CHARACTERIZATION OF COPPER ELECTRODEPOSITION AS A NEW FILLING TECHNIQUE IN 316L STAINLESS STEEL BRAZING

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ABSTRACT

The objective of this research is to characterize a new technique of copper filler addition to the brazing joints of 316L stainless steel to overcome the wetting problem between them. This technique includes the electrochemical deposition of copper on the stainless steel joint parts to insure optimum coinciding, minimum oxidation during brazing heating, and consequently good wetting and bonding. An evaluation of the present technique and a comparison with traditional one were performed. The samples were tested to find the shear strength, microhardness, microstructure and x-ray diffractometry. In general, the present new electrodeposited fillers were clearly better than the traditional filler in producing perfect joints with higher shear strength. On the other hand, there was an opportunity of production acceptable joints with electrodeposited fillers under air environment.

تقييم الترسيب الكهربائي للنحاس كآلية جديدة للتحشية في لحام الموئة للفولاذ المقاوم للصدأ من نوع 316L

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الخلاصة

يهدف البحث إلى تقييم طريقة جديدة في إضافة حشوة النحاس الى وصلات لحام الموئة للفولاذ المقاوم للصدأ 316L لتجاوز مشكلة البلل بينهما. تتضمن هذه الطريقة الترسيب الكهربائي للنحاس على مرئي الوصلة لضمان تطابق تام لتقليل التأكسد خلال تسخين اللحام والنتيجة بلل والتصاق جيدين. تم تقييم هذه الطريقة ومقارنتها مع الطريقة التقليدية في الإضافة حيث اجريت فحوصات مقاومة القص والصلادة الدقيقة و التركيب المجهري و حيود الأشعة السينية. وعموما فقد ظهر أن الحشوات الجديدة المرسبة أفضل بكثير من الحشوات التقليدية في إنتاج وصلات ذات مقاومة قص اعلى . من ناحية أخرى فأن هنالك فرصة للحصول على وصلات مقبولة عند إجراء اللحام بالحشوات المرسبة وفي جو من الهواء.

KEYWARDS: brazing, electrodeposition, stainless steel, wetting, columnar phase

INTRODUCTION

Brazing is one of the important joining methods in many applications due to its versatility and because its heating ranges are under the fusion temperature of the substrates, so they suffer less distortion and structural variations [1,2]. Manufacturing of most stainless steel assemblies requires such advantages, but the chromium oxide layer that naturally covering stainless steels prohibits the wetting by the liquid fillers which is the main requirement of the succeeded joints [3-6]. Some investigators proposed a solution to overcome this obstacle, by utilizing of fillers containing active metals such as Ti or Zr which react with the oxide layer and promote the wetting and adhesion [7].

In this research, a new technique of Cu-filler addition by electrodeposition method is suggested as a new solution to the wetting problem. The oxide layer above the stainless steel is removed or thinned before the electrodeposition process, then an adhered Cu layer is electrodeposited on the stainless steel surface, which can be liquidized by brazing heating above the melting temperature , then it easily wets and interferes with stainless steel substrate.

EXPERIMENTAL PROCEDURE

For characterization the electrodeposition method as a filling technique to overcome the wetting problem, the copper filler was added in two ways; firstly by the present method as electrodeposited layer once on one part, and then

on both parts of the lap joint, and secondly by the traditional method as a foil. The brazing joints substrates were selected from the 316L stainless steel plates with dimensions (100 X 20 X 2.5mm). The chemical analysis of these plates was listed in table(1). Before starting the electrodeposition process, mechanical grinding and polishing and dipping in 10% sulfuric acid were applied to remove the oxide layer. Then they were transferred to the electrodeposition bath directly without drying to prevent the reoxidation of processing zone. The electrochemical bath consists of copper sulfate aqueous solution. The conditions of the electrodeposition process were taken from Metals Handbook,vol.5 [8] and detailed in table (2). The electrodeposited filler thicknesses were controlled by the deposition time and checked by optical microscope measurements. Figure (1) contains a photograph of 316L stainless steel plate which was electrodeposited with Cu-filler on edge. Figure (2) shows a 316 stainless steel fixture which was utilized to fix the two part plates of the lap joint during brazing processes. After inserting the fixed samples inside the brazing furnace, the argon pumping initiated simultaneously with the heating running, till the temperature reaching 1125°C , so it was hold for different times, then the power was switched-off and the furnace left to cool to 200°C with continuing argon pumping which then stopped. Figure (3) illustrates the thermal circulation of the brazing process. Several samples were brazed with different cases as shown in table (3). Some of these samples were prepared from the side surface for the microstructure and microhardness examinations. Also other samples were shear tested by tension using Instron machine. Figure (4) consists a photograph of the side of brazed lap joint tensile sample (1). Finally, x-ray diffraction test by Philips diffractometer was employed to identify the phases in these joints.

RESULTS AND DISSCUSIONS

Figure (5) shows a comparison between the shear strength values of the first four cases brazing joints in table (3). All of these cases were brazed with the same conditions of (100μm) filler thickness and (7.5 second) brazing time under argon gas, except the fourth case which was brazed under air environment. It develops a clear superiority of the present technique in filler addition by electrodeposition (especially at both joint parts) in raising the shear strength of brazing joints in comparison with the traditional method of foil filling. This superiority can be explained by the good adhesion between the electrodeposited filler and the stainless steel substrate (as appeared in figure1) which during brazing process it offers a good wetting between them and forbid the air pocket presence and oxidation. Figure (6) includes a photograph of two shear surfaces of fractured lap-joint edges of sample (1) which was brazed with both parts Cu-filler electrodeposition and sample (3) which was brazed with Cu-filler foil addition. This figure shows the significance of the present technique of Cu-filler electrodeposition in resulting a successful clean joint (free of oxides) which has a high shear strength, while the joint of traditional Cu-foil filling technique suffered from broad oxides that prevented producing of good strength joint. Also, table (3) shows that in sample (4), the present technique offers an opportunity to gain a joint with a moderate shear strength although, the brazing process was performed under air (without protected environment).

In figure (7), the micrograph of sample (1) (electrodeposition of two brazing joint parts), develops a typical joint microstructure with the absence of any oxides. Figure(8) contains a micrograph of sample (2) (electrodeposition of one brazing joint part). It shows a severe oxidation in the undeposited joint part, while the deposited other part appeared clean. On the other hand, in figure (9) the micrograph of traditional foil filler brazing joint (sample 3), shows that the oxides spread on both parts. In the fourth case (sample 4 in figure 10), when the brazing process of filler electrodeposited two brazing joint parts was performed under air, a general oxidation developed on all the joint area.

The micrographs of the succeeded joints (samples 1 and 6) in figures(7 and 12) respectively show that, they consist of three zones; the substrate, the columnar phase, and the filler center. Sometimes there is an appearance of substrate dissolution islands (sample 7 in figure 11) which may result due to the local overheating.

Some micrographs show an inhomogeneous thickness of the columnar phase once on the same side (figure 12), and other between two sides (figure 7). This can be attributed to the uneven fixing pressure or uneven deposition layer thickness or due to the effect of gravity.

Figures (13-16) contain Vickers microhardness values of the joint three zones for four different conditions. It is clear that the metal substrate far of the joint has the maximum hardness values and the columnar binding phase has the minimum values while the Cu-filler zone center has the intermediate values. X-ray diffraction charts of two samples (1 and 3) in figures (17 and 18) develop the presence of both Cu and Cu-Fe-Ni phases only due to the limitation of the instrument sensitivity that made the identification of the columnar phase was a hard mission.

The Effect of the Deposition Layer Thickness

Figures (19 and 20) show that the deposition thickness range (80-90 μm) gives the highest shear strength at (7.5 and 10 min.) holding times respectively. This can be explained by that when the thickness was less than this range; most of the deposition layer will dissolve in the substrate and produce the soft columnar phase as seen in figures (13-16), while, when the thickness was more than this range, the filler center become far of the substrate atoms diffusion, so it remains pure and soft too.

The Effect of the Holding Time

Figure (21) shows that the best brazing time was about (10 min.) which gave the maximum shear strength. But, when the time was less than that, it was not enough to the adhesion and dissolution processes to be occurred which were responsible of production acceptable joints. Also, when the time was higher than this range, there will be an excessive dissolution of the substrate and widen the soft columnar phase which weakened the joint too.

CONCLUSIONS

1-The present new electrodeposition technique of copper filler gave excellent brazing joints of 316L stainless steel with superior properties in comparison with the traditional foil filler.

2-The electrodeposition filling technique offered the opportunity to produce an acceptable joint with moderate properties in the absence of protected atmosphere.

3-The best thickness of copper deposition layer were (80-90 μm).

4-The most suitable brazing time was about (10 min.).

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Table (1) The chemical analysis of 316L stainless steel brazing joint plates

Element	%
C	< 0.03
Si	<1.00
Mn	<2.00
P	=< 0.04
S	=< 0.03
Cr	17.00
Mo	2.25
Ni	12.00

Table (2) The operating conditions of the electrodeposition cell[8]

Copper sulphate concentration	220 gm/l
Sulphuric acid concentration	60 gm/l
Temperature	35 ° C
Current density	5 A/dm^2
Voltage	6 V
Anode	Copper

Table (3) The brazing samples cases

Sample code	Filler addition method	Filler thickness (μm)	Brazing time (second)	Brazing environment
1	Both sides deposition	100	7.5	Argon
2	One side deposition	100	7.5	Argon
3	Foil	100	7.5	Argon
4	Both sides deposition	100	7.5	Air
5	Both sides deposition	70	7.5	Argon
6	Both sides deposition	120	7.5	Argon
7	Both sides deposition	60	10	Argon
8	Both sides deposition	80	10	Argon
9	Both sides deposition	120	10	Argon
10	Both sides deposition	60	2.5	Argon
11	Both sides deposition	60	15	Argon

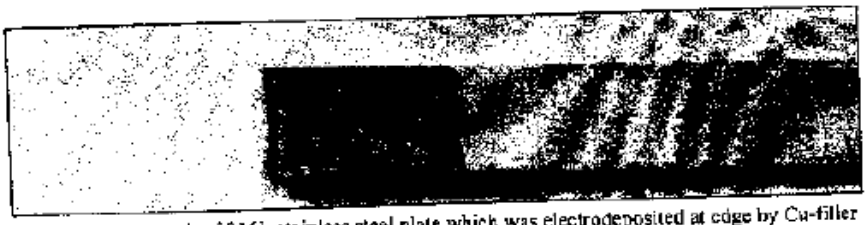


Figure (1) Photograph of 316L stainless steel plate which was electrodeposited at edge by Cu-filler

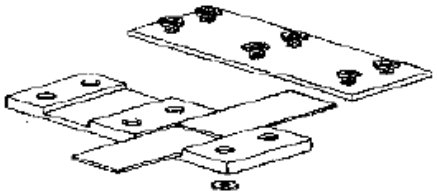


Figure (2) 316 stainless steel fixture of Lap-joint brazing samples

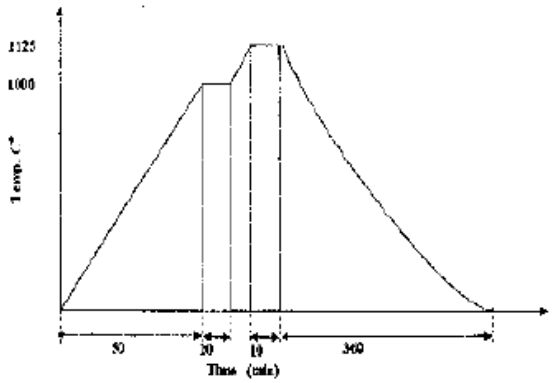


Figure (3) Thermal circulation of brazing

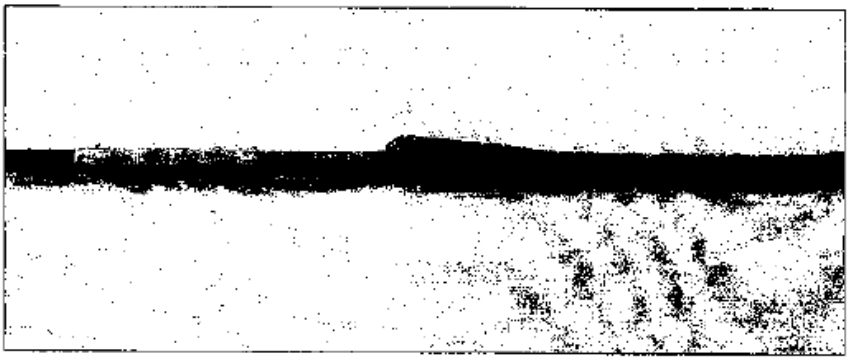


Figure (4) Photograph of the side of brazed lap joint tensile sample (1)

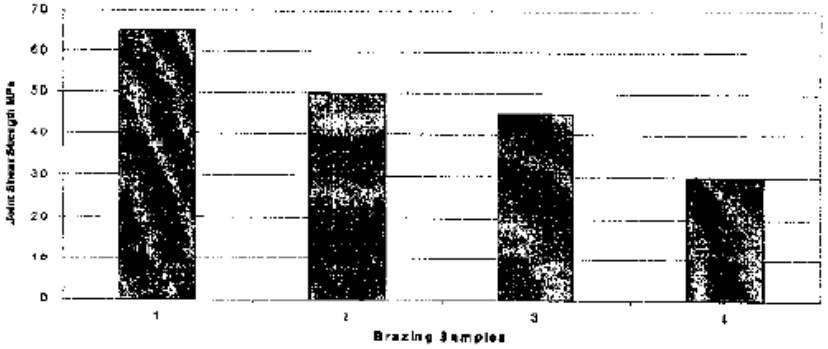


Figure (5) Joint shear strength of four different cases

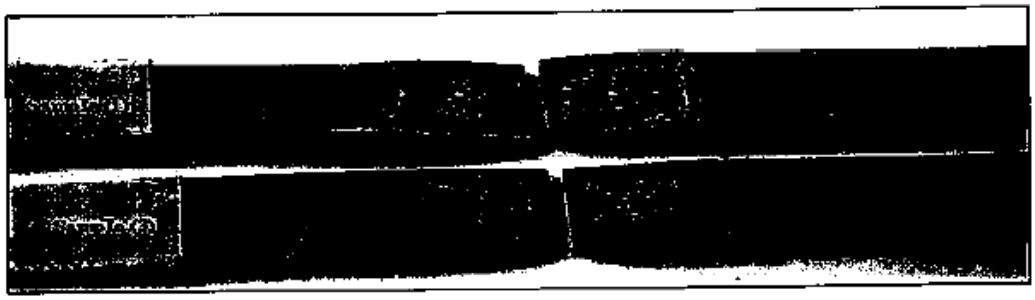


Figure (6) Photograph of sheared two surfaces of fractured lap-joint edges of : Sample (1) which was brazed with both parts Cu-electrodeposition and Sample (3)which was brazed with Cu-foil addition

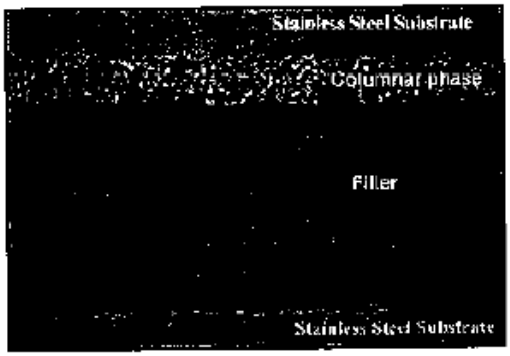


Figure (7) Micrograph of sample (1), brazing joint of two parts Cu-filler electrodeposition (under argon)
100 X

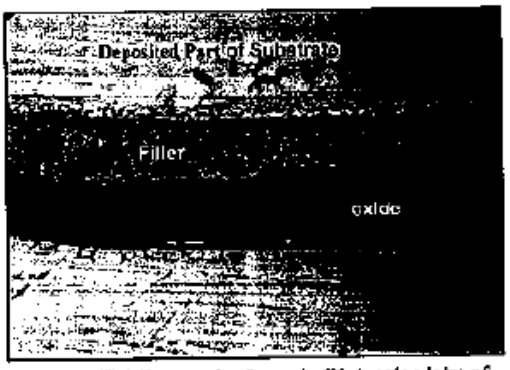


Figure (8) Micrograph of sample (2), brazing joint of one part Cu-filler electrodeposition (under argon)
50 X

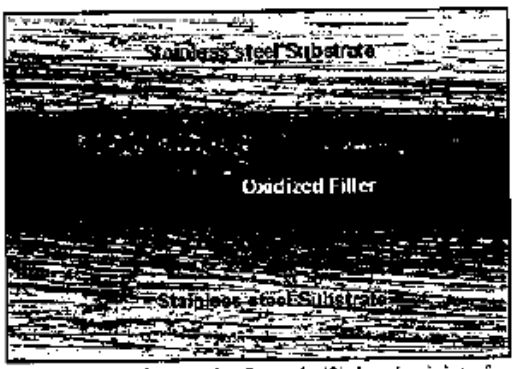


Figure (9) Micrograph of sample (3), brazing joint of traditional Cu-foil addition (under argon)
50 X

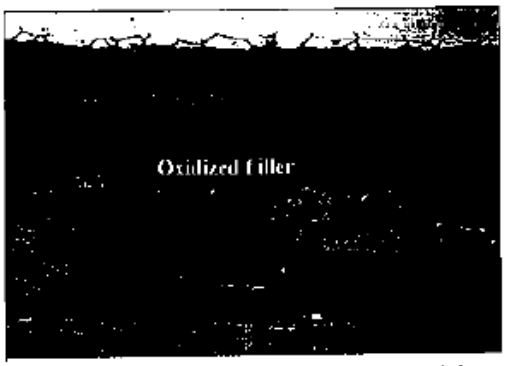


Figure (10) Micrograph of sample (4); brazing joint of two parts Cu-filler electrodeposition (under air)
100 X

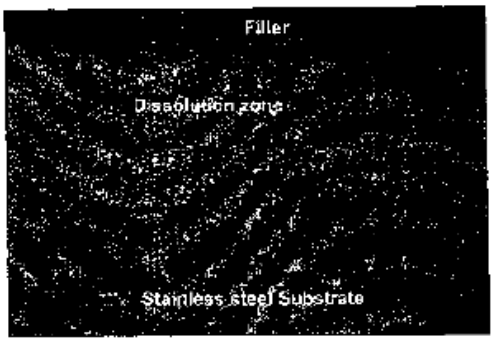


Figure (11) Micrograph of sample (7) joint
200 X

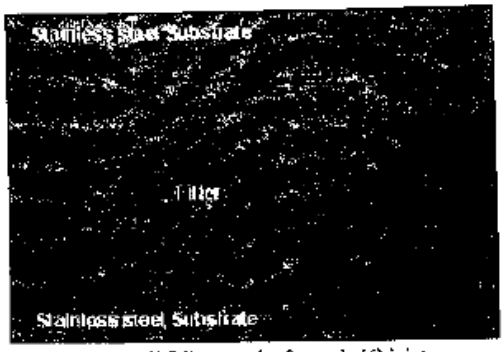
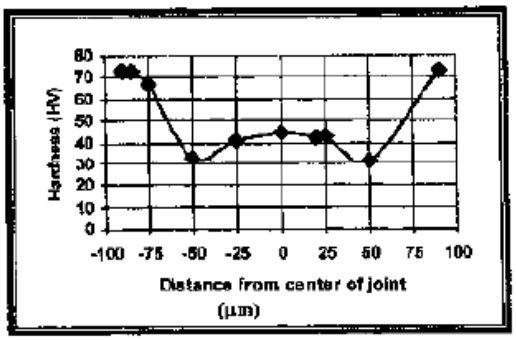
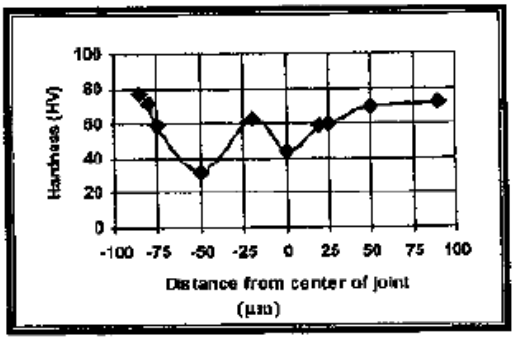


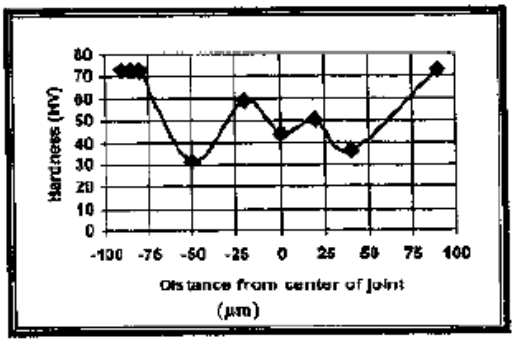
Figure (12) Micrograph of sample (6) joint
100 X



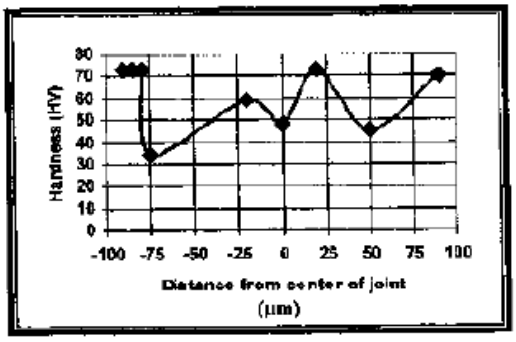
Figure(13) Microhardness of sample(6) joint



Figure(14) Microhardness of sample(8) joint



Figure(15) Microhardness of sample(11) joint



Figure(16) Microhardness of sample(3) joint

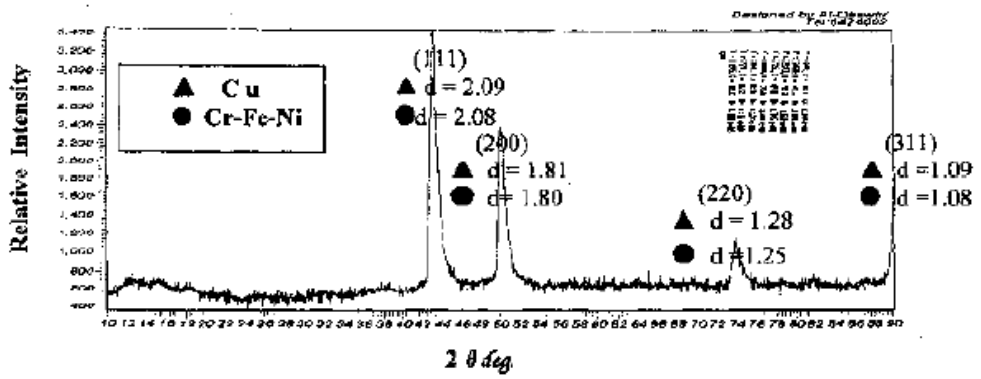


Figure (17) Diffraction chart of sample (1)

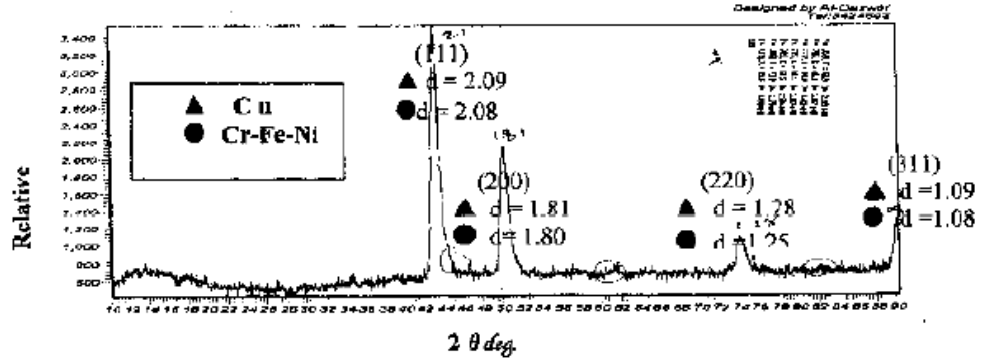


Figure (18) Diffraction chart of sample (3)

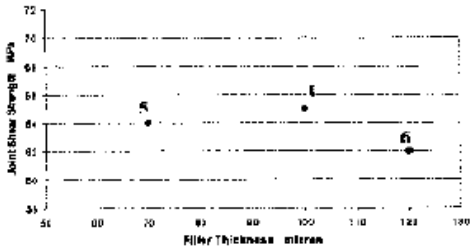


Figure (19) Joint shear strength of samples (5,1 and 6), with 7.5 min. brazing time

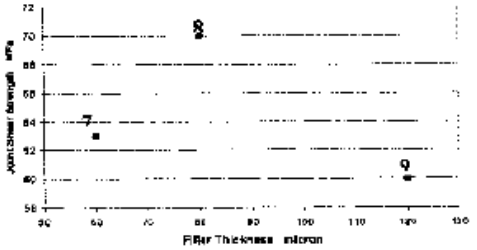
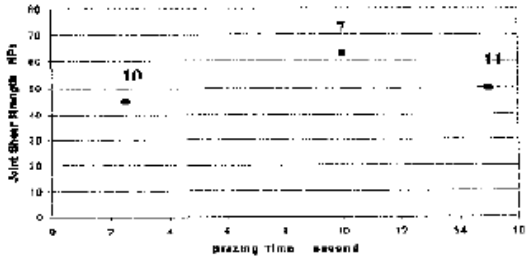


Figure (20) Joint shear strength of samples (7,8 and 9), with 10 min. brazing time



Figure(21) Joint shear strength of samples (10,7 and 11), with 60 um filler thickness