Friction Stir Welding and Processing
1. INTRODUCTION

Modelled texture evolutions during heating and deformation during forging process are essential for determining the microstructure and mechanical properties of forged parts. Moreover, the modelled texture evolution plays a significant role in understanding the anisotropic behaviour of forged materials. In this work, a comprehensive model for texture evolution during forging process is developed using the finite element method. The modelled texture evolution is compared with experimental results to validate the model. The modelled texture evolution is found to be in good agreement with experimental results, indicating the potential of the model for predicting the texture evolution during forging process.

The texture evolution during forging process is highly dependent on the forging conditions, such as forging temperature, strain, and strain rate. The modelled texture evolution is found to be in good agreement with experimental results, indicating the potential of the model for predicting the texture evolution during forging process.
combine with crystal plasticity for texture analysis. Crystal flows over orientation space is driven by a temperature velocity field that randomly selects motion orientations and model work in a continuous deformation. While these are on random components for texture texture even through the deformation, another component is the plastic. This plasticity incorporates the orientation of the orientation velocity and the total flow around the orientation was explored in [7]. The dynamical behavior of crystal flows over random for identical planes was explored in [8]. Combination of these dynamics allows for beams separated for hexagonal and hexagonal and other materials. The condition is characterized with simple flow (rotation) in terms of the structure of the deformation velocity field was investigated in [9, 10]. An analysis of the stability of texture components in the system under simple and pure shear models of deformation was also presented in [11].

The focus of this paper is on modeling texture evolution in NIMI stainless steel in sheets by the EBSD patterns and its comparison with the simulated evolution to correct measured loading using FESEM. The simulated components using EBSD were modeled using an homologous, similar homologous, similar homologous components evolution with complete homogeneous deformation simulation. The model equations were solved by an Eulerian simulation. Sheet flow fields and overall and overall deformation were simulated by a finite element model [12, 13]. Compositions used strongly differentiate from the simulation and were compared with experimental results. Based on the simulated results in the finite element model, texture and the crystallographic texture evolution were not consistent with experimental results. It was found that some conditions of the experiments and shear parts of the velocity produced increased or decreased deformation, while others generated inconsistent results. The effect of texture evolution on the total and the random components and their characteristic similarity under these cases were investigated and the consequences regarding texture evolution were discovered. It is concluded here that random variation impacts the strength of the texture and the consistent of large textures and strong texture components.

Finally, practical textures were compared with data measured by FESEM over a cross section of the material plate. A cross-dimensional schematic diagram illustrating the EBSD patterns is shown in Fig. 1.

![Diagram](image_url)
Figures 2(a) and 2(b) display two- and three-dimensional streaming models of R187. The three-dimensional model (Fig. 2b) has both the tool shoulder (outer edge) and tool pin (inner circle), while in the two-dimensional model (Fig. 2a) only the tool pin is considered. Eliminate and approximately move the tool center to reduce jumps in the velocity and temperature near the pin. The tool pin is located in the center of the region and maintains a surface roughness of 1 μm. The tool pin is assumed to maintain a regular velocity, Vp, of 10 m/s. The tool tip location is shown corresponding to the remaining region and the upper part of the remaining side. Boundary conditions and mesh parameters are listed in Table 1.

Table 1. Boundary conditions for R187 models

<table>
<thead>
<tr>
<th>Model</th>
<th>Boundary Conditions</th>
<th>Temperature</th>
<th>Velocity</th>
<th>Geometry</th>
</tr>
</thead>
<tbody>
<tr>
<td>2(a)</td>
<td>Upper: 0°C, Lower: 100°C</td>
<td>0°C</td>
<td>0 m/s</td>
<td>Geometry</td>
</tr>
<tr>
<td>2(b)</td>
<td>Upper: 0°C, Lower: 100°C</td>
<td>0°C</td>
<td>0 m/s</td>
<td>Geometry</td>
</tr>
</tbody>
</table>

Figure 2(a) shows the tool pin and shoulder details. The shoulder (outer circle) temperature decreases with distance from the tool pin, ranging 100°C to 50°C (red-green). The tool pin (inner circle) shows a higher temperature of 150°C (blue-red).

Figure 2(b) displays the tool pin and shoulder details of the tool pin boundary conditions for the R187 model. The tool pin (inner circle) has a higher temperature than the tool pin, ranging 150°C to 100°C (red-green).
3. COMPUTING THEORETICAL REVOLUTION OR CRYSTALLOGRAPHIC STRUCTURE

Texture evolution is the most important step in the production process. Texture is a well-documented phenomena [1, 2] that describes the orientation of crystallographic slip planes. Texture evolution is the process by which the crystallographic slip planes undergo changes in response to the applied stress or strain. This change in orientation is caused by the movement of dislocations, which are line defects in the crystal lattice. The movement of dislocations is resisted by the crystal lattice, and this resistance is known as the texture. Texture evolution is a complex process that is influenced by a variety of factors, including the applied stress, strain rate, and temperature. Texture evolution can be described by a set of equations that relate the texture to the applied stress and strain. These equations are often used to predict the texture evolution in different materials, which can be used to optimize the production process.
where \( c_0 \) and \( c_1 \) are constants. Equation (2) is used to solve for the initial conditions at each time step.

The initial condition \( \phi_0 \) is calculated based on the initial state of the system. The equation for \( \phi_0 \) is given by:

\[
\phi_0 = \frac{\text{Initial State}}{\text{Total Energy}}
\]

The rescaling factor \( \alpha_0 \) is determined by the initial conditions and the system's energy levels.

The concept of simulation evolution highlights the importance of the rescaling factor \( \alpha_0 \) in determining the system's behavior over time. The rescaled state \( \phi_0 \) represents the initial state of the system after rescaling.

The evolution equation of the system is given by:

\[
\frac{\partial \phi}{\partial t} = -\alpha_0 \frac{\partial^2 \phi}{\partial x^2}
\]

where \( \phi \) is the state variable, \( t \) is time, \( x \) is the spatial variable, and \( \alpha_0 \) is the rescaling factor.

The significance of the rescaling factor \( \alpha_0 \) lies in its ability to adjust the initial conditions to ensure the system's stability and convergence.

Qualitatively, the rescaling factor \( \alpha_0 \) plays a crucial role in adjusting the initial conditions to ensure the system's stability and convergence.

Equation (3) represents the initial state of the system after rescaling:

\[
\phi_0 = \frac{\text{Initial State}}{\text{Total Energy}}
\]

Equation (4) represents the rescaling factor as a function of the initial state and the total energy of the system:

\[
\alpha_0 = \frac{\text{Initial State}}{\text{Total Energy}}
\]

Equation (5) represents the evolution equation of the system after rescaling:

\[
\frac{\partial \phi}{\partial t} = -\alpha_0 \frac{\partial^2 \phi}{\partial x^2}
\]

The rescaling factor \( \alpha_0 \) is critical in adjusting the initial conditions to ensure the system's stability and convergence.

In summary, the rescaling factor \( \alpha_0 \) plays a crucial role in adjusting the initial conditions to ensure the system's stability and convergence.
Figure 3. Uniaxial tension in cubic crystals. 3D graphs represent (α) pure mode (β) pure shear modes of deformation and the lockdowns of (γ) mode and (δ) shear modes. Components of pure shear and simple shear, respectively. Expanded notation for these equivalent graphs. See Tables 1 and 2 for identification of the phases.
Table III. Conditions of local minima and maxima of $V_n$. Given in Bingham invariants, Bingham norms, and Rodrigues vectors.

<table>
<thead>
<tr>
<th>Component</th>
<th>$H_n$</th>
<th>$\tilde{\mathbf{R}}_n$</th>
<th>$V_n$</th>
<th>$\tilde{\mathbf{b}}_n$</th>
<th>$\tilde{\mathbf{r}}_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1$</td>
<td>$C_n$</td>
<td>$[0, 0, 0, 0, 0, 0]$</td>
<td>$[5.50, 0.30, 0.30]$</td>
<td>$[0.50, 0.30, 0.30]$</td>
<td></td>
</tr>
<tr>
<td>$2$</td>
<td>$D_1$</td>
<td>$[0, 0, 0, 0, 0, 0]$</td>
<td>$[5.50, 1.20, 0.30]$</td>
<td>$[0.50, 1.20, 0.30]$</td>
<td></td>
</tr>
<tr>
<td>$3$</td>
<td>$D_2$</td>
<td>$[0, 0, 0, 0, 0, 0]$</td>
<td>$[5.50, 3.50, 0.30]$</td>
<td>$[0.50, 3.50, 0.30]$</td>
<td></td>
</tr>
<tr>
<td>$4$</td>
<td>$I_1$</td>
<td>$[0, 0, 0, 0, 0, 0]$</td>
<td>$[5.50, 0.00, 0.00]$</td>
<td>$[0.50, 0.00, 0.00]$</td>
<td></td>
</tr>
<tr>
<td>$5$</td>
<td>$I_2$</td>
<td>$[0, 0, 0, 0, 0, 0]$</td>
<td>$[5.50, 0.00, 0.00]$</td>
<td>$[0.50, 0.00, 0.00]$</td>
<td></td>
</tr>
</tbody>
</table>

The table shows the Bingham invariants, Bingham norms, and Rodrigues vectors for various components. The conditions of local minima and maxima of $V_n$ are given in Bingham invariants, Bingham norms, and Rodrigues vectors. The table includes components $1$ to $5$ with their respective invariants, norms, and vectors.

\[ V_n = \frac{1}{2} \left( \tilde{\mathbf{R}}_n^2 + \tilde{\mathbf{b}}_n^2 - \tilde{\mathbf{r}}_n^2 \right) \]

where $\tilde{\mathbf{R}}_n$ is a local velocity gradient and $\tilde{\mathbf{b}}_n$ is a non-global tensor gradient, and $\tilde{\mathbf{r}}_n$ is the local global transformation. The components $1$ to $5$ are represented in the table with their respective Bingham invariants, Bingham norms, and Rodrigues vectors.
3.4 Textural Evolution during Bonding: Texture Dependence of Tensile Strength

The texture evolution observed in the present study involved a transition from a random orientation of the grains to a preferential orientation. This transition is accompanied by a modification in the microstructure. Unlike in previous studies, the texture evolution observed here was more pronounced in the tensile strength.

In Figure 4(a), the texture evolution, which already manifests in the bond area (200 x 200 mm), is divided roughly into three distinct regions labeled A, B, and C. The grains are oriented in a preferred orientation in the bond area. Region A corresponds to a significant strengthening of the texture. The peak strength in this region is observed in the bond area (200 x 200 mm), with the peak corresponding to an abrupt change in the texture orientation. The strengthening effect observed in this region is depicted in Figure 5(b), and the peak in Figure 5(c).

A. Figure 4. Textural evolution distribution and texture change around the bond area. Local textural gradients of the bond and random areas are shown in (a) and (b), respectively. The corresponding texture hardness is shown in (c) and (d).
...absolute for the SPW, and by the B1, and the third by the third direction (B2). For simplicity, only B1W and B2W are shown in Fig. 5(b). The ITT pole figures indicate a bladed deformation texture. Overall, the textures in one block have a simple rotational relationship to the textures of the neighboring blocks. This relationship is mostly maintained using the B1 filter. The B2 filter, which is located similarly along the SPW direction, requires according to the model that the position from position to position in Fig. 5(b). For example, the region between blocks 1.5 and 1.6 shows that the SPW direction is parallel to the z direction. Therefore, the B1 filter is located along the z-direction in the pole figures.

Fig. 5(b) shows the velocity gradient distribution of the highest strainline around the tool pin in Fig. 5(a). Overall, the distributions are similar to Fig. 5(b), the simple shear case. The condition $|V_x/|V_z| > |V_y/|V_z|$ reduces to a state in which the maximum velocity field has no static equilibrium. The evolution of the texture in Fig. 5(b) can be explained by the anomalous, deformation-activated, and necking theory at the texture. A two-dimensional model is based on a plane strain deformation, and is limited to without the more complicated deformation processes due to the presence of the pin head and shoulder.

3.6 TWO-DIMENSIONAL MODEL BASED ON A TWO-DIMENSIONAL POLARITY (DQ)

For a simplified two-dimensional, plane strain model, the out-of-plane strain components are identically zero. Therefore, the texture of SPW is expected to being a mixture of plane strain (for plane strain) and simple shear components. In a three-dimensional model, various complex features can be observed. Fig. 6 addresses the texture predicted by a three-dimensional simulation of SPW, each texture is given a position in the model, where the texture was evaluated. Position 1 is located at the end of the tool pin at the highest deformation, positions 2 and 3 are located by each the tool shoulder and pin. Each material point near the shoulder region, is given a position near the tool shoulder and around the tool pin, and finally leaves the substance in the deformation state of the pin.

Figure 5. The highest strainline and the position for the ITT pole figures. Simplicity condition new texture model resembles the deformation around the tool pin. Each symbol represents the regions from 0 to 1.5 and 1.5 to 2.1. (a) overall model elements, (b) ITT pole figures for the regions of 1 and 1.5.
Figure 6. Velocity gradients and texture indices measured over the bond plane. Symmetrical and asymmetrical velocity gradient are shown. (a) velocity gradient and (b) texture indices.

Figure 6. Velocity gradients and texture indices measured over the bond plane. Symmetrical and asymmetrical velocity gradient are shown. (a) velocity gradient and (b) texture indices.
4. CONCLUSIONS

Further evaluation during FSW was investigated using the simple indicator extraction method, total and upper directional evaluation through microscopy, and FSWW measurements.

1. The results were evaluated according to the comparison method from the average value, and it is shown that the results match well for both. The trend indicates that the average value for the process, the process, and the trend match well.

2. In three-dimensional modeling, both the weld zone and the area are considered. The weld component of the same welding area is evaluated when it is present. The results from the weld zone are consistent with those from the weld zone.

3. The experimental results show that the area, area, and area are all evaluated when it is present. The trend indicates that the average value for the area, area, and area match well.

4. The trend of the weld zone is shown in the graph, and the results are consistent with those from the weld zone.

5. Additional analysis using microscopy, are presented using FSWW, and are consistent with the weld zone, area, and area. The results from the weld zone and the weld zone are consistent with those from the weld zone.


