Joining Cast Iron to Carbon Steel by Adhesive and Brazing

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Abstract

The large difference in physical and mechanical properties between cast iron and carbon steel, has led the designers to pay increased attention to achieve high integrity joint between them. Brazing and adhesive bonding are a true processes to obtain reliable joint. Many applications to join cast iron to carbon steel such as pulley to steel shaft, gear to steel shaft, impeller to steel shaft and so on. Most of these applications joints made by fastening of inserted keys between two components. In heavy load, Keyes subjected at high stresses concentration and failed in fatigue fracture early. Fasteners often do not develop the full strength of the base materials, particularly if one of base materials is brittle like gray cast iron. In this paper , brazing with ductile filler metal (Ag-base alloy) and epoxy adhesive are more reliability to join carbon steel / gray cast iron with high shear strength and more uniform stresses with less defects. A gray cast iron-to-low carbon steel cylindrical lap joint was studied: a steel rod brazed and adhesive inside cast iron tube using BAg-7 braze alloy and epoxy adhesive. The shear strength of joints of varying lengths was made.

الخلاصة

نظراً للاختلاف الكبير في الخواص الفيزياويه والميكانيكية بين حديد الزهر والفولاذ الكاربوني, قاد المصممين للإعارة الانتباه المتزايد في تحقيق ربط متكامل بشكل كبيربينهما. يعتبر الربط بالمونة واللصق من عمليات الربط الحقيقية للحصول على ربط بتحمل عالي. تطبيقات متعددة لربط حديد الزهر مع الفولاذ مثل ربط بكر من حديد الزهر مع عمود دوران فولاذي , مسنن من حديد الزهر مع عمود دوران فولاذي ,دفاعة من حديد الزهر مع عمود دوران فولاذي وتطبيقات أخرى. تتم اغلب تطبيقات الربط هذه بواسطة التثبيت والربط الميكانيكي وذلك بإدخال مفاتيح بين المركبتين. في الأحمال العالية تكون تلك المفاتيح تحت تركيز عالي للأجهادات وحصول فشل الكلال مبكراً. غالباً لا تعطي تلك المثبتات المقاومة الحقيقية للمواد المترابطة وخصوصا إذا كانت إحدى المادتين هشة مثل حديد الزهر الرمادي. في هذا البحث ,الربط بالمونه باستخدام معدن حشو مطيلي (سبيكة –أساس فضة)واللصق باللأيبوكسي أعطى ربط ذو تحمل عالي بين حديد الزهر والفولاذ الكاربوني مع مقاومة قص عالية , اجهادات منتظمة, مع قلة العيوب. درس الربط التناكبي الأسطواني : بربط قضيب من الفولاذ بالمونة واللصق بداخل أنبوب من حديد الزهر وباستخدام سبيكة المونة(أساس فضة) واللصق باللأيبوكسي. تم قياس مقاومة القص للروابط بمختلف الأطوال.

1. Introduction

In brazing and adhesive bonding, a thin liquid layer of filler metal or adhesive is used in which there is no temperature gradient in the joint assembly and the filler metal melts at the joining temperature.

Brazing is a method by which a metals are joined above 425 ^{o}C, while adhesive bonding occur at room temperature or close it.The joints for carbon steel- to-cast iron that required high temperature , adhesive have signification drawbacks. For example, epoxy interlayer that in general, has a low melting temperature and cannot be used above about 200 ^{o}C (Bolton,1998; Schwartz,1987).

Bonding mechanism can be categorized in terms of mass transfer across the interface between carbon steel- and -cast iron. Where there is only charge transfer without mass transfer across the interface, the bonding is called adhesive bonding(in some literature, is also called chemical bonding).Where there is mass transfer across the interface such as chemical reaction and diffusion in brazing, the bonding mechanism is called chemical reaction bonding(Howe,1993; ASM HANDBOOK, 1993).

Adhesives consist of fluids that fill the hill and valleys of the solid surfaces. The adhesive bond is created by surface tension forces or mechanical interlocking of the adhesive in the pores and valleys of the solid. This produces bonds that are weaker than the interatomic bonds formed during welding. As a result, adhesives work best when joining materials of high surface to volume ratio such as sheets, fibers or small particles. The large joint surfaces area provides strength and distributes the forces over a large area , thus reducing stress concentrations in the assembly (Bolton,1998; Kafkalidis &Thoyless,2002).

Brazing is another true bonding process by using a filler metal have a melting point lower than the melting point of two solids and added to gap between components. The most critical property of an adhesive and brazing is the surface energy, which determines the wetting angle between the fluid adhesive and the solid adherend (see Fig.1) .A low angle represents good wetting and a high angle represents poor wetting. Generally, contact angles of less than 30° are necessary for bonding (Nascimento, Martinelli & Buschinelli , 2003)

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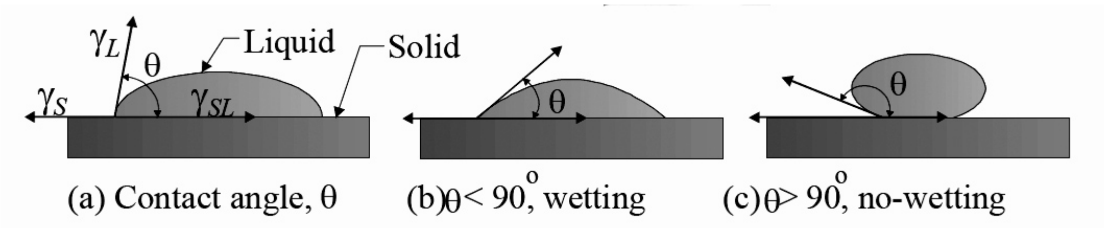

Figure 1: The angle θ is the contact angle,$\gamma_L$is the liquid vapor surface energy, γ_S is the solid vapor surface energy and γ_{SL} is the solid liquid interfacial energy(Nascimento, Martinelli & Buschinelli ; 2003).

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Many factors influence this wetting angle, including surface roughness of the solid (better wetting) and surface contamination (poorer wetting). An adhesive and brazing alloy that wets two solids will form a thin film with a concave meniscus at the liquid-air interface as shown in Fig.2.

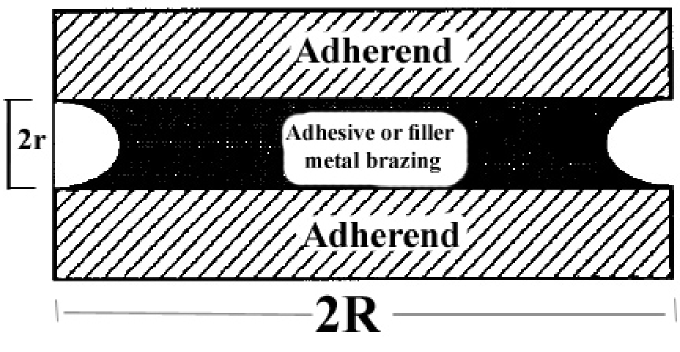

Figure 2 : Idealized adhesive and brazing joint(Eagar; 1987).

If the area of contact of the adhesive with adherend is circular with a radius *R* and thickness *2r*, the deference of pressure in the air. P_A, and in the liquid,P_L is approximately:

$P_L - P_A = \gamma_{LV}\left\{\frac{1}{R} - \frac{1}{r}\right\}$---------------------(1)

If r >R, then P_L- P_A is negative and the pressure in the air is grater than the pressure in the liquid. The two solids are held together with a pressure, P_L- P_A .Thus, any thin film of fluid, which wets two solids, will act as an adhesive(Eagar; 1987)..

Many individual joining processes may be used in assembling of carbon steel-to-cast iron such as welding,. brazing, solid state, adhesive bonding and mechanical fastening. There are many factors affecting the choice of the joining process and these include consideration of the metallurgical compatibility, strength requirement, cost requirement and permanency of the joint(Rajesh; 2002).

Brazing method of the joining carbon steel-to-cast iron can be used to advantage in many applications where welded joints are undesirable or difficult to a achieve such as in the joint of dissimilar metals. Most of the common brazing techniques are used including induction, furnace, resistance, torch; and dip brazing. Because silver-copper compounds are relatively ductile, silver and silver base alloys are used as brazing filler metals to produce brazed joints. Although alloying consequent formation of brittle intermetallics are not eliminated, ductile joints are possible when the copper content of the silver is low. Silver and silver base brazing filler metals form strong joints with stable strength up to 315-425 ^oC. Among other brazing alloys of interest are the siver-cadimium-zinc filler metals developed for oxyacetylene torch-brazing applications(Ag-5Cd-25Zn is typical) (Schwartz,1987).

Adhesive method of the joining carbon steel-to-cast iron shares in many factors with other joining techniques. A wide variety of chemical compounds have been used for adhesives. Assembly of an adhesive bonded joint after surface preparation involves applying the adhesive, positioning and holding the adherends in the desired relationship, and curing. Adhesive application depends on the type of adhesive used and can involve roller coating, brushing, toweling, dipping, spraying, or laying on since thick or thin liquids, viscose plastics, tapes or sheets may be the adhesive form used. Curing may be possible at room temperature but the higher strength adhesives are cured at elevated temperatures. Curing time is quite important and joints properly processed and cured can be very satisfactory from a mechanical properties viewpoint (Lancaster; 1987; Irving, 1994; Samhan &Darwish, 2003).

The object of this paper to study the effect of overlap joint and joint thickness on the shear strength of epoxy adhesive and torch brazing for joining gray cast iron-to-carbon steel.

2. Experimental Procedure

2.1 Base Materials

The chemical composition of gray cast iron tubes in this study is listed in the Table 1. The outer diameter of the tubes was approimatalely 25mm. The inner diameter was precision machined (using rimier tool in finishing)to10mm.

Table1: Chemical composition of base metals (wt%).

Metal	C	Mn	Si	Mn	P	S
Gray cast iron	3.2	0.7.	2	0.6	0.9	0.15
Carbon steel	0.20	0.65	0.25	0.6	0.04	0.05

Four types of low carbon steel diameters rods were brazed and adhesive inside the cast iron tubes as shown in Fig.3.

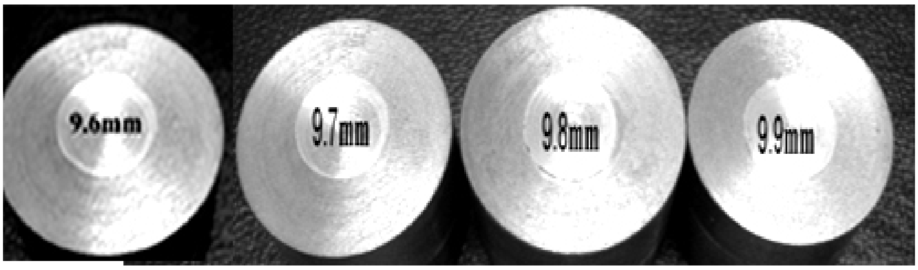

Figure 3: Some samples prepared to shear test.

2.2 Filer Metal Brazing

The brazing filler metal was L-Ag 55 Sn as per Din 8513, AWS/ASME SFA-5.8 B-Ag 7.The liquids and solidus temperature of the BAg7 filler metal 652 ^{o}C and 618^{o}C. respectively [(Schwartz,1987). The alloy was supplied as a wire form (2mm thick) and coated with a flux .

2.3 Epoxy adhesive

Epoxy type (ARCAABON DR 900H) was used as a viscous liquid .The chemical composition of epoxy (Bisphenol-A-Epoxide harze) which mixed at a same ratio with hardener type (ARCADUR R 900H) that chemical composition (N, N-Di Methyl Di Propylene Triamine).

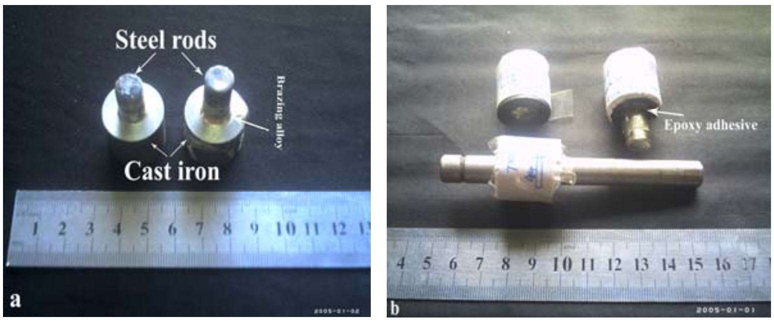

Figure 4 : (a) Brazing Joints (b) Adhesive joints.

2.4 Joint strength test

2.4.1 Samples Preparation

Each sample was individually prepared for brazing and adhesive. By varying the diameter of the steel road, the thickness of layer could be varied. Joints with steel rods diameters between 9.9 to 9.6 were made. Length of cast iron tubes were 38mm.The dimensions of the shear test samples as shown in Fig.5. The steel rods were cut to size using a low speed lath machine .The burrs on the cut edge were removed using sand paper. Gray cast iron tubes cleaned prior to brazing and adhesive in fused-salt (ASM HANDBOOK, VOL.6 1993) .The process of cleaning carryout in a molten salt bath operating at 460-480 ^{o}C in the furnace with hand agitation. The bath composition consists of 75% sodium hydroxide, 5% sodium chloride, 5%

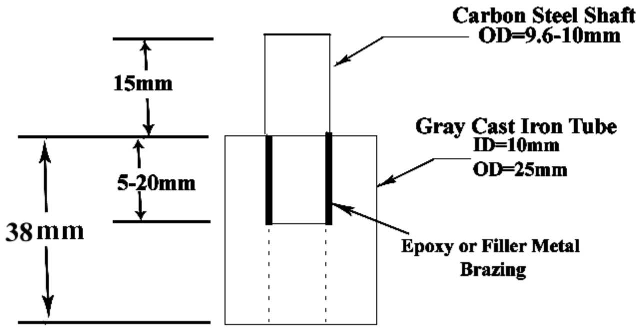

Figure 5: Approximate dimensions of shear test samples.

sodium fluoride, 14% sodium carbonate and 1% potassium carbonate for 20 min. Preparation is completed by rinsing the cast iron tubes in hot water to remove the salt and then drying . Before applied a filler or adhesive, all the sample of components manually cleaned with acetone. A small spatula was used to apply a layer of adhesive paste(epoxy) to inside of the cast iron and to the outside of the steel rod, where the components were to be adheasived together . The steel rod was then inserted into the tube, trapping paste between the two components and squeezing out the excess. After few mints, the epoxy solidified and the joints cured inside a resistance heated furnace at a temperature 100 C for 1hr , then cooling in air. Brazing carried out by torch flame.

2.4.2 Strength testing

The shear strength of the brazed and adhesive joints were measured by loading the samples in compression, as illustrated in Fig.6. The compression loading stressed the brazed and adhesived in shear. An universal testing machines with a 100 and 3 ton load was used (SNS-China and PHYWE-Germany universal tests) . The samples were tested at uniform compression lower rate. The load-displacement data was measured .

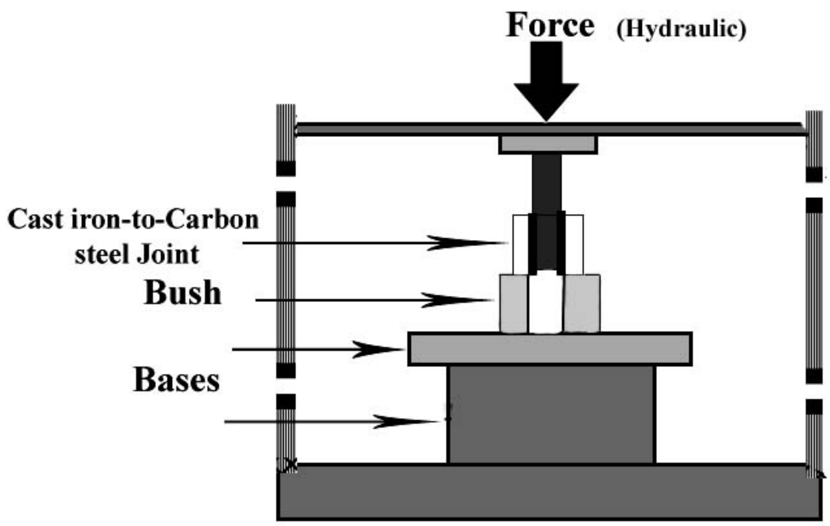

Figure 6 : Experimental shear test setup.

2.5 Microscopy

To prepare the joints for microstructure analysis, joints cut in half lengthwise, and one half sample was mounted and polished on series of silicon carbide papers to No.1000 and alumina powder to 0.25µm as shown in Fig.7. Joints were examined using optical microscopy type Union(Japan) fitted with digital camera used to analysis. Many magnification were used in this analysis.

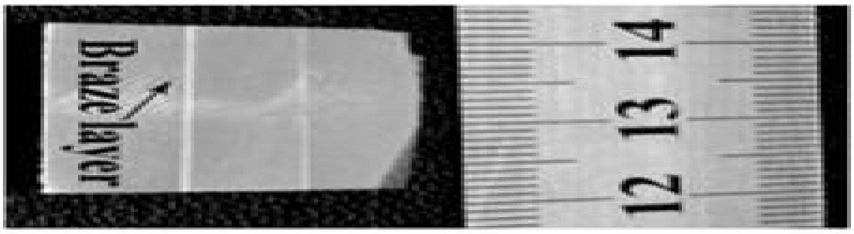

Figure7 : Joint after grinding and polishing.

3. Results and discussion

3.1 Shear strength

Load-displacement curves representing the behavior of load distributed along the length of joint. Fig.8.and Fig.9 shows the load supported versus displacement for the brazing and adhesive joints. It is clear that all joints failed in the ductile mode. In adhesive joint , all failed at the adhesive epoxy, while in brazing joint, all failed in filler metal-cast iron interface. The joint shear strength at failure was calculated by dividing the maximum load supported by the lap joint interface area:

$$\tau = \frac{F}{\pi dl}$$

Where *F* is the load , *l* is the joint length and *d* is the diameter of the joint. The joint diameter at the midpoint of the braze or adhesive was used as the diameter for the calculation.

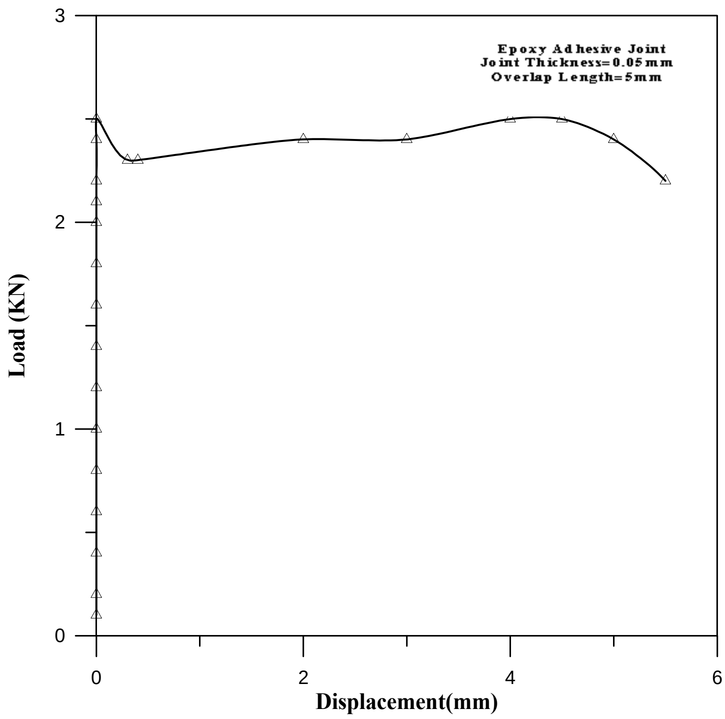

Figure 8 : Load-displacement curve for adhesive joint.

The joint samples by adhesive and brazing exhibited a peak stress , then the stress declined slightly before increasing again; In this case the grater of the two peaks was considered to be the maximum load. It is also noted that the load remain approximately in constant values with increasing the displacement, this mean that a good bonding along the length joint. It is clear that nearly all the joints made by epoxy and brazing failed in ductile mode.

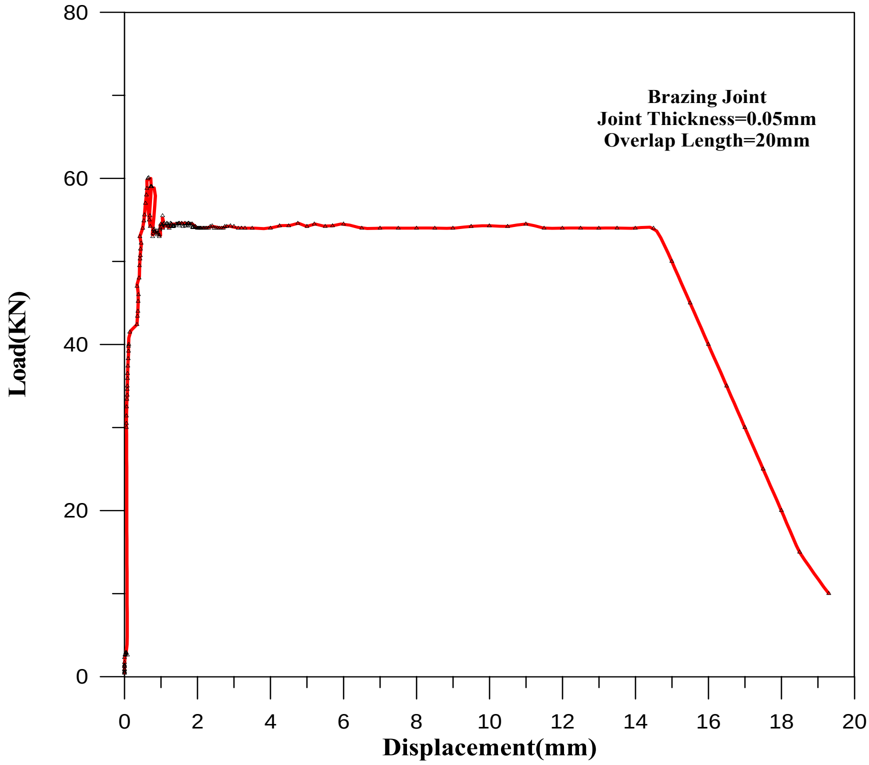

Figure 9: Load-displacement curve for adhesive joint.

3.2 Effect length of overlap on the shear strength of brazed and adhesive joints

Figures 10, 11, 12 and 3 shows the effect of overlap length on shear strength of brazing and adhesive joint for low carbon steel to gray cast iron joints. It is observed that maximum strength occurred in15mm overlap length in brazing and 20mm in adhesive.

In brazing joints, the shear strength increased with an increase of overlap length and reached a maximum value in15 mm then remain about constant .

The length of overlap affects two significant aspects of brazing ; the strength of the joint and the ease with which a joint is brazed. Although, it appeasers from these figures , that more overlap length is betters, overlap beyond 15mm dose not increase the strength of the joint any further; in fact, increasing the overlap much beyond 15mm makes it more difficult for making sound joint. The main reason is ; the braze metal(B-Ag7)has to flow into a small gap between carbon steel rod and cast iron cylinder for the entire length and circumference of the joint. Although there are other factors, one obvious obstacle is that the longer the overlap is, the further the braze metal has to flow and the more opportunity the is to trap gas which causes voids in the joint as shown in Fig.14. As a result, longer lap (more than 15mm)may waste brazing filler metal and use more base metal material than is really needed, without increase in joint strength and a shorter lap will lower the strength of the joint.

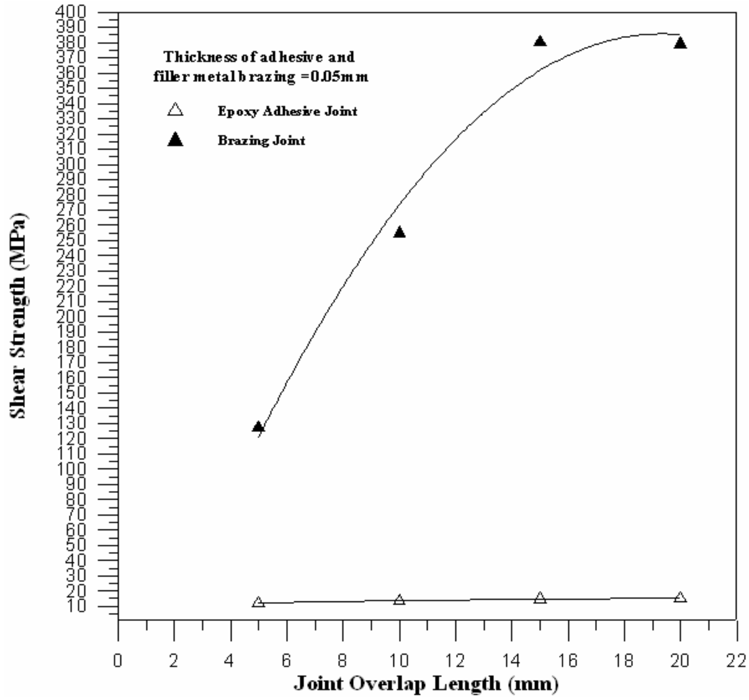

Figure 10 : Shear strength of joints at joint thickness 0.05mm.

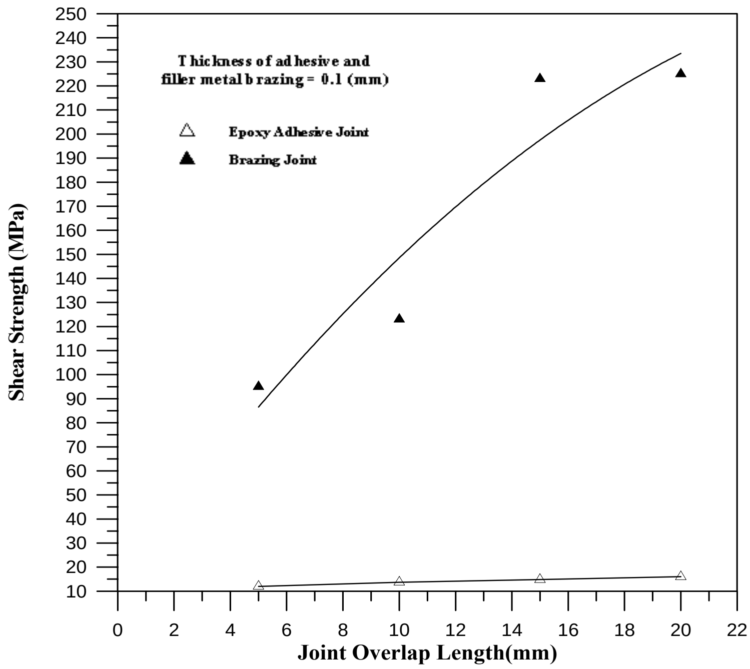

Figure 11 : Shear strength of joints at joint thickness 0.1mm.

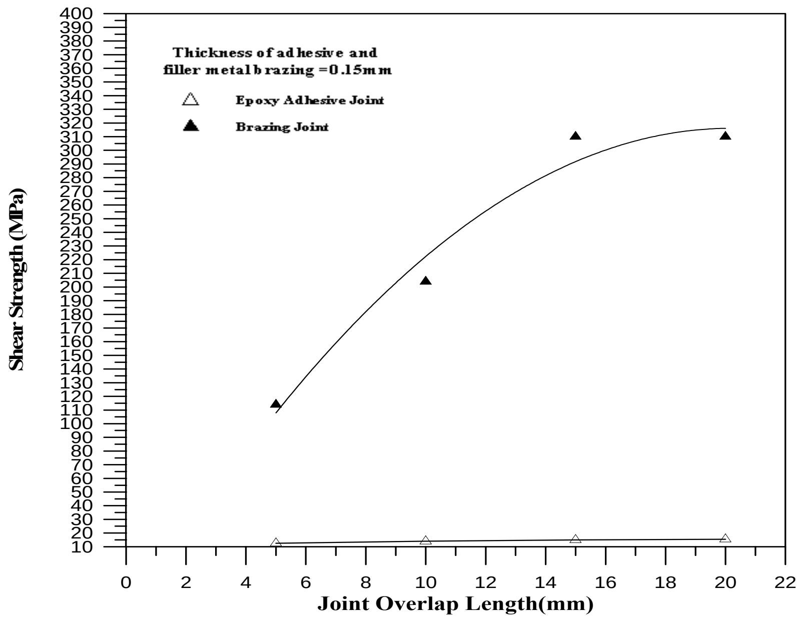

Figure 12 : Shear strength of joints at joint thickness 0.15mm.

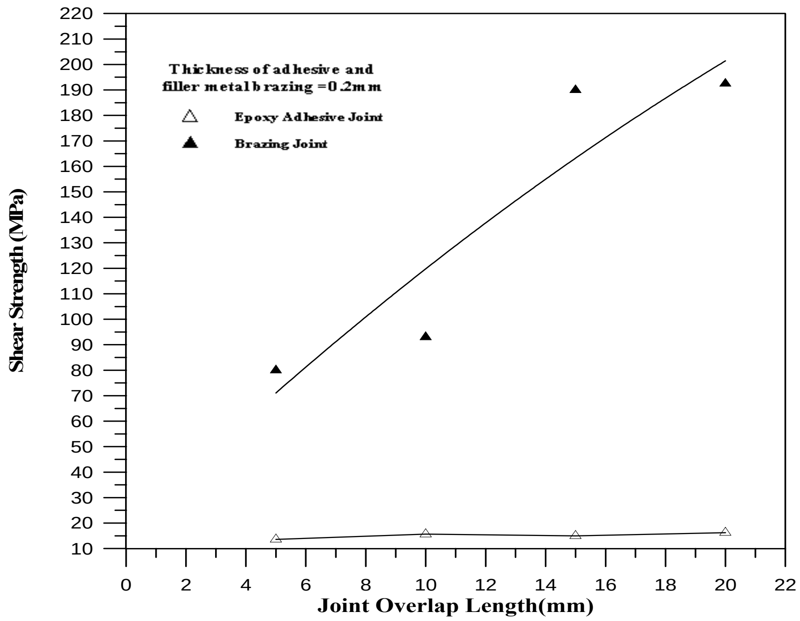

Figure 13 : Shear strength of joints at joint thickness 0.2mm.

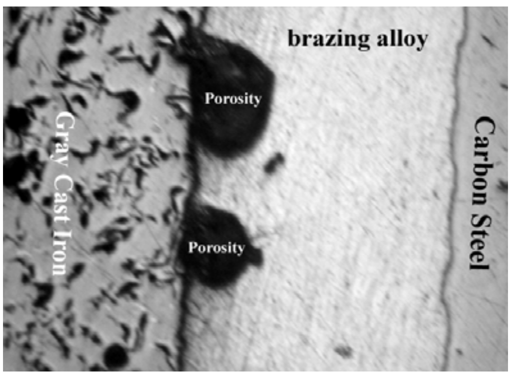

Figure14: Microstructure of gray cast iron to-carbon steel brazing joint (at joint thickness 0.2mm and 20mm overlap length)150X.

In adhesive joints, a continuous increasing with slow rate in the strength observed with increasing overlap length, this is due to by less defect in low temperature of solidification with compare of brazing. Adhesive bond is created by surface tension or mechanical interlocking of the adhesive in the pores and valleys of carbon steel and cast iron. The fluid of adhesive is very viscous and the flow of adhesive is the less factor to affect on the joint strength such as brazing, therefore ; the large and long surface area provides strength and distributes the forces over a large overlap. It is interested from the microstructure as shown in Fig.15 for adhesive low carbon steel to gray cast iron, that many mechanical bridges especially in gray cast iron help to adhesive carbon steel. This behavior is may be due to by the presence of many pores and flakes in gray cast iron to created mechanical interlocking between them.

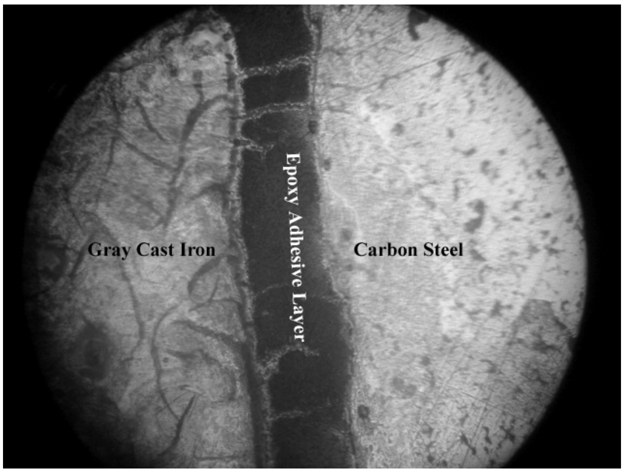

Figure15: Microstructure of gray cast iron to-carbon steel adhesive joint (joint thickness:0.2mm and 20mm overlap length- Etched in 2%Nital)150X.

3.3 Effect joint thickness on the shear strength of brazed and adhesive joints

Fig.10 shows that the stronger(380MPa) braze joint of gray cast iron to carbon steel occurred at a thinner clearance (at thickness 0.05mm). When the clearance is narrower than this , its may be harder for the filler metal to distribute itself adequately throughout joint and joint strength is reduced, in addition, the difference in thermal expansion and elastic properties between cast iron and carbon steel required a suitable gap to reduce residual stress between them . If the gap is wider than 0.05mm , the strength of joint reduced, so the filler metal may fail to fill the joint completely and lowering joint strength as shown in Fig.11,12 and 13. So that the ideal clearance for brazing gray cast iron to low carbon steel is in the neighborhood of 0.05mm. Maximum strength occurred at the 0.05mm clearance in brazing, because brazing depend on the capillary to distribute molten filler metal between the surfaces of the base metals and chemical reaction occur between the filler metal alloy and surfaces of base metal and more phases are product. This chemical reaction is very strong than mechanical or physical bonding in adhesive. Another reason for this grater strength in the thinner , that braze metal is constrained from deforming due to the adjacent base metal and produce a triaxial state of stress in the braze, which makes the entire joint stronger.

Joints by adhesive are not affected by the clearance, It is clear from the Figs.10, 11, 12 and 13 that the strength slowly increased with increased thickness of the joint, this is due to that adhesive bonding depend on the joint area to increase the strength and the viscose fluid of epoxy required a wide gap to distributed between gray cast iron and low carbon steel to achieve sound joint.

3.4 Microstructure of brazing and adhesive joints

Fig.16 and Fig.17 shows the microstructure of the braze and adhesive joint. It is observed that gray cast iron consist of graphite as flakes shape embedded in a matrix of pearlite(dark-lamellar). Low carbon steel consist of ferrite(white) plus little pearlite. Braze alloy observed as a layer which play a main role to achieve reaction layer and wetted the surfaces to be joining. Also, in small clearance showed a uniform flow of braze alloy and well distributed in entire surfaces with no defects observed. Microstructure revealed the formation of interfacial reaction with good wetting between a liquid of braze alloy and base metals and spreading occurs to achieve a high value of work of adhesive.

Fig.18 shows the microstructure of adhesive bonding between gray cast iron and low carbon steel, its clear that the mechanical interlocking between the base metals, but no interfacial reaction occurred. Therefore, the strength of adhesive is more lower than brazing.

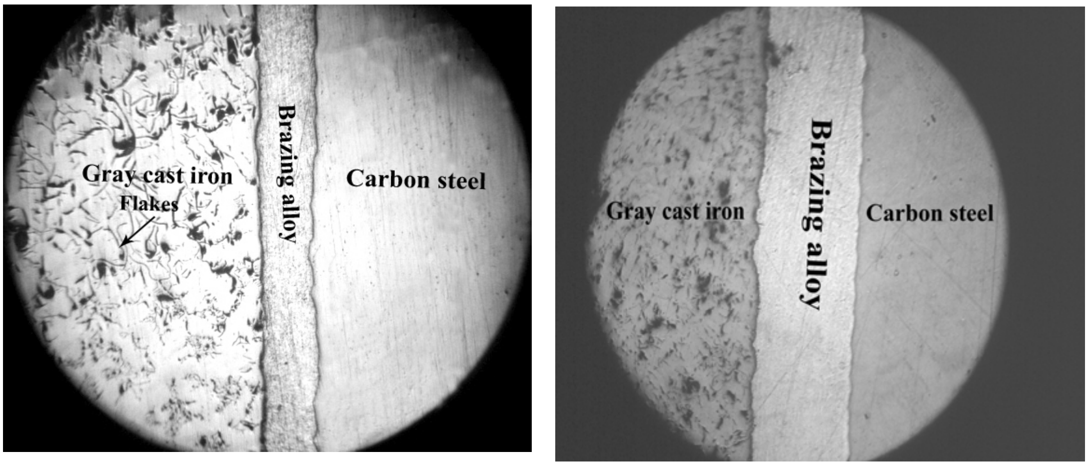

Figure 16: Microstructure of gray cast iron to-carbon steel brazing joint at the joint thickness, left: 0.05mm, right: 0.2mm , Unetched-60X)

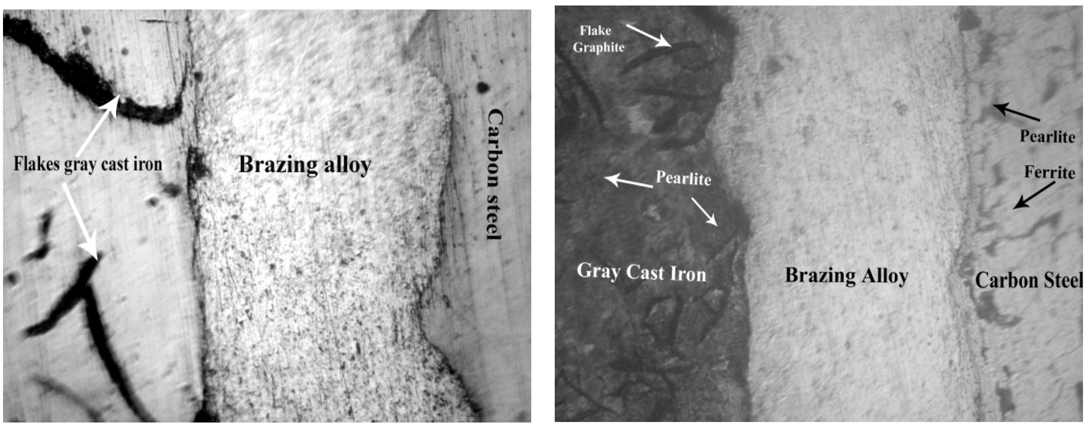

Figure 17 : Microstructure of gray cast iron -to-carbon steel brazing joint (left: at joint thickness 0.05m, 600X-Unetched, right: at joint thickness 0.1m, 400X-Etched in 2%Nital .

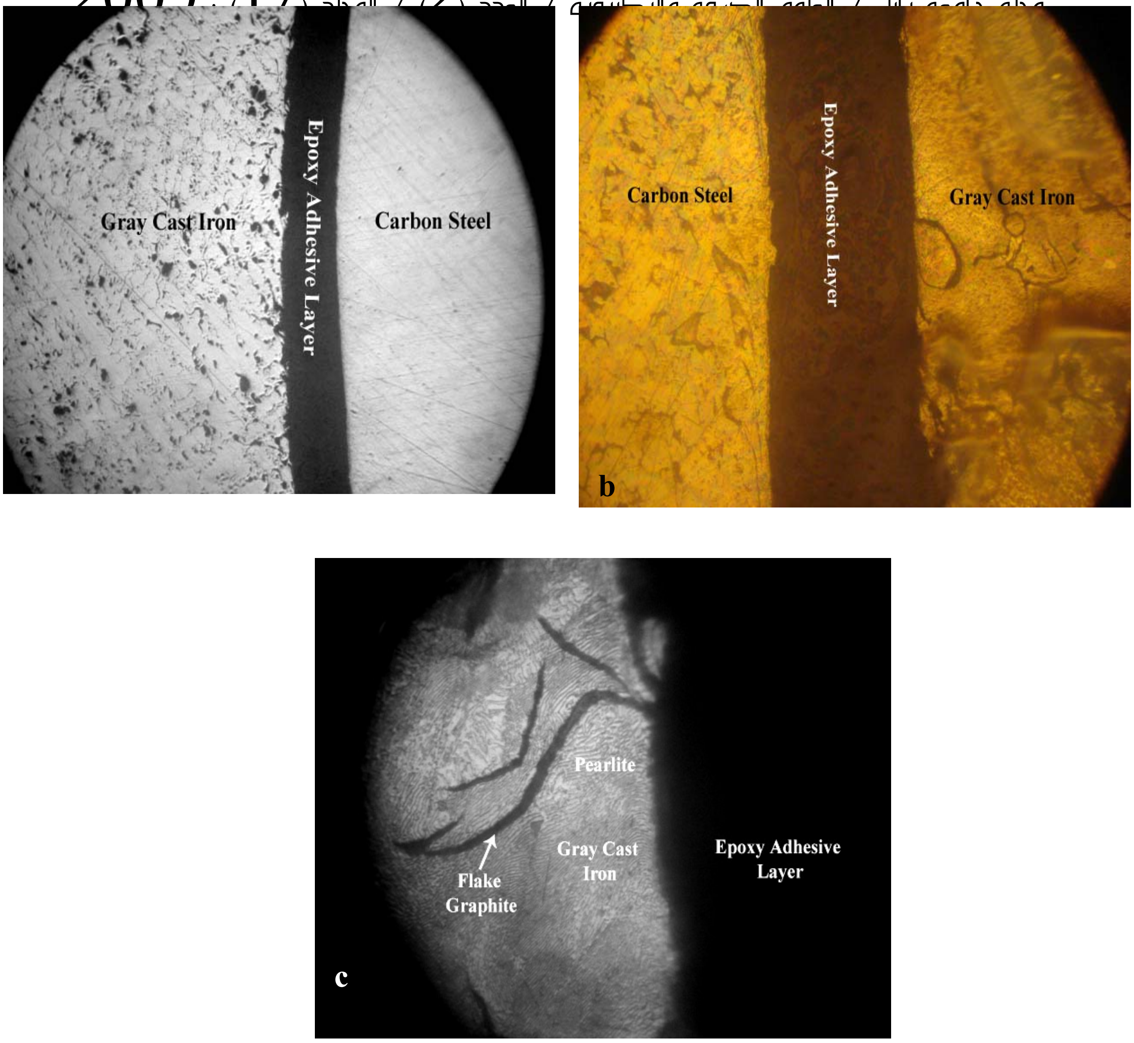

Figure 18: Microstructure of gray cast iron -to-carbon steel adhesive 0.05m(a) at joint thickness 0.05mm- 60X,Unchted(b) at joint thickness 0.1mm - 100X, Etched in 2%Nital (c) at joint thickness 0.05mm 1000X, Etched in 2%Nital.

4. Conclusions

1-Maximum shear strength obtained at a thinner clearance(0.05mm) in brazing, while in adhesive, shear strength increase when the clearance increase .

2- Maximum shear strength obtained when the overlap length 15mm in brazing, while in adhesive, shear strength increase when the length of overlap increase(up to 20mm).

3-The microstructure revealed that a chemical reaction occur in the interface between base metals and filler metal alloy, while in adhesive, mechanical interlocking occur only.

4-All specimens of adhesive joint failed in the epoxy adhesive after shear test, While in brazing , most specimens failed between filler alloy and gray cast iron at the stress higher than the strength of filler metal alloy.

5-Cleaning gray cast iron by fused salts prior to join it with carbon steel , enhanced the wettability between them and sound joint was obtained.

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