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Brazing of aluminum alloy AA 5050 to ductile iron ASTM 60-40-18

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ABSTRACT

This research deals with brazing Aluminum alloy AA5050 to Ductile Iron ASTM 60-40-18 using two filler metals Al-5%Si and Al-12%Si without flux or protective atmosphere in a muffle furnace. Butt joint with a gap of 140 ± 5 µm at 5, 15, 25 and 35 minute holding time was chosen. X-ray diffraction for the brazed similar specimens of ductile iron with Al-5%Si showed the formation of the inter-metallic compounds Mg_2Si, $AlFe_3$, Al_5Fe_2, Fe_3Si, FeSi, Al_2Si, with α-Al as well as α-Fe. The natures of the produced inter-metallic compounds were altered when similar specimens of Al alloy were brazed. Al_4Si and Mg_2Si were distinguished with Al-5%Si as well as α-Al phase and free Si. While the amount of α-Al phase and Si increased when using Al-12%Si. The dissimilar brazed joints of ductile iron and Al alloy showed higher shear strength when using Al-5%Si.

Keywords; filler metals, inter-metallic compounds, double shear test.

INTRODUCTION

The brazing of dissimilar materials is not always possible because there is little or no chemical inter-mixing of the parent materials; this minimizes the possibility of forming brittle inter-metallic components [(1-5)]. The filler metal acts as a buffer layer between the dissimilar components. Difficulties which arise in the brazing of dissimilar materials are mechanical rather than metallurgical; they result usually from differences in expansion coefficients between the materials. Also, stresses are retained in the joint as braze metal cools from solidus to ambient temperature [(6-8)]. Weng and Chuang [(9)] succeeded in joining AA 6061 aluminum matrix composites reinforced with alumina particulate and using Al-12Si filler metal by vacuum brazing. The microstructure examinations revealed that the bonding strength was strictly related to the reinforcing alumina particles and the reaction products which were presented in the joint interfaces. The Si in the filler metal penetrated into the composite matrix and were segregated at the alumina/6061 Al interfaces. Roulin, Luster, Karadeniz and Mortensen [(10)] studied the structure and shear strength of brazed joints of aluminum to stainless steel using a modification of the double lap joint. It was found that during furnace brazing at 600°C, using Al-12Si brazing alloy, the interfacial zone consisted of two inter-metallic layers. The first was formed in the initial instants of the process and features an overall composition similar to that of the compound $FeSiAl_5$. The second appeared after a hold time of 10 minute at the brazing temperature, and featured an overall composition that parallels the $FeAl_3$ inter-metallic. Tsao, Tsai, Wu and Chuang [(11)] evaluated the bonding strength of the 6061-T6 aluminum alloy brazed with A1-12Si, Al-9.6Si-20Cu, and Al-7Si-20Cu-2Sn filler metals at a temperature of 550 °C. It was found that joints with good integrity can be produced with Al-7Si-20Cu-2Sn filler. So the goals of this research were attempting to overcome the difficulties associated with joining Aluminum to ductile iron, in addition to simplifying the process through not using controlled atmosphere or flux.

EXPERIMENTAL WORK

In the present work, furnace brazing of Al alloy AA 5050 (Table-1&2) to ductile iron ASTM 60-40-18 (Table-3&4) was performed without flux or protective atmosphere. Aluminum and ductile iron specimens (14x14x10mm) were ground with emery papers ASTM grids of 220,320 and 400 before assembling (fig. 1).

Table (1); Chemical composition of AA 5050

%Si	%Fe	% Cu	% Mn	% Mg	% Cr	% Zn	%Al
0.35	0.61	0.030	0.007	1.07	0.004	0.0015	Balance

Table (2); Mechanical properties of AA 5050

Tensile strength (MPa)	Yield strength (0.2% offset) (MPa)	Elongation (%)
158	69	26

Table (3); Chemical composition of Ductile Iron ASTM 60-40-18

%C	%Mn	%Si	%S	%P	%Mg	%Fe
3.16	0.45	2.38	0.035	0.002	0.014	Balance

Table (4); Mechanical properties of Ductile Iron

Tensile strength (MPa)	Yield strength (0.2% offset) (MPa)	Elongation %
419	285	19

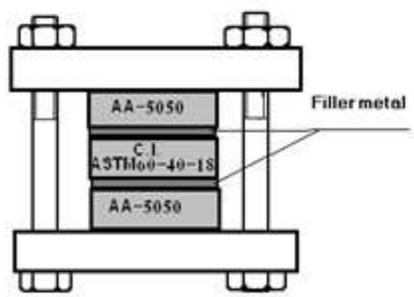

Fig.1; Specimens assembly for brazing

The fixture shown in figure (2) was used to hold the specimens for the double shear test. Oxy-acetylene flame was used to remove free graphite from cast iron surface followed by 30 minutes cleaning employing ultrasonic bath with alcohole. Two types of filler metals Al-5%Si and Al-12% Si as foils of 140 μm ±5μm in thickness were used.

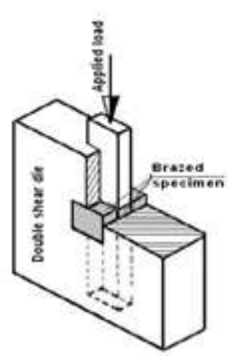

Fig.2; Die used for double shear testing

RESULTS AND DISCUSSION

For the purpose of determining the brazing variables in terms of time and types of fillers, similar samples of cast iron and aluminum were joined firstly.

- **Brazing Ductile Iron to Ductile Iron**

It was found that when brazing with filler metal Al-5Si, the maximum shear strength was 37.5 MPa at holding time of 25 minute (fig.3 and fig.4).

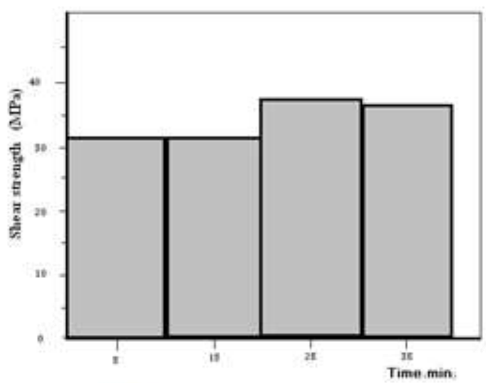

Fig. (3): Shear strength of brazed ductile irons with filler metal Al-5Si

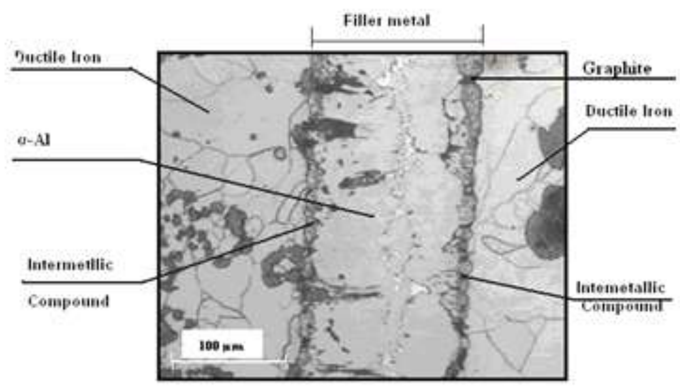

Fig. (4): Brazed joint of ductile irons with filler Al-5Si and 25 min.

X-Ray diffraction indicated the forming of inter-metallic compounds of $AlFe_3$, Al_5Fe_2, Mg_2Si, Fe_3Si, FeSi, $FeSi_2$, Al_4Si, α-Al and α-Fe. It is clearly that the presence of graphite at the interface interrupts the continuity of interface, i.e. prevents wetting. When the holding time was reduced to 5 minute, a certain areas of the surface were left dewetting and the joint strength was reduced to 32 MPa. The wetting occurs at small distinct areas while the large areas of filler metals lack wetting and this due to aluminum oxide film which needs more time to diminish [3, 9] moreover to the existing of graphite. When using Al-12Si as filler metal, brazing with lower shear strength were achieved (fig.5).

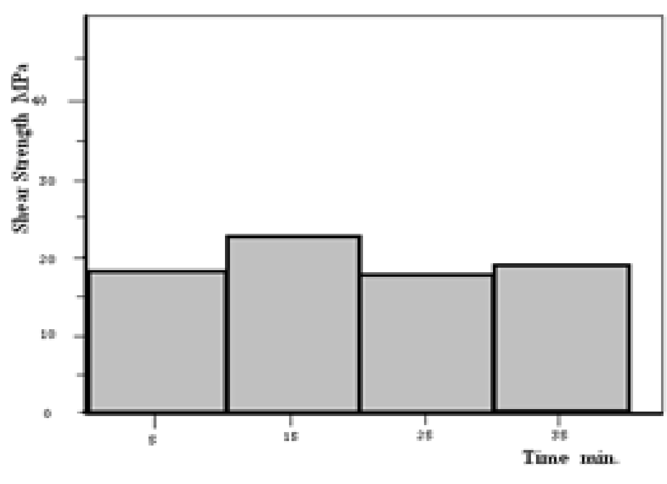

Fig. (5); Shear strength of brazed ductile iron with Al-5Si

Maximum shear of 35.7 MPa was reached at holding time of 15 minute.

- **Brazing of AA 5050 to AA 5050**

Brazing of AA 5050 to AA 5050 with a filler metal of Al-5Si gives maximum shear strength of 32.7 MPa at holding time of 25 minute (fig.6).

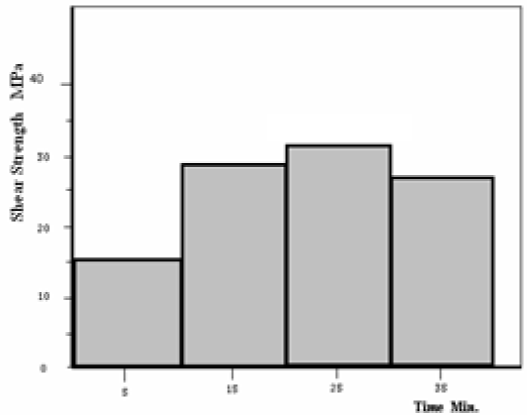

Fig.(6) ; Shear strength of brazed AA 5050 with Al-12Si

The interface between base metal and filler metal contained inter-metallic compound of Al_4Si and Mg_2Si as well as soild solution of α-Al. Lowering the holding time to 5 minute results in reducing the shear strength to 16 MPa .While when the holding time was increased to 35 minute the shear strength of the brazed joint decreased too. The interface between the filler metal and base metal is wavy and the cracks are appearing at the interface. These cracks are an indication of severe grain growth [(11)]. Brazing using Al-12Si gives maximum shear strength of 22.6 MPa at holding time of 15 minute (fig.7 and fig.8).

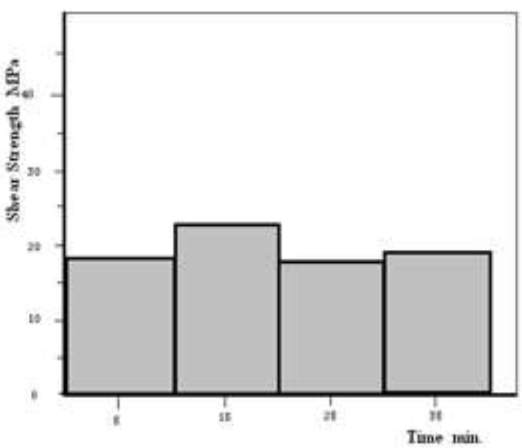

Fig. (7); Shear strength of brazed AA 5050 with filler Al-12Si

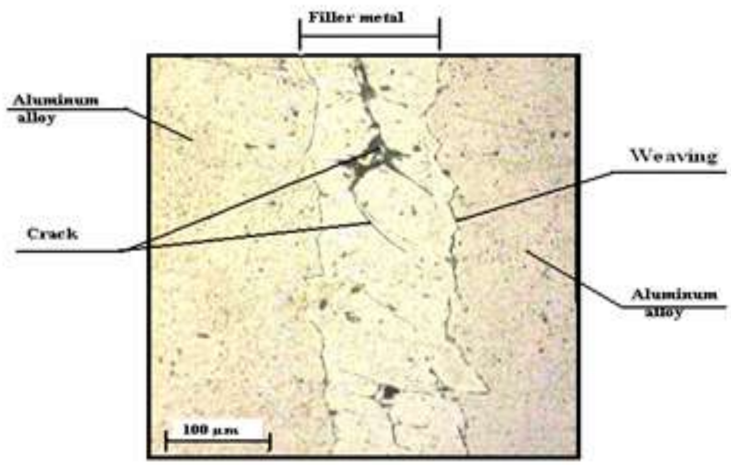

Fig. (8); Brazed joint of AA 5050 with filler of Al-12Si and 15 min.

X-ray diffraction showed that the interface layer contained Al_4Si, Mg_2Si and α-Al. Declining the holding time to 5 minute resulted in decreasing the shear strength to 18 MPa. This reduction is due to the discontinuity of interfacial inter-metallic layer.

- **Brazing of dissimilar metals**

Brazing with Al-5Si filler metal gave a maximum shearing stress of 41.5 MPa at 15 min. (fig.9). The inter-metallic compounds observed from the Al-side are Al_2Fe , Mg_2Si and Al_4Si in addition to α -Al ,while the inter-metallic compounds found on the ductile iron side are Mg_2Si , Al_2Fe , FeSi , Al_4Si, $FeSi_2$, Fe_3Si, Al_5Fe_2 in addition to α -Fe. Microstructure examinations of the brazed joint of maximum shear (fig.10) shows three regions (The first region is rich in Al_5Fe_2 and Al_2Fe phases, while FeSi, $FeSi_2$ and Fe_3Si are dominating the second region. The third region includes a large amount of Al_4Si). The continuity of the inter-metallic compound layers on both sides may the reasons behind the maximum shear strength of these specimens. Increasing the holding time to 35 minute results in decreasing the shearing strength to 22 MPa, this is attributable to the transfer of silicon to the center of the filler metal and forming a band resulting in a weak joint (fig.11).

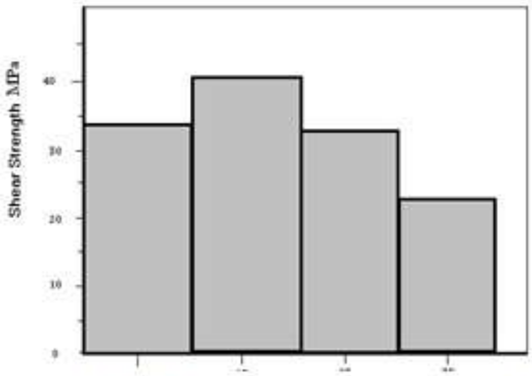

Fig. (9); Shear strength of brazed ductile iron to AA 5050 with filler Al-5Si

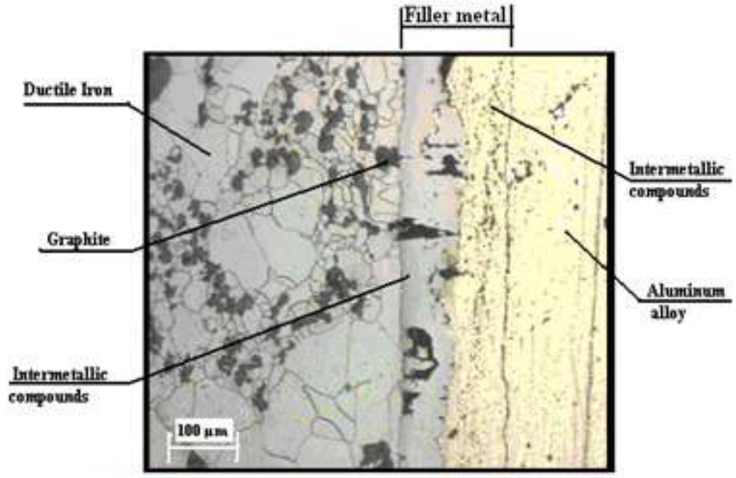

Fig. (10); Brazed joint of AA 5050 and ductile iron with filler Al-5Si and 15 min.

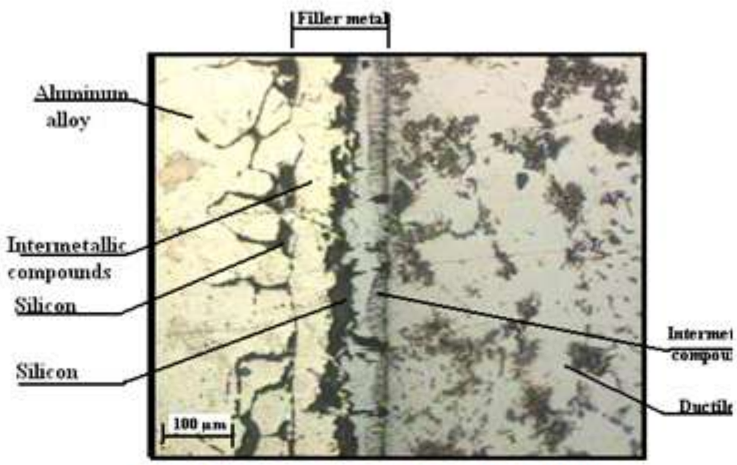

Fig. (11); Brazing joint of AA 5050 and ductile iron with filler Al-5Si and 35 min.

The α-Al solid solution grains nucleate at the liquid/solid interface and grow toward the joint centre. Since silicon has lower solubility in the α-Al, it was rejected into inter-granular residual liquid region [6, 7]. Brazing of AA 5050 to ductile iron by using Al-12Si gave brazed joint of low shear strength when compared with brazing by Al-5Si at the same holding time and temperature. The maximum shear strength was 33 MPa at 25 minute (fig.12).

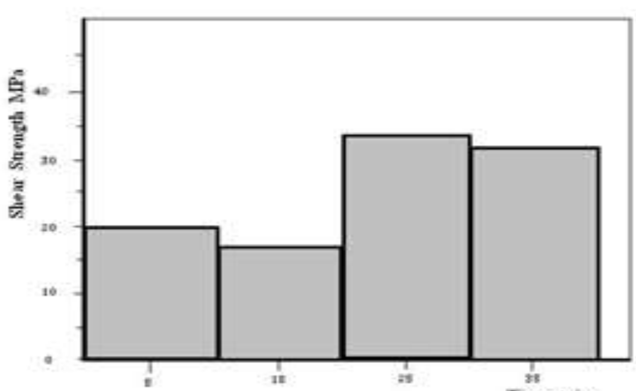

Fig. (12); Shear strength of brazed ductile iron with filler Al-12Si

This reduction in shear strength is due to the increase of volume fraction of α-Fe. The region near AA5050 contains the inter-metallic compounds of Al_2Fe, Mg_2Si, Al_4Si, α-Al, Si, while that near the ductile iron seems to contain the inter-metallic compounds of Mg_2Si, Al_5Fe_2 and $FeSi_2$ (fig.13).

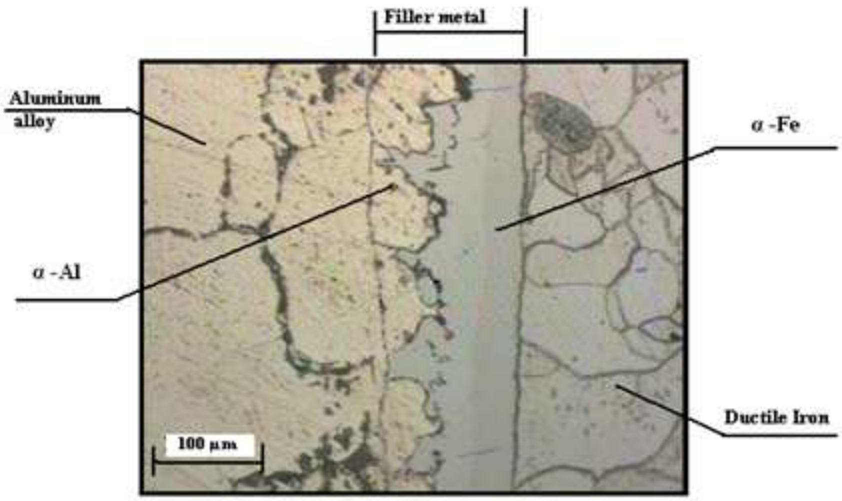

Fig. (13); Brazing joint of AA 5050 to ductile iron with filler Al-12Si and 25 min holding time

CONCLUSIONS

1. Furnace brazing of Al alloy AA 5050 to ductile iron ASTM 60- 40-18 using Al-5%Si and Al-12%Si as filler metals is possible without flux and protective atmosphere.
2. Al-5%Si as filler metal gives maximum shear strength when brazing Aluminum alloy AA5050 to Ductile Iron ASTM 60-40-18.
3. More seggregation of Si at the interface with Al-12Si filler may be related to the reduction of shear strength of the brazed joints.

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