Applications of EBSD

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Applications of EBSD

- Grain size distribution studies
- Grain reconstruction in phase transformation
- Grain boundary engineering
- Texture and microstructure in laser welding, FSW
- Microstructure and phase analysis
- Orientation gradients / strains around crack tip
- Phase identification
- 3D EBSD
TABLE I  A comparison of grain dimensions for the low carbon steel measured by both SIS Imager and EBSD

<table>
<thead>
<tr>
<th></th>
<th>SIS Imager</th>
<th>EBSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Count grain, N</td>
<td>1021</td>
<td>1594</td>
</tr>
<tr>
<td>Mean (µm)</td>
<td>14.22</td>
<td>9.24</td>
</tr>
<tr>
<td>Minimum (µm)</td>
<td>5.48</td>
<td>3.19</td>
</tr>
<tr>
<td>Maximum (µm)</td>
<td>46.16</td>
<td>26.51</td>
</tr>
<tr>
<td>Standard deviation (µm)</td>
<td>5.56</td>
<td>4.05</td>
</tr>
</tbody>
</table>

Figure 4  Optical image (a) and EBSD analysis (grain boundary map) (b) of the Al-2.2Cu-0.94Mg-0.42Mn-1.6Li wt% alloy on ST section.
Grain size distribution studies in AA 6022

(a) Inverse Pole Figure map with 5 µm step size. (b) Grain boundary map. Black solid lines are 15° and higher misorientation boundaries. (c) Average grain size as a function of the step size and the threshold boundary misorientation angles.
Twinning in Inconel Superalloy

(a) Inverse Pole Figure map of Inconel 718 shows twinning boundaries.
(b) Grain Size Map after excluding twin boundaries. (c) Grain size distribution with twin boundaries as grain boundaries (d) Grain size distribution without twin boundaries as grain boundaries.
Characterisation of ultra fine grained steels
Phase transformation mechanisms in a low-alloyed TRIP steel
Grain Boundary Engineering (GBE™)

Grain Boundary Engineering GBE is a technique for optimizing the population of “special” boundaries in an effort to improve material performance.

Numerous studies have shown that low $\Sigma$ CSL grain boundaries (usually $\leq \Sigma 29$) can possess “special” chemical, mechanical, electronic, kinetic, and energetic properties.

First, identify the effect of various thermomechanical processing steps used to make a component material on the “special” grain boundary population.

OIM is the ideal tool for the statistical characterizations of grain boundary character necessary for this procedure.

Intergranular penetration depth after 500 hours exposure to Na2So4 at 850°C and improvement in room temperature fatigue resistance in alloy 738 – an advanced aerospace material.

Creep resistance in alloy 625 – a superalloy used in gas turbine components. Samples creep tested under tensile stress applied at 700°C
Microstructure and phase analysis of duplex stainless steel after heat treatment

Vickers hardness measurements for the 2205 DSS samples heat-treated at 850°C as a function of time

Table 2:
List of phases investigated in the DSS alloy using EBSD.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Crystal structure</th>
<th>Lattice parameters (Å)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ferrite</td>
<td>Body Centred Cubic (BCC)</td>
<td>a = 2.87</td>
</tr>
<tr>
<td>Austenite</td>
<td>Face Centred Cubic (FCC)</td>
<td>a = 3.66</td>
</tr>
<tr>
<td>Sigma</td>
<td>Hexagonal</td>
<td>a = 0.80, c = 4.46</td>
</tr>
<tr>
<td>Chi</td>
<td>Body Centred Cubic (BCC)</td>
<td>a = 8.92</td>
</tr>
</tbody>
</table>

EBSD phase map from the same region shown in Figure 3. Ferrite (Blue), Austenite (Red), Sigma(Yellow), Chi(Green).
EBSD phase map and EDS map for Mo (L\textsubscript{\textepsilon}) from the region highlighted in Figure 4.

Ferrite (Blue), Austenite (Red), Sigma(Yellow), Chi(Green).

EBSD has been shown to be a useful tool for phase identification in duplex stainless steels, which is particularly evident in the analysis of the Sigma and Chi intermetallic phases.
Samples deformed in the GBS regime (stress exponent, n ~ 2) exhibit dynamic grain growth and a random texture.

Samples deformed in the dislocation creep regime (n = 5) show development of a two-component fiber texture consisting of grains having either a <100> or a <111> aligned with the tensile axis.
Laser Beam Welded Duplex Stainless Steel

Quantitative studies on austenite phase distribution

<table>
<thead>
<tr>
<th></th>
<th>Non-preheated weld</th>
<th>Preheated weld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base Metal</td>
<td>31%</td>
<td>33.2%</td>
</tr>
<tr>
<td>HAZ</td>
<td>11.4%</td>
<td>22.6%</td>
</tr>
<tr>
<td>Weld Metal</td>
<td>3.3%</td>
<td>28.4%</td>
</tr>
</tbody>
</table>
Contoured inverse pole figures (RD) showing the variation in ferrite texture between the weld metal for the 2 samples. (a) Non-preheated Weld Metal (b) Preheated Weld Metal.

Preheating the DSS both increases the austenite content and alters the ferrite texture, resulting in enhanced weld properties.
Texture and microstructure in FSW Al alloy AA 2024

On advancing side
There are significant differences in microstructure and texture between the weld nugget, the advancing side TMAZ and the retreating side TMAZ. The boundary between the nugget and the TMAZ is much sharper on the advancing side, with a corresponding difference in the grain size.
Characterizing local strain variations around Vickers indent

Maps showing the strain about a Vickers Indent: (a) EBSP quality map; (misorientations); (c) Intrgranular misorientation map. The scale bars are 10µm, and non-indexed areas shaded black.
Maps showing the strain at the tip of an air fatigue crack (a) EBSP quality map with grain boundaries marked in black; (c) Intragranular misorientation map. The scale bars mark 100 μm, and non indexed regions are shaded black.

Fatigue crack growth in CT sample of AISI 304
Phase identification of carbide and nitride precipitates in a ferritic stainless steel

Forescatter images.

Left – orientation contrast image collected using the lower forescatter diodes, showing grains and surface topography.

Right – atomic number contrast image collected using the top diodes, showing 2 types of precipitate in the ferrite matrix – types 1 and 2.
The integrated EBSD+EDS system:
This allows phase identification. From a single point, an EDS spectrum is collected along with the diffraction pattern (EBSP); the spectrum peaks are identified and this chemistry is used to search a phase database (or several databases) to find all matching phases.

Type 1 precipitates are aluminium nitrides (AlN - hexagonal),
Type 2 precipitates are chromium carbides (Cr$_{23}$C$_6$ - cubic).
Phase map showing the same area imaged in figure 1.

Blue = ferrite, Red = AlN and Green = Cr$_{23}$C$_6$. Black lines represent grain boundaries, and the scale bar is 50 μm.
Coated superconductors based on YBCO

Anisotropy of $\text{YBa}_2\text{Cu}_3\text{O}_{7-\delta}$

Current transport along ab (CuO) planes is much higher than along c-axis.

$\Rightarrow$ Grain boundaries are weak links in YBCO
Critical current, $J_c \downarrow$ as GB mis-orientation angle, $\theta \uparrow$

Fig. 2: Critical current density of YBCO films across [001] tilt grain boundaries measured at 4.2 K and self field by various groups, following on original work of Dimos et al. (1990), [Heinig 1999]

$\Rightarrow$ Achieving a strong bi-axial texture with low GB mis-orientation angles ($< 5^\circ$) in YBCO is very important.
Typical Coated Conductor architecture

- **YBCO**: 200 - 700 nm
- **Epitaxial CeO$_2$**: 100 nm
- **Epitaxial YSZ**: 500 nm
- **Epitaxial Y$_2$O$_3$**: 40 nm
- **Textured Substrate**: 80 μm

Buffer layers should have good lattice match.
Texture in substrate and subsequent buffer and superconducting films
Deviation from the cube orientation

- EBSD is used to evaluate the quality of the texture grain boundary mis-orientations
Current transport measurement in YBCO

With improving texture
Three-dimensional EBSD analysis

A two dimensional (2D) electron backscatter diffraction (EBSD) analysis reveals three of the necessary parameters, which describe the lattice misorientation across the boundary. A three dimensional (3D) EBSD analysis is required to obtain the other two parameters that are used to describe the orientation of the grain boundary plane normal.
3D EBSD is a powerful tool in characterising the microstructure and will be very helpful in structure-property correlations.
Summary

• The most important imaging mode for quantitative microstructural characterization is automated EBSD.

• Automated EBSD, or OIM, provides maps of orientation over large areas with spatial resolutions down to 20 nm (in FEG system) and angular resolution $\geq 0.5^\circ$.