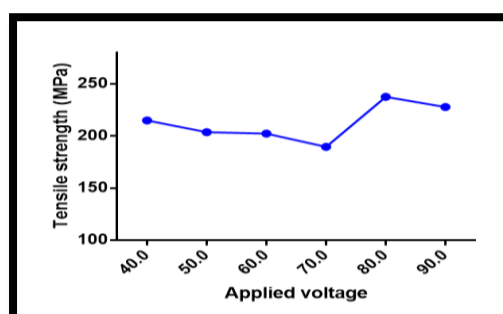


Table (2): Effect of Voltage on Fracture Tensile Strength.

The pin head shape of 30-degree welded joints as shown in figure (3-2) show maximum tensile value of (237.7 MPa) at80 volt of the applied voltage or 400 watt where it can be seen that the fractured welded surface in figure (4-1) was completely welded without any void or bubbles and it's had a regular weld surface. By observing 80V out view there is a metal jacketed stand parallel to pin axis adhere strongly to pin which increase joint strength. In the same time, this jacket may be protecting the joint for instantons oxidation while the joint melted from atmosphere. The construction of this jacket may be caused by the magnetic field generated by passing high current across the joint at contact period where this current pass from the sheet (Cathode) to pin (Anode) with a short

time. Therefore the strong magnetic field parallel to the pin axis will attract the excess melted metal toward the pin generating this cup like shape.

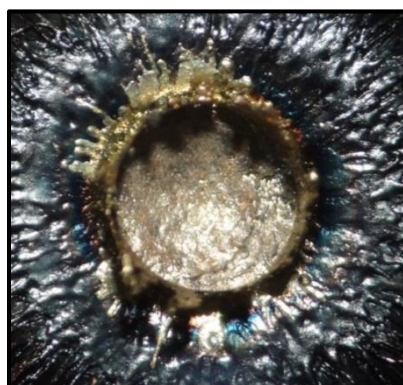
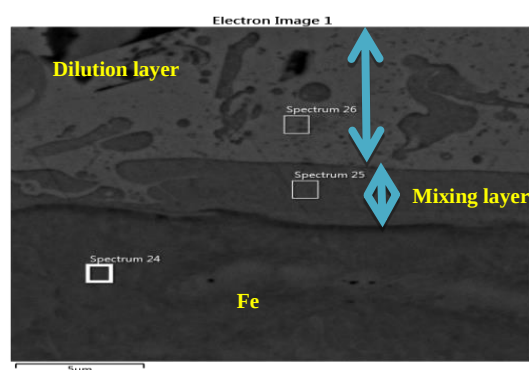


Figure (5): shows the weld joint surface in 80V.

The other voltages below and above this voltage achieve good strength values in range between (202.3 to 227.8). The joints of this voltage ranges had a void, the voids lead to minimize the tensile strength significantly. The causing of these voids as bubbles of miss-welded areas to the equilibrium of the needed consumed power to the welded surface area. Therefore, the data in this work is predicted to the specified dimensions and cannot apply to other dimensions of pin diameter or another material type. So, when the consumed power less than needed, as applied voltage or the capacitance values, the welding process will not sufficient to melt the needed metal amount at contact short time during welding process. Then the appearance of the fractured surface showed welded area less than the pin diameter. Increasing the welding power lead to increase the liquidation and evaporation of the contacted metal at welding joint which gives better joint, but when the welding power exceed the desired value evaporation will happened more than liquation which cause effect like explosion which cause splashing the liquid metal outside joint clearance and leading to generate bubbles which decrease the real joint area.

- **Analysis of Joints layers:**

From Figure (6) seen the elements distribution of the weld joint layer surface with chemical composition and there is two separated layers; first was mixing layer, as in spectrum No.25 show its chemical composition consisted in there element Fe, Cu and Zn. and second was diffusion area, the spectrum 26 show its chemical composition of Cu, Zn and some Fe. This two layer localized between brass and steel.



NO.	%Fe	%Cu	%Zn
24	100	0	0
25	72.0	18.7	9.2
26	11.1	54.3	34.6

Figure (6): The elements distribution along the weld joint layers.

- **First layer**

Figure (7) shows in detail a series of point analysis across joint beginning from steel region along the joint forward to a brass. EDS analysis of selected points to approve the elemental diffusion across weld joint. In the mixing layer, there are three elements of Fe, Cu and Zn in different rate. The table in figure (7) showed the rate of element in mixing area. The Fe particles were diffuse to brass area. That mean Fe particles was pass the mixing layer and reach to brass however the Cu and Zn didn't pass to steel. The region in spectrum (1) in figure (7) regard as melted Brass and there are some fine Iron particles, the Iron percentage in this point is 6.1% and this particles separated through the brass matrix causing area with high hardness and strength. However, in spectrum No.2 have the same amount of Iron concentration. The fine particles of Iron of a grain sizes less than one micrometer responsible to increase hardness in brass matrix as an obstacle to move dislocation just as strengthening by dispersion. Spectrum No.2 located in a large region with chemical composition similar to mixing layer. It separated from mixing layer due to flow force during discharge time where the metals melted.

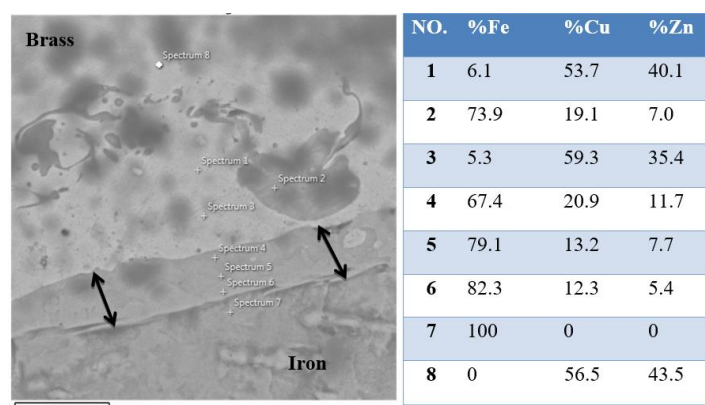


Figure (7): The elements distribution along the weld joint area.

- **Second layer: mixing or (Alloying) layer**

The figure (8) show the details of EDS analysis of selected points, where the chemical composition for this layer from spectrum No.10 to No.15 composed of the three elements (Fe-Cu-Zn) with concentrations of (80-76, 12-25, 6.2-10.8) respectively. The chemical composition range indicate phases of Cu_4Fe_6 , FeZn_{13} , FeZn_{10} , CuZn_5 and ϵ phase as discussed above

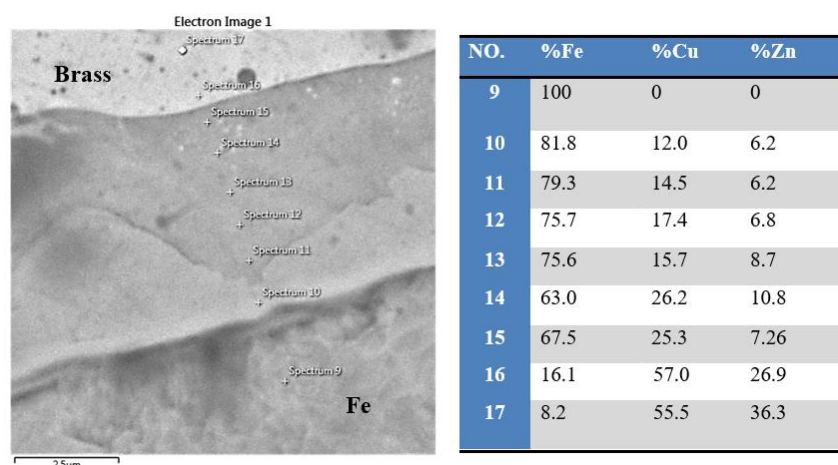
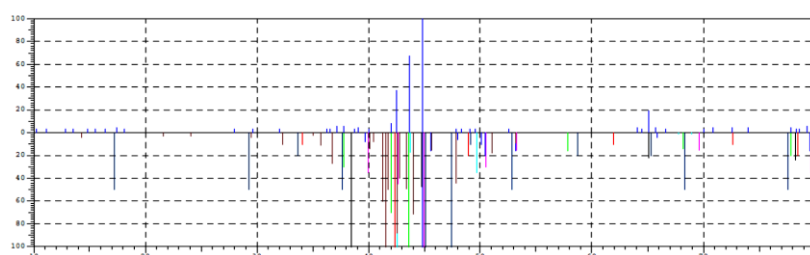


Figure (8): The elements distribution along the joint mixing area.

- **X-Ray Analysis**

In figure (9) show the X-Ray diffraction pattern, Match results No. 1, 3, 4, 6 are neglected where there are no elements in tested sample while the other are considered. No. 1 Match data is CuZn_5 which represent in weight percent. Match No.7 with a composition of FeZn_{13} called Iron zinc which represent in weight (6.2% Fe and 93.8% Zn) which is a FeZn_{10} -type hexagonal. Finally, No.8 Match represent a composition of ($\text{Cu}_{40}\text{Fe}_{60}$) representing as (56% Cu and 44% Fe) in weight which is a solid solution when projected on Iron-Copper transformation equilibrium diagram. So there is no compound collect the three elements (Fe-Cu-Zn) founded in the welding layer as it tested using the X-Ray diffraction test. Alloying zinc with copper and Iron with low percentages gives solid solutions and gives no data in X-Ray diffraction or EDS tests due to limitations of these two methods in detecting traces.



<Entry Card>									
No.	Card	Chemical Formula	S	L	d	I	R		
		Chemical Name (Mineral Name)		Dx	WT%	S.G.			
1	00-031-0487	Cu ₅ .6Sn		0.313	0.667 (4/10)	0.801	0.756	0.404	
		Copper Tin			7.79		P4/n		
2	00-035-1151	CuZn5		0.382	0.667 (4/10)	0.949	0.489	0.309	
		Copper Zinc							
3	00-017-0333	Fe ₇ C ₃		0.760	0.583 (7/17)	0.695	0.661	0.268	
		Iron Carbide			7.61		P63mc		
4	00-006-0686	FeC		0.657	0.714 (5/12)	0.618	0.566	0.250	
		Iron Carbide							
5	00-025-0322	(Cu,Zn)		0.375	0.600 (3/ 7)	0.730	0.394	0.173	
		Copper Zinc			8.17		R-3m		
6	00-004-0787	Al		0.373	1.000 (4/ 9)	0.779	0.192	0.150	
		Aluminum (Aluminum, syn)			2.70		Fm-3m		
7	00-034-1314	FeZn ₁₃		0.381	0.381 (8/21)	0.685	0.454	0.119	
		Iron Zinc			7.29		C2/m		
8	00-046-1058	Cu ₄₀ Fe ₆₀		0.300	0.750 (9/21)	0.521	0.269	0.105	
		Copper Iron							

Figure (9): The peaks data compared to X-Ray diffraction pattern recognized using Jade Software.

The hardness value varied from the steel and brass as well in the weld area, the value of Vickers hardness in the base metal (Steel) around 90, in the same time in the pin metal around 140. The hardness value increased in the contact line between the two metals steel and brass as well the mixing layer for the two metals, the maximum Vickers hardness in the mixing layer was 260.4, this mixing layer high hardness as discussed in the microstructure where the hardness increase in mixing first layer caused by phenomena as strengthening by dispersion of small steel particles in brass matrix.

V. Conclusion:

In The presenting work of joining dissimilar metals by CDW process capable to weld low carbon steel (C10) and brass (Cu60-Zn40) material in CDW successfully. The brass pin tip of 30° configuration in 80 V achieved the highest tensile strength in values of 237.7MPa. The most factors effected on the weld quality is the void formation due to the interrupted gasses formed by burning of contaminants or evaporated metal stayed by solidification of surrounding region for joint before flow the inner melted region . Welding low carbon steel with brass alloy using CDW gives phases (CuZn₅, CuZn, FeZn₁₃ and Cu₄₀Fe₆₀) and these phases are the main responsible phases of joining. There is tow layer in weld surface between tow welded metals. The Mixing layer and near mixing layer and achieving highest values of hardness than base metals.

IV. References:

- [1.] Welding and Brazing and Soldering" "Metals Hand Book", Volume Six, 9th Edition. ASM, 2004.
- [2.] Džiho, Mr Edin, and Mašinski Fakultet Mostar. "Capacity discharge welding of small diameter wires". 17th international research/expert conference , september 2013.
- [3.] Welding hand book " Welding and Metal Fabrication " Volume 40 IPC Scientific and Technology Press, 1972.
- [4.] T.S. Sudarshan, T.S. Srivatsan "Rapid Solidification Technology: An Engineering Guide " (1993).
- [5.] R.T. Kieppura and B.R. Sanders. "Metallograph and Microstructure," Hand Book, ninth edition Vol. 9, America Society for Metals, 2004
- [6.] Wilson RD. Explore the potential of capacitor discharge welding. Adv Mater Process 1994.
- [7.] Kristiansen M. Pulsed power applications.' Yokohama, Japan, April 1995.
- [8.] S. Venkataraman, J.H. Devlietan, Welding Research Supplement, 1988.
- [9.] R.L. Alley, ASM handbook, Welding, Brazing and Soldering "CapacitorDischarge Stud Welding", vol. 6, American Welding Society, 1991.
- [10.] V. Dattoma, F.W. Panella, in: Proceedings of the XXXII National ConferenceAIAS, Salerno, 3–6 Sept., 2003.
- [11.] WiwatThaneepakorn " Effect of Capacitor Discharge Welding on Single Crystal Copper" A THESIS Oregon State University, 1999
- [12.] R.D. WILSON, D.E. ALMAN and J.A. HAWK " RAPID SOLIDIFICATION JOINING OF INTERMETALLICS USING CAPACITOR DISCHARGE WELDING " Mat. Res. Soc. Symp. Proc. Vol. 364 01995 Materials Research Society, 1995.
- [13.] Davies, A. C. "The Science and Practice of Welding: Volume 2 (the Practice of Welding)."CAMBRIDGE, tenth edition, (1993)
- [14.] Srinivas M. Patnaik " Development of an Automated Capacitor Discharge Welding System",Oregon State University, 1997