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Effect of process conditions on the evolution of microstructure and mechanical properties of AA3003 vacuum furnace brazing joints

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Abstract

In this study, vacuum furnace brazing was used for joining AA3003 alloy with different thicknesses of 0.6 and 3 mm using BAlSi-4 filler metal. Firstly, the samples were degreased using water and soap and then cleaned with acetone. The set-up was assembled and pre-heated for two-steps at 235 and 339 °C and subsequently, moved to furnace. Vacuum brazing was conducted at temperature range of 590 to 630 °C for different holding times of 5 and 10 min followed by furnace cooling. After primary visual checking, three samples for each thickness were selected for evaluation of microstructure and mechanical properties. Results indicated that furnace temperature and holding time significantly influenced microstructural evolution and mechanical properties. This effect was attributed to the distribution of Si and its relevant eutectic and pro-eutectic phases. It was deduced that the amount and distribution of such phases together with joint assembling design controlled the mechanical and fracture behavior. Furthermore, it was found that the quantitative amounts of pro-eutectic Si and Al–Si eutectic phases significantly increased the hardness of the joint. Therefore, the joint brazed at 610 °C and dwelling time of 10 min was identified to offer the optimal mechanical properties.

1. Introduction

Due to their exceptional strength to weight ratio, corrosion resistance and good formability, AA3003 aluminum alloy is extensively used in various industrial applications like packaging, heat exchangers and automobile industry [1]. Joining AA3003 is faced with manufacturing complications when fabrication of multi-component industrial parts is involved [2]. Many different approaches have been recently developed or utilized in joining similar or dissimilar metals and alloys to each other [3–5]. The utilized welding process would not necessarily result in reduced mechanical properties, as for example, it has been observed in many different alloys, that application of friction stir processing has yielded significantly improved properties [6–8]. Brazing has been identified as one of the most beneficial techniques to be used in joining of aluminum alloys. Many parameters such as selection of brazing filler metal, oxide and pre-joining cleaning process, composition of protective gas, flux and lubrication can influence the quality and reliability in vacuum brazing of metallic alloys [9, 10] and ceramic joining [11–13]. In addition to the mentioned technological aspects of process, fluid mechanics-related factors like base metal/filler metal wettability, filler metal density, viscosity and temperature dependency of capillary motion of filler metal can significantly influence the approval of the final joint [9, 14, 15]. As the most important factors among all abovementioned items, the composition and related physical properties of Al-based filler metals plays a key role in the joining process. This is due to the fact that as an operational parameter, it indirectly influences the fluidity and flowability of the filler metal during brazing [15].

As a crucial element for brazing of aluminum alloys, commercial Al–Si alloys have been developed to serve as aluminum brazing filler metals such as BAlSi-3, BAlSi-4, BAlSi-7 and BAlSi-9 with Si contents up to a maximum of 13 wt% [16]. However, the brazing temperature must be in a specific range of 590 °C–630 °C, which is close to the solidus temperature of many industrial aluminum alloys, e.g., AA3003 [17]. In this regard, it seems imperative to perform the brazing of AA3003 alloy system considering the fact that the Al constituents may
Table 1. Chemical composition of AA3003 base metal.

| Element | Mg  | Si  | Mn  | Fe  | Cu  | Ti  | Al   |
|---------|-----|-----|-----|-----|-----|-----|------|
| Wt%     | 0.02| 0.22| 1.45| 0.43| 0.1 | 0.023| Bal  |

Table 2. Chemical composition and standard designation for Al–Si filler metal.

| UNS number | AWS classification | Element | Wt% |
|------------|--------------------|---------|-----|
| A94047     | BAlSi-4            | Al      | 88  |
|            |                    | Si      | 12  |

possibly melt. In addition, it is possible that the sample would not mechanically stand the thermal exposure circumstances during brazing in the furnace. Therefore, introduction of novel low-melting-point filler metals and wise application of phase diagram calculations seem to be a necessary step for having sound Al brazed joints for industrial applications [18].

In the past few years, numerous related research works including metallurgical and operational considerations have been done to study different aspects of brazing of aluminum alloys. However, investigation of the effects of filler metals and their related topics are rarely reported. The effects of addition of rare earth elements and their roles on the improvement of mechanical properties of Mg-based and Al-based systems are extensively considered by several scientists. It is also claimed in many works that these elements have outstanding impact on joint corrosion resistance of such alloys both in crystalline and amorphous structures [19]. Rare earth elements play a special role during formation of hyaline. The direct and indirect effects of rare earth elements on heat resistance, formability and shear strength of final products have been studied as well [20]. Moreover, addition of copper and nickel to the conventionally used Al–Si filler metals can decrease the melting point of the filler metal and can be considered as another extensive research field in this context [18, 21, 22]. It should be noted that development of low melting point filler metals by different approaches have been the purpose of many other related investigations regarding vacuum brazing of Al alloys [23]. Different amounts of two aforementioned alloys were added to Al–Mg alloys as a complementary constituent and their impact on corrosion resistance, bond shear strength, microstructural evolution of filler metal and hardness in the regions adjacent to the interface have been examined [15, 24]. The development of novel filler metals with introduction of germanium [19], zinc [24] or tin into conventional Al–Si or low melting point Al–Si–Cu alloys have also been studied taking both mechanical properties and corrosion resistance of joints into account. However, some difficulties such as high cost of Ge supply and relatively high vapor pressure of Zn together with lower corrosion resistance of these doped fillers currently make their applications unreasonable in Al vacuum brazing process [18].

Regarding abovementioned considerations, deep understanding of the relation between microstructure and mechanical properties in brazed joints with conventional Al–Si filler metal with no added elements is of great importance and should be studied in more details. In this paper, the mechanical properties and microstructure of two sheet joints with different thicknesses using Al–Si filler metal were investigated. The assessment of joint quality of vacuum brazed AA3003 alloy with Al–10Si filler metal was carried out by tensile testing as well as distinguishing the interfacial microstructures and fractography.

2. Experimental procedure

AA3003 aluminum alloy and foil shape BAlSi-4 (Al–Si based) were selected as base and filler metal in this research, respectively. BAlSi-4 is considered as a general class of Al-based corrosion-resistant filler metal with good flowability. Chemical compositions of these two materials are presented in tables 1 and 2.

Two different AA3003 alloy sheets with different thicknesses of 0.6 and 3 mm were used as basic joints. In order to remove the contaminations, superficial scales and oil from the contact surfaces, cleaning was performed using a mixture of 10% HNO₃ and 0.5% HF (% Vol.) acids followed by a drying step. Base metals and filler metal were assembled in lap joint mode using a fixture for assuring the deliberate and precise accommodation of joint component and easy filler flow during vacuum brazing. It should be noted that the material used for fixture should have a decent thermal stability at temperature range of brazing to avoid exertion of excess force into the joint due to unwanted expansion and contraction. In this research, in order to avoid surface oxidation and hydrogen adsorption the vacuum furnace was utilized under 10⁻² torr. After loading the samples into the
furnace and prior to applying the main vacuum, a two-step pre-heating was performed by 15 min holding the samples at temperatures of 235 and 339 °C. In the final vacuum brazing process, samples were heated up to the final brazing temperatures of 590, 610 and 630 °C with a heating rate of 10 min/°C. The samples were placed on the stage in the vacuum furnace which was equipped with thermocouples to precisely control the temperature. Moreover, the thermocouples and furnace temperature were calibrated prior to the tests. The soaking time was different for the samples depending on the sheet thicknesses, i.e., 5 and 10 min for 0.6 mm thick samples and 10 and 15 min for 3 mm thick samples. Finally, vacuum-brazed samples were cooled down in the furnace up to ambient temperature for further mechanical and microstructural investigations. It is to be added that the gap between two base metals was set to 0.24 mm for both sheet thicknesses but two overlap values of 9 and 15 mm² were tested to assess the effect of contact area. The samples were then washed by water.

The test specimens were machined for as-brazed samples for uni-axial tensile testing and fractography of failed joints. The surface preparation of the samples for subsequent microstructural study was carried out by grinding, polishing and final 10 s room temperature etching with NaOH. The microstructure was studied by optical microscope (OM) and scanning electron microscope (SEM) equipped with energy dispersive x-ray spectroscopy (EDX). Microhardness tests with pyramidal indenter in Vickers unit considering 300 gf weight were performed using ASTM E-384-99 standard with holding time of 15 s.

### 3. Results and discussion

#### 3.1. Microstructural evolution

##### 3.1.1. Brazing of Al sheet joints with 0.6 mm thickness

In this section, three samples with different brazing strategy were considered and for a better traceability and ease of discussions, they were labeled as listed in table 3.

Table 3. Labels of the samples used in this part of the study (The brazed samples with 0.6 mm thickness).

| Sample name | Brazing temperature (°C) | Brazing time (min) |
|-------------|--------------------------|--------------------|
| B0.6-A      | 610                      | 10                 |
| B0.6-B      | 610                      | 5                  |
| B0.6-C      | 590                      | 5                  |

Figure 1 illustrates the low and high magnification SEM micrographs of B0.6-A which is vacuum brazed for 10 min at 610 °C. It can be seen that a good and uniform bonding has formed in both upper and lower base metals/filler metal joints. This may be attributed to diffusion of Si atoms into the base metal and partial melting of the base metal adjacent to the interface. The formation of this as-brazed microstructure which contains α-Al phase together with Al–Si eutectic, formed at final solidification steps, demonstrates the proper selection of brazing temperature and exposure time.

For a better understanding of solidification and phase formation during brazing, EDS analysis of two points marked by A and B in figure 1(b) was performed and the results are depicted in figure 2. Point A which is of dark color, is characterized by dominant presence of Al and small content of Si. This proves the formation of α-Al...
phase with diffused Si of filler metal. On the other hand, figure 2(b) as chemical micro-analysis of point B, presented with bright color in the SEM image, illustrates Al and Si peaks with relatively identical contents which is a good reason for formation of Al–Si eutectic formed at ultimate solidification step.

Results of EDS mapping of the eutectic region is presented in figure 3. It can be seen that the microstructure of as-brazed sample contains dominant presence of Al and Si elements. The continuous red color in the background proves the existence of $\alpha$-Al and needle-like green Si indications is the demonstrative for forming of Al–Si eutectic.

According to the results observed so far, it can be concluded that due to the sufficiently high brazing temperature and dwell time, almost all Si content of the filler metal have been dissolved into the aluminum matrix and changed the composition of filler metal to Si contents lower than 12%. In fact, based on Al–Si phase diagram, the solidification process begins with pro-eutectic $\alpha$-Al phase and ends with formation of Al–Si eutectic phase as shown in figure 4.

An OM image of as-brazed sample B0.6-B at 610 °C for 5 min, is shown in figure 5(a). This sample was indeed processed at shorter brazing time with respect to B0.6-A. In addition, a SEM image showing a section of
the OM image at higher magnification and few white formed particles during brazing (an example indicated by point A) is shown in figure 5(b). Results of EDS measurements on point A and the matrix are presented in figure 5(c). It can be seen in OM image that the needle-like Al–Si eutectic coexists with pro-eutectic blocky Si.
phases in $\alpha$-Al matrix. This has been observed during solidification of other alloys with similar composition as well\[25\]. It can be seen in figure 5(c) that Al and Si co-exist which represents the formation of Al–Si eutectic phase. However, the lower intensity and weight percent of Si peaks in point A shows formation of composite-like eutectic structure with lower quantitative Si amount with respect to the eutectic phase formed in sample B0.6-A.

The cubic particles in figure 5(a) denote coarse blocky pro-eutectic Si phase with approximate size of 20 $\mu$m. For measurement of size of these pre-eutectic phases, a variety of particles at different zones were selected from main image considering the maximum analogy of that region with respect to the overall distribution of Si throughout microstructure. The Si phase boundary and phase boundaries monitored via OM were evaluated using image processing toolbox of MATLAB. The (B/W) pattern of Si was compared with the (B/W) pattern of the whole micrograph and a certain quantitative degree of similarity was assigned to each selected volume element section. The section with maximum similarity with whole microstructural system was selected as the appropriate representative volume and saved as image file. The obtained (B/W) image files were converted into DXF format with defend boundaries which is readable and appropriate format to be imported to Image-J image analysis commercial package. Based on measurement on contrast difference between zones with boundaries, the average size of Si phase was determined. The formation and further growth of blocky Si phase together with Al–Si phase in Al matrix was reported in other investigations regarding the solidification and phase composition study of Al–7Si–0.3Mg alloy\[26\].

The presence of blocky pro-eutectic Si phase in the microstructure of sample B0.6-B can be attributed to the local increase of Si in Al melt to higher values than Si in Al–Si eutectic phase. According to Al–Si phase diagram, Si has low solubility in Al but Al has no solubility in Si. Therefore, all Si content of the alloy precipitates in two types of Si eutectic and primary blocky pro-eutectic Si phases. In addition, due to time shortage for diffusion of Si from filler to base metal and according to the solidification of a hyper-eutectic alloy, primary blocky pro-eutectic Si initially forms followed by precipitation of hard Al–Si eutectic phase.

Figure 6 illustrates the microstructure of B0.6-C which is vacuum brazed at 590 °C for 5 min. It is easily possible to distinguish between the matrix and the particles which are observed in this image. Indeed, the bright particles are eutectic phases and the matrix is the aluminum. Two major features can be highlighted in the microstructure of this sample which are overall distribution of blocky Si phase and formation of eutectic phase with low Si content. It can be deduced that at lower temperature and holding time, Si does not have the opportunity to be dissolved in Al matrix and consequently, uniform scattering of blocky Si takes place.

3.1.2. Brazing of Al sheet joints with 3 mm thickness
In this section, three samples with different brazing temperature and similar dwell time were considered for more clear interpretation of microstructure-mechanical response. Using the same terminology concept as it was used in the last section, the samples were labeled as in table 4.

The SEM micrograph of sample B3-B is shown in figure 7 in three different magnifications. It can be seen that bright needle-like Si particles, i.e., eutectic phase, is well-distributed throughout Al matrix. For a more detailed clarification of phase distribution during brazing, EDS analysis was conducted on the filler/base metal interface as can be seen in figure 8(a). The upper regions (with point A as representative) with relatively bright color is with high Al content compared to the phase morphology of figure 7. On the other hand, the composite-
like lower regions (represented by point B) entails needle-like Si crystals which indicate the final Al–Si eutectic solidification.

The EDS map data taken form points A and B support the aforementioned phase compositions and formation during 10 min brazing of Al sample at 610 °C. Point A is with high amount of Al and low amount of Si.

Figure 5. (a) OM image showing the microstructure of B0.6-B sample, (b) a SEM image at higher magnification indicating points A for EDS measurements presented in (c).

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that reflects insignificant diffusion of Si form filler to base metal and point B on the counter, with high Si content adjacent to relatively high Al which confirms Al–Si eutectic formation. The uniformity of distribution of involved phases during brazing can be characterized by using EDS mapping, as illustrated in figure 9. It can be seen that the microstructure contains Al, Si, Fe and Cu and regions with red color represent α-Al in the base and filler metal. Despite of this matrix phase, the continuous blue regions show the company of Si elements between Al which confirms Al–Si eutectic phase. The microstructures of samples B3-A and B3-C are not discussed in details as B3-A fails at early stages of deformation during tensile test and B3-C is along with preliminary defects.

**Figure 6.** Microstructure of B0.6-C sample with low content of Si eutectics and high content of pro-eutectic Si phases.

**Table 4.** Labels of the samples used in this part of the study (The brazed samples with 3 mm thickness).

| Sample name | Brazing temperature (°C) | Brazing time (min) |
|-------------|--------------------------|--------------------|
| B3-A        | 590                      | 10                 |
| B3-B        | 610                      | 10                 |
| B3-C        | 630                      | 10                 |
Figure 7. SEM micrographs of B3-B at different magnifications.
Indeed, brazing at 610 °C for 10 min is the only condition that helps to successfully acquire the required mechanical properties.

3.2. Hardness of brazed samples

3.2.1. Brazing of Al sheet joints with thickness of 0.6 mm

The micro-hardness values for three different as-brazed AA3003 samples with 0.6 mm thickness are reported in table 5. Regarding this point that the hardness of Si is 8 times higher than Al, this element play the role of reinforcement phase throughout the composite-like structure of eutectic Al– Si structure. In this regard, the more uniform the distribution of eutectic phase (i.e. less micro-segregation in solidification), the higher the hardness of AA3003 joint. In addition, sample B0.6-C achieved higher hardness than B0.3-B that is itself quite harder than B0.6-A as well and this can be attributed to the higher amount of hard blocky pro-eutectic Si phase with very elevated hardness of 400 Vickers in harder samples.

3.2.2. Brazing of Al sheet joints with thickness of 3 mm

The micro-hardness values for 3 mm thick AA3003 Al joint is measured at different locations throughout B3-B brazed sample and listed in table 6. As can clearly inferred, the hardness of brazed region is quite higher than two other regions and also, the hardness of interface is less than base metal zones. The formation of hard Al–Si eutectic phase in brazed region is the main cause of rising hardness in this joint area while the outward diffusion of Si atom to base metal leads to a reduction in Si amount in the place and decrease hardness at interface due no enough Si for eutectic formation. It should be also pointed that, the hardness in brazed region itself is not

| Element   | Series | UNN (% wt.) | Nom. (% wt.) | Atom (% wt.) |
|-----------|--------|-------------|--------------|--------------|
| Aluminum  | K series | 63          | 62           | 65           |
| Silicon   | K series | 26          | 24           | 27           |
| Iron      | K series | 7           | 8            | 6            |

| Element   | Series | UNN (% wt.) | Nom. (% wt.) | Atom (% wt.) |
|-----------|--------|-------------|--------------|--------------|
| Aluminum  | K series | 87          | 83           | 82           |
| Silicon   | K series | 10          | 11           | 12           |
| Iron      | K series | 2           | 4            | 3            |

Figure 8. Results of EDS measurements of B3-B sample on points (a) A and (b) B.
uniform and has a gradient over this region. Due to capillary motion and outward diffusion of Si atoms form filler metal center to the near interface places, the center and boundary zones of filler metal get the compositions of hypo-eutectic (with low amount of hard Si) and hyper-eutectic (with high amount of hard Si) phases, respectively. In another word, by scanning the brazed region in the Al joint from End to end, a decreasing trend is observed up to reaching a maximum at the halfway point of joint and over again, it gets a decreasing inclination as approaching to the other end.

Figure 9. EDS maps taken from filler/base metal interface of B3-B sample.

Table 5. Hardness check for 0.6 mm Al joint for different brazed samples.

| Sample name | Hardness value (Vickers) |
|-------------|-------------------------|
|             | Brazed region (filler) | Filler/base metal interface | Base metal area |
| B0.6-A      | 47                      | 46                           | 46              |
| B0.6-B      | 52                      | 50                           | 47              |
| B0.6-C      | 61                      | 52                           | 50              |
3.3. Tensile properties

3.3.1. Effect of brazing conditions

3.3.1.1. Brazing of Al sheet joints with thickness of 0.6 mm (Effect of thickness)

Effect of sheet thickness on the stress-strain curves of the samples with 3 and 0.6 mm thickness are shown in figures 10(a) and 10(b), respectively. Figures 10(a) and (b) shows the shapes of the brazed samples after tensile tests and as can be seen that the samples may break from the joint (figure 10(a)) or the base metal (figure 10(b)).

Indeed, the design of the tensile tests results in a shear stress on the joint and tensile stress on the base metal. Therefore, if the ultimate shear strength (USS) of the sample is higher than the ultimate tensile strength (UTS) of

| Location          | Point 1 (Vickers) | Point 2 (Vickers) | Point 3 (Vickers) | Average (Vickers) |
|-------------------|-------------------|-------------------|-------------------|-------------------|
| Base metal        | 56                | 53                | 52                | 54                |
| interface         | 50                | 49                | 50                | 50                |
| Brazed region     | 73                | 75                | 74                | 74                |

Figure 10. (a) Stress-strain curves for brazed samples: Shapes of the samples after tensile tests showing samples which are broken from (b) the joint in the 3 mm thick samples and (c) the base metal in the 0.6 mm thick samples.
the base metal, fracture is expected to occur in the base metal, e.g., in the samples with 0.6 mm thickness. On the contrary, fracture occurs in the joint, if its USS is less than the UTS of the base metal, e.g., in the samples with 3 mm thickness. This also may be explained considering the fact that due to lower thickness of the 0.6 mm samples, they can bear less tensile force and reach the UTS earlier than the UTS of the joint that was also previously seen in the related researches [27].

3.3.1.2. Brazing of Al sheet joints with thickness of 3 mm (Effect of temperature)

Figure 11 shows the stress-strain curves of the initial material together with samples B3-A, B3-B and B3-C. Results indicate that maximum tensile strength and elongation is achieved for sample B3-B. At lower temperature, e.g., in B3-A, or higher temperature, e.g., B3-C, the strength and elongation reduce. However, the minimum strength is observed in B3-B. The tensile behavior of the material clearly shows that the mechanical behavior is not complete and the sample is broken prior to completing its course of uniform deformation, necking and localized deformation. This is indeed in line with the fact that this sample is not broken and is indeed dismantled from the joint area. It should be noted that B3-B exhibits higher tensile strength and plastic deformation than B3-A which is brazed at higher temperature. This may be due to increasing the volume fraction of the eutectic phases due to enhancement of temperature from 590 to 610 °C. However, by further temperature increase to 630 °C, improved and more complete amalgamation of filler metal in base metals leads to the formation and coalescence of shrinkage porosities. The improved mix and co-diffusion of atoms lead to more eutectic phase with different. As listed in table 2, the chemical composition of filler alloy contains nearly 12% silicon and hence, adequate silicon is existing for solution of base metal in the brazing pool at 630 °C. Therefor by increasing temperature to 630 °C increase in silicon concentration happens which assists the base material to melt and go into to the liquid pool zone of the brazing filler. Just after solidification completion of this pool region, voids and cavities may form due to its shrinkage. The superposition of relatively higher shrinkage porosity amount together with lower eutectic microstructure can be expected to lead to a lower mechanical strength of the solidified joints during brazing. This founding is accordance with the finding of related researchers performed the similar process with same filler on AA4047 and AA3003 base metals as well [27]. Therefore, it may be concluded that the porosity-free brazed Al joint with lower hard Al–Si phases, i.e., similar to B3-B, may be of superior mechanical properties rather than B3-C which has defects like porosity in microstructure.

3.3.2. The influence of dwell time on joint strength

In order to evaluate the influence of dwell time on brazed joint structure, samples with 0.6 mm thickness at constant overlap values of 15 mm and at brazing temperature of 590 °C were brazed for two different dwell times of 10 and 15 min It was observed that, by increasing brazing dwell time from 10 to 15 min, the UTS of as-brazed sample decreased. The reason for this phenomenon may be the diffusion of Si form filler metal to the base metal adjacent to filler/base metal interfaces that causes a decrease in melting point of base metal to values lower than 660 °C. This reduction of melting point in the mentioned regions leads to the flow of near-interface molten base metal into filler metal neighborhoods [28]. The difference in thermal expansion coefficient between near filler/base metal interface and central regions of filler metal then give rise to misfit and finally shrinkage porosity
formations. The reduction of strength by increasing the brazing time for joining aluminum plates due to occurrence of shrinkage and voids has been considered elsewhere.

3.4. Topography of fracture surfaces

Figure 12 shows the SEM micrograph of fracture surfaces for two samples of B3-A and B3-B with distinct bright and dark regions. As can be clearly seen, sample B3-B is with relatively higher dark regions which dictates the fracture and failure mode for brazed joints.

For a better understanding, a selected dark part in figure 12(a) in sample B3-B was examined by EDX analysis and results are presented in figure 13. Considering the Al and Si peaks with weight percent of respectively 55.33 and 15.55, it can be deduced that these sections can be attributed to Al–Si eutectic phase and the remaining white parts are α-Al phase. It should be noted that the composition of phases in sample B3-A is similar to B3-B but with different quantity as can be observed in figure 12. Sample B3-A with higher amount of α-Al (bright ones) experienced ductile fracture together with surface voids while the increased regions of continuous dark colors (hard Al–Si eutectic) in B3-A endorses the occurrence of brittle fracture. In other words, the more extensive presence and distribution of ductile Al phase which is more malleable than hard Al–Si eutectic cause ductile
fracture in B3-A sample whereas brittle fracture of B3-B is due to eutectic phase formation. The cross-section of sample B3-B that clearly indicates the α-Al pro-eutectic islands surrounded by continuous Al–Si eutectic can be observed in figure 13. It is also good to add that by increasing the dwell time of vacuum brazing at a constant temperature, the amount of hard eutectic phase rises and the fracture mode changes from ductile to brittle gradually.

4. Conclusions

Vacuum furnace brazing of AA3003 aluminum alloy was carried out using BAlSi-1 filler metal. The effects of sheet thickness, process parameters and lap joint overlap on the microstructure and tensile properties of the samples were considered. Based on the obtained results, the following conclusions can be made;

1. During brazing AA3003 samples with 0.6 mm thickness and dwell time of 10 min, Al–Si eutectic solidifies together with α-Al and blocky Si pro-eutectic phases at processing temperatures of 610 °C and 590 °C, respectively.

2. For 3 mm thick samples brazed at temperature range of 590, 610 and 630 °C at constant dwell time of 10 min, maximum tensile strength and elongation were obtained for samples brazed at 610 °C. In the other samples with higher or lower brazing temperature, the strength and elongation reduce. Lower amount of volume fraction of eutectic phases was observed at 590 °C. Formation and coalescence of shrinkage porosities are the reasons for lower mechanical properties of samples brazed at lower and higher temperatures, respectively.

3. The overlap was changed in the samples with 0.6 mm thickness, in which fracture is more likely to occur in the base metal. Indeed, if fracture is supposed to occur in the base metal, increasing the overlap may not affect the tensile strength of the samples.

4. By increasing dwell time during brazing, higher diffusion of Si from filler metal to the base metal adjacent to filler/base metal interface occurs. This give rise to a decrease in melting point of base metal and yields shrinkage porosity because of difference in thermal expansion between filler/base metal interface and central regions of filler.

5. The higher presence and distribution of ductile Al phase which is more malleable than hard Al–Si eutectic causes ductile fracture in brazed samples while brittle fracture of brazed samples is due to formation of hard non-deformable eutectic phase formation.

6. The development of Al–Si eutectic phase is the key source of rising hardness in this Al joint area while the outward diffusion of Si atom to base metal that leads to a reduction in Si amount, causes a decrease in hardness at interface due to no sufficient eutectic formation.

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