APPENDIX 1

CALCULATION OF AMOUNT OF INORGANIC SALTS

Molar weight of $\text{ZrB}_2 = 112.85$ g/mol
Molar weight of $\text{K}_2\text{ZrF}_6 = 283.11$ g/mol
Molar weight of $\text{KBF}_4 = 125.90$ g/mol

$\text{K}_2\text{ZrF}_6 + 2\text{KBF}_4 \rightarrow \text{ZrB}_2 + 4\text{KF} + \text{Heat}$

283.11 g $\text{K}_2\text{ZrF}_6 + 2.4 \times 125.90$ g $\text{KBF}_4 = 112.85$ g $\text{ZrB}_2$

(Salt ratio 1:2.4 is adopted to avoid $\text{Al}_3\text{Zr}$ phase)

To form P g of $\text{ZrB}_2$, amount of inorganic salts required is

$\text{K}_2\text{ZrF}_6 = (283.11 \times P / 112.85)$ g
$\text{KBF}_4 = (2.4 \times 125.90 \times P / 112.85)$ g

To form Q wt.% of $\text{ZrB}_2$, amount of inorganic salts required is

Die weight = 1250 g
Die weight is taken as matrix weight to avoid blow holes since $\text{ZrB}_2$ particles occupy less volume.

If matrix weight is 1250 g, weight of Q wt.% of $\text{ZrB}_2 = (Q \times 1250) / (100-Q)$ g

$\text{K}_2\text{ZrF}_6 = (283.11 \times Q \times 1250) / (112.85 \times (100-Q))$ g
$\text{KBF}_4 = (2.4 \times 125.90 \times Q \times 1250) / (112.85 \times (100-Q))$ g

Assume 5wt.% $\text{ZrB}_2$ is to be fabricated, amount of inorganic salts required is

$\text{K}_2\text{ZrF}_6 = (283.11 \times 5 \times 1250) / (112.85 \times (100-5)) = 165$ g
$\text{KBF}_4 = (2.4 \times 125.90 \times 5 \times 1250) / (112.85 \times (100-5)) = 176$ g
APPENDIX 2

IMPORTANT SPECIFICATIONS OF FSW MACHINE

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spindle</td>
<td>ISO 40</td>
</tr>
<tr>
<td>Spindle motor</td>
<td>440V AC Drive.</td>
</tr>
<tr>
<td>Spindle speed</td>
<td>0 to 3000 rpm (infinitely variable)</td>
</tr>
<tr>
<td>Z axis stroke (Auto)</td>
<td>300 mm</td>
</tr>
<tr>
<td>Z axis stroke</td>
<td>25 mm (Manual – hand wheel)</td>
</tr>
<tr>
<td>Z axis thrust</td>
<td>5 kN (Min) – 50 kN (Max)</td>
</tr>
<tr>
<td>X axis stroke</td>
<td>600 mm</td>
</tr>
<tr>
<td>X axis feed</td>
<td>0 to 500 mm/min.</td>
</tr>
<tr>
<td>X axis thrust</td>
<td>2.5 kN (Min) – 25 kN (Max)</td>
</tr>
<tr>
<td>X axis rapid traverse</td>
<td>5000 mm/min</td>
</tr>
<tr>
<td>Y axis stroke (manual)</td>
<td>200 mm</td>
</tr>
<tr>
<td>Table</td>
<td>600 mm x 350 mm</td>
</tr>
<tr>
<td>Hyd. Power pack motor</td>
<td>2.2 kW / 440V</td>
</tr>
<tr>
<td>Guide ways ‘Y’</td>
<td>Hardened &amp; ground steel strips</td>
</tr>
<tr>
<td>Slide ‘Y’</td>
<td>Turcite coated</td>
</tr>
</tbody>
</table>
APPENDIX 3

HEAT INPUT CALCULATION

\[ Q = \left( \frac{2 \pi}{3} \right) \times \tau_c \times \omega \times (R^3 + 3r^2h) \times (1-\delta) \times \eta / S \]

Where

- \( Q \) = Heat generated (KJ/mm)
- \( \tau_c \) = Contact stress (MPa)
- \( \tau_c = \mu \times P \)
- \( \mu \) = Coefficient of friction \( \sim 0.3 \)
- \( P \) = Axial pressure (kN/m²)
- \( P = F/A \)
- \( F \) = Axial force (kN)
- \( A \) = Tool shoulder area (m²)
- \( \omega \) = Angular tool rotational speed (rad/s)
- \( \omega = \left( \frac{2\pi}{60} \right) N \)
- \( N \) = Tool rotational speed (rpm)
- \( R \) = Tool shoulder radius (m)
- \( r \) = Tool pin radius (m)
- \( h \) = Tool pin height (m)
- \( \delta \) = Material velocity / Tool velocity \( (0 \leq \delta \leq 1) \)
- \( \delta = 0 \) (Assuming perfect sliding)
- \( \eta \) = Heat transfer efficiency \( \sim 0.8 \)
- \( S \) = Tool traverse speed (m/s)

For example, heat generated during FSW of trial run T01 is computed as follows

\[ Q = \left( \frac{2 \pi}{3} \right) \times (0.3 \times 5 / \pi \times 0.009^2) \times (2 \pi \times 1075 / 60) \times \\
(0.009^3 + 3x 0.003^2 \times 0.0057) \times (1-0) \times 0.8 / (40/60) \]

\[ = 1.47 \text{ KJ/mm} \]
APPENDIX 4

GRG ALGORITHM

Step 1. Choose:
- a starting set of variable $V^0$ of feasible $V_i$’s
- an initial number of iterations $N_s$
- an accuracy $\varepsilon$ for convergence and stopping

Set $p = 1$ (iteration counter)

Step 2. Identify basic, non-basic and super-basic variables
- If $p = 1$, variables that are not basic are set to be super-basic
- Calculate search direction $G_R$
- Calculate an optimum step size
- Calculate $V^p$

Step 3. Convergence and Termination

Convergence for GRG
- If the Kuhn–Tucker conditions are satisfied then STOP.

Stopping Criteria
- Variable increment $\Delta V = |V^p - V^{p-1}|$
  - If $\Delta V < \varepsilon$ then STOP.
- If $p = N_s$
  - Find the extrapolated maximum number of iterations $N_{\text{max}}$
    - If $N_{\text{max}} > N_s$ then set $N_s = N_{\text{max}}$ else STOP.

Continue to the next iteration (increment $p$ by one)
- Go to step 2