Investigating the effect of change in various process parameters on the mechanical properties of a brazement with Aluminium 6061 as the base material

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Abstract: The aim of this Research to investigate the effect of variation in brazing parameters like clearance gap between base plates, scarf angle and soaking temperature on mechanical properties of brazed joint of Al 6061 plates. Brazing method used for investigation is torch (flame) brazing with oxy-LPG flame and Zn-18Al flux cored filler wire. Brazed joint tested for tensile strength and hardness. Multi-objective optimization was carried out. Results indicate that Clearance gap, scarf angle and soaking temperature have a significant effect on tensile strength, Hardness of joint and filler material consumption. Among Clearance gap, Scarf angle and Soaking temperature, the effect of scarf angle and clearance gap are more dominant. Values of tensile strength and hardness of joint are almost same as parent base material. Parameters that provides maximum tensile strength are Clearance gap 0.183 mm, scarf angle 57.18° and soaking temperature 250.87°C. Parameters that provides minimum hardness are clearance gap 0.298, scarf angle 85.67°C and soaking temperature 296.33°C. Parameters that provides maximum tensile strength, minimum hardness and minimum filler material consumption are Clearance gap 0.216 mm, scarf angle 63.79° and soaking temperature 294.35°C. These numerical optimization is carried out by software Design Expert Version 12.

Keywords- Brazing, Aluminium, Scarf angle, soaking temperature, Mechanical Properties, Numerical Analysis, Optimization

I. INTRODUCTION

The frequently preferred process for joining aluminium alloy is tungsten inert gas welding. However, this process causes grains to coarsen in the fusion zone, distortion, an increased tendency to undergo hot cracking and residual stresses. Brazing is a metal joining technique where in a filler metal is used to join two or more materials by drawing it into the joint by capillary action. Brazing allows for more precise control of tolerances and provides a clean joint with no need for additional finishing. Therefore, brazing has wide range of applications in industries like aerospace, automobile industries, electrical circuits, heat exchangers and medical instruments. Therefore joining of aluminium alloy is important concern. Lots of efforts have been made in the previous years in developing different filler a Wei Dai, Songbai Xue, Jiyoun Lou and Shuqing Wang designed ternary Al-Si-Zn filler metals in order to join the 6061 aluminium alloy. The microstructure, phase constitution and fracture morphology of the brazed joint were investigated [1]. S.Y. Chang, L.C. Tsao, T.Y. Li, T.H. Chuang designed Al-Si-Cu filler materials and carried out brazing of Aluminium 6061[2]. Jilong Yang, Songbai Xue, Peng Xue, Zhaojing Lv, Weimin Long, Guanxing Zhang, Qingke Zhang, Penghe have conducted brazing of Al6061 to stainless steel 304 using Zn–15Al–xZr filler metal and the effects of Zirconium(Zr) addition on the properties and microstructures of Zn–15Al filler metals were investigated. The experimental results indicated that the liquidus temperature of Zn–15Al–xZr was approximately 445 °C and Zr addition had little influence on the melting point of the Zn–15Al–xZr filler metal[3]. Dai Wei, Xue Songbai, Sun Bo, Lou Ji, Wang Suqing developed Al-Si-Zn filler metals containing Ti and Sr and which is used for brazing Al6061 The results indicate that the addition of Zn into the Al–Si filler metal lowers the solids temperature from 583 °C to around 520 °C. The minor addition of modification element Sr and refine element Ti into Al-Si-Zn alloy will cause the remarkable modification of Al-Si eutectic and the α-Al phase is also refined[4]. Wei Dai, Song-bai Xue, Feng Ji, Jiang Lou, Bo Sun, and Shui-qing Wang developed Al-6.5Si-42Zn and Al-6.5Si-42Zn-0.09Sr filler metals which is used for brazing 6061 aluminium alloy. Air cooling and water cooling were applied after brazing. Si phase morphologies in the brazing alloy and the brazed joints were investigated[5]. Dai Wei, Xue Song-bai, Lou Ji-juan, Lou Yin-Bin, Wang Shui-qing were used torch brazing for brazing Al3003 using Al-Zn filler. Using Zn-Al filler metal with Al content of 2%-22% (mass fraction) and improved Csf-AlF3 flux, wetting properties of Zn-Al filler metal on 3003 Al substrate were investigated[6]. L.C. Tsao, M.J. Chiang, W.H. Lin, M.D. Cheng, T.H. Chuang have studied series of Al–Si–Cu–Zn alloys For the development of a low-melting-point filler metal for brazing aluminum alloys[7]. Fangfei Sui, Weimin Long, Shengxin Liu, Guanxing Zhang, Li Bao, Hao Li, Yong Chen have carried out ion was carried out. Results indicate that Clearance gap, scarf angle and soaking temperature 296.33°C. Parameters that provides maximum tensile strength, minimum hardness and minimum filler material consumption are Clearance gap 0.216 mm, scarf angle 63.79° and soaking temperature 294.35°C. These numerical optimization is carried out by software Design Expert Version 12.

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Al-20Cu-7Si braze alloys containing various contents of Er were prepared, and their melting temperature, microstructure, hardness, and wettability in contact with 3003 aluminum alloy substrates were determined[10]. Yang Jinlong , Xue Songbai , Xue Peng , Lv Zhaoping , Dai Wei , Zhang Junxiang have developed novel CsF–RbF–AlF₃ flux for aluminum brazing[11]. Bing Xiao , Dongpo Wang , Fangjie Cheng , YangWangIntermediate-temperature brazing of the 5052 aluminium alloy was conducted using Zn–xAl (x = 8, 15, and 22 wt.%) filler metals with a ZrF₄-containing CsF–AlF₃ flux developed in this study[12]. Haojiang Shi, Jiazhen Yan, Ning Li, Xin Zhu, Kangwei Chen, Lingfei Yu have investigated the effect of brazing time and brazing temperature on joint strength of brazing FeCrMo damping alloy[13]. Huei Lin, Jiun Ren Hwang And Chin-Ping Fung have investigated how different process parameters affect the tensile properties of 6061-T6 aluminum vacuum brazed joints. The parameters including the soaking temperature, soaking time, brazing temperature, and brazing time were taken into consideration[14]. Arkan Kh. Al Taie and Alaa A. Ateia have investigated the effects of clearance width on the tensile, bending and torsion strength of a low carbon steel butt weld joint. Experiments have proved that the joint strength increases with clearance width to reach a maximum value at a clearance width of (0.29-0.3mm)[15].

Literature review shows that lots of research work in the field of brazing is done in filler material and flux material development. Effect of variation of Scarf angle, clearance gap between base plates and post brazing heat treatment on properties of brazement for Al6061 has not been studied.

II. EXPERIMENTAL SETUP AND METHODOLOGY

Experimental setup for the brazing of Al is shown in below Figure 1. As shown in figure, manual flame brazing method was used for the brazing purpose. Flame type is oxy-LPG. Base material selected is Al 6061 having size of 50 X 25 X 6 mm3.

Figure 1: Experimental setup of flame brazing (Heat source and nozzle)

Composition of Al 6061 is shown in Table 1. Filler metal used in this research is an alloy of Aluminium and Zinc. Filler wire is flux cored. The properties and composition of the filler wire is shown in Table 2 and Table 3. Filler wire CsKAlF₄ flux which is non-corrosive and non-toxic in nature. Before brazing process was carried out, both base plates were machined to required scarf angle. After that both plates were cleaned using aqueous cleaning technique. After that both plates were assembled in proper alignment with different geometric parameters and held in their respective position by c clamp. Gap between two plates was measured with the help of filler gauge. The experiments were performed as by selecting different parameters. In this research, find the effect of variation in scarf angle, clearance gap and soaking temperature on mechanical properties of joint. Scarf angle, Clearance gap and Soaking temperature are variable parameters. After selecting variable parameter, three levels for each parameter were selected as shown in Table 4. Design of experiments performed by box-behnken method. It is an experimental design for response surface methodology. 15 experiments performed as per DOE. The design of experiment given by box-behnken method is shown in Table 5.

Table 1: Chemical compositions of base metal Al 6061

<table>
<thead>
<tr>
<th>Element</th>
<th>Mg</th>
<th>Si</th>
<th>Cu</th>
<th>Cr</th>
<th>Mn</th>
<th>Zn</th>
<th>Ti</th>
<th>Fe</th>
<th>Al</th>
</tr>
</thead>
<tbody>
<tr>
<td>% wt</td>
<td>0.56</td>
<td>0.410</td>
<td>0.001</td>
<td>0.12</td>
<td>0.008</td>
<td>0.009</td>
<td>0.008</td>
<td>0.1</td>
<td>98.83</td>
</tr>
</tbody>
</table>

Table 2: Properties of filler material

<table>
<thead>
<tr>
<th>Type</th>
<th>SU-TC 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting Temperature</td>
<td>425 – 490 °C</td>
</tr>
<tr>
<td>Diameter</td>
<td>1.4 mm</td>
</tr>
<tr>
<td>Shape</td>
<td>Wire Shape</td>
</tr>
</tbody>
</table>
Table 3: Chemical compositions of filler material

<table>
<thead>
<tr>
<th>Element</th>
<th>%wt</th>
</tr>
</thead>
<tbody>
<tr>
<td>Al</td>
<td>18.53</td>
</tr>
<tr>
<td>Zn</td>
<td>81.27</td>
</tr>
<tr>
<td>Other Element</td>
<td>0.20</td>
</tr>
</tbody>
</table>

Table 4: Levels of the variables according to RSM

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Level -1</th>
<th>Level 0</th>
<th>Level 1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clearance gap (d)</td>
<td>0.1</td>
<td>0.2</td>
<td>0.3</td>
</tr>
<tr>
<td>Scarf angle (θ)</td>
<td>30°</td>
<td>60°</td>
<td>90°</td>
</tr>
<tr>
<td>Soaking Temperature (T)</td>
<td>200 °C</td>
<td>250 °C</td>
<td>300 °C</td>
</tr>
</tbody>
</table>

Table 5: Values of the variables of the matrix of experiments

<table>
<thead>
<tr>
<th>Order</th>
<th>Coded Variable</th>
<th>Real Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Clearance gap “A”</td>
<td>Scarf Angle “B”</td>
</tr>
<tr>
<td>1</td>
<td>-1</td>
<td>-1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>-1</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>-1</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>0</td>
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<tr>
<td>9</td>
<td>0</td>
<td>-1</td>
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<tr>
<td>10</td>
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<td>1</td>
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<tr>
<td>11</td>
<td>0</td>
<td>-1</td>
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<tr>
<td>12</td>
<td>0</td>
<td>1</td>
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<td>13</td>
<td>0</td>
<td>0</td>
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<tr>
<td>14</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Specimen brazed according to the DOE is shown in Figure 2. Post brazing, joints are put in furnace which are heated from room temperature to required temperature (200°C, 250°C, 300°C) for 60 minutes and after that cooled in furnace (Annealing process). For grain growth and desirable results of testing 14 days time is given to specimens for natural ageing of aluminium and after that mechanical testing is carried out.

Specimens were tested for the ultimate tensile strength and hardness. The ultimate tensile strength of the joint was examined by Fie universal testing machine UTE 40. For hardness, Fie Vickers hardness tester VM 50 was used. To select optimum parameters for required strength and hardness, optimization and numerical analysis were performed using ANOVA.

III. RESULTS AND DISCUSSION

Result obtained from the experiment are shown in Table 6. To analyze this result and perform optimization of process parameters Design expert software version 12 was used for this purpose. Analysis of variance (ANOVA) has been performed to find the effects of each factors and their interactions with the responses. ANOVA provides an estimate of variance via the mean square of the residuals.

For ultimate tensile strength and hardness, mathematical model was developed to relating response and the factors to facilitate the optimization of the process.
3.1 Ultimate tensile strength

The second order Ultimate tensile strength model is developed using Response surface methodology (RSM) from the experimental results of Ultimate tensile strength (UTS), The final equation in terms of coded factors for UTS is given by,

\[
UTS = +121.11 - 1.29*A - 2.12*B - 0.0273*C - 0.1597*AB - 0.6515*AC - 0.3190*BC - 3.89*A^2 - 11.16*B^2 - 3.05*C^2
\]

Where A = clearance gap B = scarf angle and c = soaking temperature

The analysis of variance (ANOVA) and F-ratio test have been performed to justify the goodness of fit for the second order UTS model as shown in table 7. The Model F-value of 56.57 implies the model is significant. P-values less than 0.0500 indicate model terms are significant. Regression analysis of tensile strength is shown in table 8 The “Predicted R²” of 0.8659 is in reasonable agreement with the “Adjusted R²” of 0.9728 as one might normally expect; i.e. the difference is less than 0.2. Reasonable agreement between these two terms of regression Pred R² and Adj R² shows that data obtained through the experimental investigations is properly fitted through the mathematical models obtained through the regression analysis. This implies that the model proposed is
adequate and there is no reason to suspect any violation of the independent or constant variance assumption. Hence, the model can be used for further analysis to determine the effects of various process parameters on the response.

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DOF</th>
<th>Mean Square</th>
<th>F-value</th>
<th>p-value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>560.28</td>
<td>9</td>
<td>62.25</td>
<td>56.57</td>
<td>0.0002</td>
<td>significant</td>
</tr>
<tr>
<td>A-Clearance Gap</td>
<td>13.26</td>
<td>1</td>
<td>13.26</td>
<td>12.05</td>
<td>0.0178</td>
<td></td>
</tr>
<tr>
<td>B-Scarf Angle</td>
<td>35.84</td>
<td>1</td>
<td>35.84</td>
<td>32.57</td>
<td>0.0023</td>
<td></td>
</tr>
<tr>
<td>C-Soaking Temperature</td>
<td>0.0059</td>
<td>1</td>
<td>0.0059</td>
<td>0.0054</td>
<td>0.9443</td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>0.1021</td>
<td>1</td>
<td>0.1021</td>
<td>0.0928</td>
<td>0.7730</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>1.70</td>
<td>1</td>
<td>1.70</td>
<td>1.54</td>
<td>0.2693</td>
<td></td>
</tr>
<tr>
<td>BC</td>
<td>0.4070</td>
<td>1</td>
<td>0.4070</td>
<td>0.3699</td>
<td>0.5696</td>
<td></td>
</tr>
<tr>
<td>A²</td>
<td>56.00</td>
<td>1</td>
<td>56.00</td>
<td>50.89</td>
<td>0.0008</td>
<td></td>
</tr>
<tr>
<td>B²</td>
<td>460.13</td>
<td>1</td>
<td>460.13</td>
<td>418.16</td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>C²</td>
<td>34.43</td>
<td>1</td>
<td>34.43</td>
<td>31.29</td>
<td>0.0025</td>
<td></td>
</tr>
<tr>
<td>Residual</td>
<td>5.50</td>
<td>5</td>
<td>1.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack of Fit</td>
<td>4.62</td>
<td>3</td>
<td>1.54</td>
<td>3.48</td>
<td>0.2314</td>
<td>not significant</td>
</tr>
<tr>
<td>Pure Error</td>
<td>0.8854</td>
<td>2</td>
<td>0.4427</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>565.78</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2 Effect of individual parameters on UTS

The effect of each individual parameter namely clearance gap, scarf angle and soaking temperature is shown in Figure 3. For clearance gap, with increase in Clearance gap, Ultimate tensile strength increases first, then it becomes maximum, then it starts decreasing with increase in value of Clearance Gap. At lower Clearance gap, filler metal consumption is less and very thin joint take place and due to that strength of joint is slightly low. As clearance gap increase joint thickness is increase and strength of joint is also increase. For Larger clearance gap, capillary action is not take place properly due to that the value of Ultimate tensile strength decreases at higher clearance gap. Effect of scarf angle has similar effect like variation in clearance gap. With increase in scarf angle first tensile strength increase then become maximum and after that start decreasing with increase in value of scarf angle. This behaviour is observed in Figure. For low value of scarf angle failure is combined effect of tension and shear and due to that tensile strength is slightly reduced. At very high scarf angle joint area is reduced and due to that tensile strength is reduced.
Factor Coding: Actual

Tensile Strength (MPa)
- Design Points
- 95% CI Bands

X1 = A

Actual Factors
B = 60
C = 25

One Factor

Tensile Strength (MPa)

A: Clearance Gap (mm)

One Factor

Tensile Strength (MPa)

C: Soaking Temperature (celsius)
For soaking temperature, the effect of increase in soaking temperature on tensile strength is less dominant. With increase in soaking temperature tensile strength is increase become maximum for value about 250°C and then slightly decrease with increase in soaking temperature. This behaviour can seen from figure 3.

3.3 Hardness

The second order model for hardness is developed using Response surface methodology (RSM) from the experimental results. The final equation in terms of coded factors for Hardness is given by,

\[
\text{Hardness} = 89 - 5.625 \times A - 0.875 \times B - 0.5 \times C - 0.25 \times AB - 0.5 \times BC - 0.125 \times A^2 + 0.875 \times B^2 - 1.875 \times C^2
\]

Where, A, B and C are coded variables for Clearance gap, scarf angle and soaking temperature respectively.

The analysis of variance (ANOVA) and F-ratio test have been performed to justify the goodness of fit for second order hardness model. ANOVA for hardness model shown in table 9. The Model F-value of 68.98 implies the model is significant. P-values less than 0.0500 indicate model terms are significant.

Regression model for hardness shown in table 10. The Predicted R² of 0.9698 is in reasonable agreement with the Adjusted R² of 0.9776; i.e. the difference is less than 0.2. Reasonable agreement between these two terms of regression Pred R² and Adj R² shows that data obtained through the experimental investigations is properly fitted through the mathematical models obtained through the regression analysis.

This implies that the model proposed is adequate and there is no reason to suspect any violation of the independent or constant variance assumption. Hence, the model can be used for further analysis to determine the effects of various process parameters on the response.

### Table 9: ANOVA for the Hardness model

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of Squares</th>
<th>DOF</th>
<th>Mean Square</th>
<th>F-value</th>
<th>p-value</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>279.35</td>
<td>9</td>
<td>31.04</td>
<td>68.98</td>
<td>0.0001</td>
<td>significant</td>
</tr>
<tr>
<td>A-Clearance Gap</td>
<td>253.13</td>
<td>1</td>
<td>253.13</td>
<td>562.50</td>
<td>&lt; 0.0001</td>
<td></td>
</tr>
<tr>
<td>B-Scarf Angle</td>
<td>6.13</td>
<td>1</td>
<td>6.13</td>
<td>13.61</td>
<td>0.0142</td>
<td></td>
</tr>
<tr>
<td>C-Soaking Temperature</td>
<td>2.00</td>
<td>1</td>
<td>2.00</td>
<td>4.44</td>
<td>0.0888</td>
<td></td>
</tr>
<tr>
<td>AB</td>
<td>0.2500</td>
<td>1</td>
<td>0.2500</td>
<td>0.5556</td>
<td>0.4896</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>0.0000</td>
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<td>0.0000</td>
<td>1.0000</td>
<td></td>
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</tbody>
</table>
Table 10: Regression analysis of Hardness Model

<table>
<thead>
<tr>
<th></th>
<th>Std. Dev.</th>
<th>R²</th>
<th>Adjusted R²</th>
<th>Predicted R²</th>
</tr>
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<tbody>
<tr>
<td>Mean</td>
<td>0.6708</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C.V. %</td>
<td>0.7588</td>
<td>0.9920</td>
<td>0.9776</td>
<td>0.9968</td>
</tr>
<tr>
<td>Press</td>
<td>8.50</td>
<td></td>
<td>Adeq Precision</td>
<td>27.6143</td>
</tr>
</tbody>
</table>

3.4 Effect of individual parameters on hardness

Effect of variable parameters on hardness is shown in figure individually. For clearance gap, as clearance gap is increase there is decrease in the hardness value of the joint. This behaviour is seen from the figure. This happen due to hardness value of Filler (Zn-22Al) is around 90-100 HV while hardness value of base metal is around 110-120 HV. As clearance gap increase joint is purely made of Zn-22Al.

For scarf angle, Scarf angle has negligible effect on the joint hardness value as shown in figure. Hardness value is almost same for scarf angle ranges from 30-90 degree. Slight variation in hardness value is due to noise and effect of other factors.

As shown in figure 4, the effect of increase soaking temperature on Hardness is not much dominant. Hardness value of brazed joint is almost same for entire range of soaking temperature which is chosen for these experiment.
3.5 Multi objective optimization

The process variables that affects the value of responses are clearance gap, scarf angle and soaking temperature. An optimization was carried out for finding maximum tensile strength, minimum hardness and minimum filler metal consumption. Goals apply to the factors and responses that were used for optimization are shown in table 11.

Table 11: Constraints values for the optimization for maximum tensile strength and minimum hardness

<table>
<thead>
<tr>
<th>Name</th>
<th>Goal</th>
<th>Lower Limit</th>
<th>Upper Limit</th>
<th>Importance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A: Clearance Gap</td>
<td>is in range</td>
<td>0.1</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>B: Scarf Angle</td>
<td>is in range</td>
<td>30</td>
<td>90</td>
<td>3</td>
</tr>
<tr>
<td>C: Soaking Temperature</td>
<td>is in range</td>
<td>200</td>
<td>300</td>
<td>3</td>
</tr>
<tr>
<td>Tensile Strength</td>
<td>maximize</td>
<td>103.442</td>
<td>121.543</td>
<td>3</td>
</tr>
<tr>
<td>Hardness</td>
<td>minimize</td>
<td>81</td>
<td>96</td>
<td>3</td>
</tr>
</tbody>
</table>
Results of optimization shows in table 12. Parameters that provides maximum tensile strength, minimum hardness and minimum filler material consumption are Clearance gap 0.216 mm, scarf angle 63.79° and soaking temperature 294.35°C.

<table>
<thead>
<tr>
<th>Clearance Gap</th>
<th>Scarf Angle</th>
<th>Soaking Temperature</th>
<th>Tensile Strength</th>
<th>Hardness</th>
<th>Desirability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.216</td>
<td>63.797</td>
<td>294.349</td>
<td>117.798</td>
<td>86.013</td>
<td>0.750</td>
</tr>
</tbody>
</table>

IV. CONCLUSION

1) Clearance gap, scarf angle and soaking temperature have a significant effect on tensile strength, Hardness of joint and filler material consumption. Among Clearance gap, Scarf angle and Soaking temperature, the effect of scarf angle and clearance gap are more dominant.
2) Ultimate tensile strength of the joint w.r.t. clearance gap, when increase then UTS increase, attain maximum value and then again start decreasing. Effect of scarf angle is also same as clearance gap on UTS. The effect of soaking temperature is not as much dominant as other two parameters.
3) Hardness of joint is decrease with increase in Clearance gap. The effect of scarf angle and soaking temperature on hardness of brazed joint are very less dominant.
4) For optimum joint design, Parameters that provides maximum tensile strength, minimum hardness and minimum filler material consumption are Clearance gap 0.216 mm, scarf angle 63.79° and soaking temperature 294.35°C.

V. FUTURE SCOPE

1) Effect of soaking time on the mechanical and metallurgical properties of the joint can be checked.
2) Comparative study of effect of different brazing techniques on output parameters can be recorded.
3) Microstructure and Non-destructive testing (Liquid penetrant testing) of joint can be studied.

VI. REFERENCES

