पदार्थ अभियांत्रिकी में इलेक्ट्रॉन पश्च-प्रकीर्णित विक्षेपण

Electron Back-Scattered Diffraction in Materials Engineering

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Electron Back-scattered Diffraction (EBSD) is an effective and efficient tool for point-specific measurements of crystallographic orientation in polycrystalline materials. EBSD has become a foundational characterization tool in modern materials science because it uniquely combines high spatial resolution with quantitative, crystallographic information across microstructural fields. Where transmission techniques (e.g., TEM) give atomic-scale detail at single points, and X-ray/neutron diffraction gives bulk averages, EBSD fills the crucial mesoscale niche: mapping grain orientations, boundary character, local texture, phase distributions and strain-related misorientations across areas from microns to millimetres. That capability underpins advances in processing–structure–property understanding and has been widely exploited to link deformation/processing routes to mechanical and functional behaviour [1].

One of the clearest contributions of EBSD is its ability to quantify texture and its evolution during plastic deformation and annealing processes. EBSD maps give orientation distributions and allow computation of pole figures, inverse pole figures, and orientation distribution functions (ODFs) at spatial resolution-enabling researchers to separate global texture from local, heterogenous orientation patterns caused by, for example, shear bands or retained sub-grains. EBSD has been routinely used to study texture evolution in metals processed by severe plastic deformation techniques such as equal channel angular extrusion/pressing (ECAE/ECAP), accumulative roll bonding (ARB), and extrusion, showing how processing route, strain path and temperature determine final crystallographic textures that strongly influence ductility and anisotropy. These EBSD-based texture studies have guided interpretations of why certain processing paths produce better formability or strength in Mg, Al, Ti alloys and steels.

EBSD also excels at characterizing grain boundary character and misorientation distributions quantities that control recrystallization, grain-boundary sliding, intergranular fracture, and many diffusion-controlled processes. Quantitative misorientation analysis (low-angle vs. high-angle boundaries, special coincidence site lattice boundaries) is routinely extracted from EBSD maps and used to predict and tailor mechanical response. A notable example is the study of misorientation scaling in heavily deformed metals, where detailed EBSD-derived misorientation distributions supported the discovery of general scaling laws across materials and deformation conditions - an insight that helps unify mesoscale deformation behaviour across crystal systems [1, 2].

Another powerful application is correlating microstructure with local mechanical behaviour. EBSD, when combined with indentation, in-situ deformation, or site-specific testing, allows one to connect an individual grain's orientation, boundary neighbours, and local misorientation gradient with its observed deformation mode (slip, twinning) or propensity to damage. EBSD has been used alongside TEM and mechanical testing to relate texture and local microstructure to macroscopic responses for example, explaining differences in ductility and strain hardening in Mg alloys and Ti alloys by mapping lattice rotations and twin activity across regions exposed to different processing histories. This multi-technique approach with EBSD providing the spatial orientation/strain map has been central to designing processing strategies for better ductility/strength combinations [3].

Phase identification and phase-specific orientation relationships are a further area where EBSD contributes uniquely. Modern EBSD indexing can distinguish crystallographic phases in multiphase alloys and determine orientation relationships at phase interfaces   data that are critical for understanding martensitic transformations, precipitation textures, and phase-transformation driven property changes. For instance, investigations of boron-modified Ti-6Al-4V using EBSD to follow $\beta \rightarrow \alpha$phase evolution and the associated texture changes during thermomechanical processing, related the processing schemes to final phase morphology and mechanical performance [4].

EBSD's utility also extends to nanoscale and ultrafine-grained materials when combined with careful sample preparation and complementary techniques. Fig.1 is an example of the Nb alloy Nb-1Zr-0.1C alloy subjected to severe plastic deformation by high pressure torsion to the strain levels 4.5 and 70. Grain-by-grain EBSD mapping in severely deformed or nanocrystalline materials, corroborated with TEM has allowed to reveal sub-grain formation, recovery/recrystallization pathways, and the role of low-angle boundaries in stabilizing refined microstructures. Such analyses were essential to explain mechanical behaviour after large

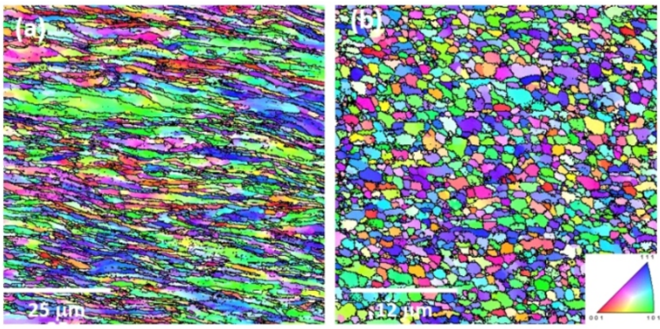

Fig.1: EBSD generated inverse pole figure maps of pure Nb subjected to high pressure torsion subjected to strain (a) 4.5 and (b) 70.

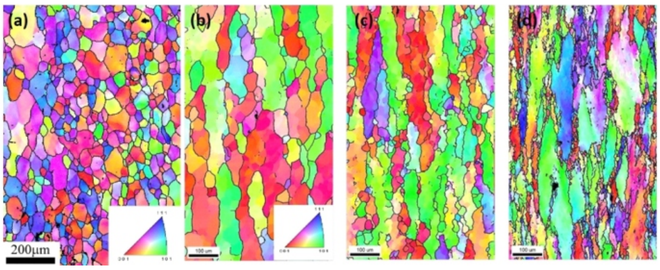

Fig.2: EBSD generated inverse pole figure map for the Nb-1Zr-0.1C alloy as the (a) starting material, materials deformed at 1500°C at the strain rates (b) 0.001 s^{-1}, (c) 0.01 s^{-1}, and (d) 0.1 s^{-1}.

strain processing and annealing, and to design post-processing heat treatments to control texture and grain size [5].

Practically, EBSD also supports industrial and applied research objectives optimizing additive manufacturing parameters, tailoring nanocomposites, and evaluating failure surfaces. SEM-EBSD stands among the core characterization tools used for both fundamental texture studies and applied projects, for example, texture-property studies in functional materials like thermo-electrics or in structural materials like selective laser melted alloys. By providing spatial maps of phase, orientation and boundary character, EBSD helps engineers identify process windows that minimize deleterious textures or adverse phase distributions.

Methodological advances tied to EBSD have also influenced broader practice. Improvements in indexing algorithms, higher-speed detectors, and better software for strain and grain-boundary analytics mean EBSD datasets can now be used quantitatively for input to crystal plasticity models and mesoscale simulations. EBSD data are not only descriptive but increasingly predictive when integrated with simulations, enabling process design rather than just post-mortem analysis [1].

EBSD-based characterization of niobium and molybdenum alloys has significantly advanced the understanding of deformation, recovery, and recrystallization behaviour in body-centred cubic (BCC) refractory metals (Fig. 2). Using high-resolution EBSD orientation mapping, texture evolution, grain boundary character, and intragranular misorientation development resulting from thermomechanical processing such as rolling, forging, and annealing have been quantified. EBSD analyses have been particularly effective in revealing the heterogeneity of stored deformation, sub-grain formation, and the role of low and high angle grain boundaries in controlling recrystallization kinetics in Nb and Mo based alloys. By correlating EBSD-derived microstructural metrics with mechanical response at elevated temperatures, critical insights have been developed into processing microstructure property relationships essential for the design and optimization of refractory alloys for high-temperature structural and nuclear applications [6].

EBSD has led to the understanding of radiation-induced microstructural evolution and its consequences for mechanical behaviour in structural alloys used in nuclear environments. EBSD in conjunction with advanced transmission electron microscopy (TEM-OIM) has been very effective to characterize irradiation-induced defects such as dislocation loops, defect clusters, grain boundary modification, and changes in local crystallographic orientation. By systematically comparing unirradiated and irradiated states, the role of irradiation on deformation mechanisms, strain localization, grain boundary stability and damage accumulation has been deciphered. These insights have contributed to a deeper understanding of irradiation tolerance and degradation pathways, providing a microstructure based framework for designing materials with improved performance and reliability under prolonged radiation exposure [7].

In summary, EBSD has transformed materials engineering research by providing spatially resolved, quantitative crystallographic information across length scales directly relevant to mechanical and functional properties. EBSD maps have been used to quantify texture evolution after plastic deformation and annealing, to measure misorientation statistics that led to general scaling insights, to resolve phase-specific orientation relationships in engineering alloys, and to tie local microstructural features to macroscopic mechanical outcomes. Together with complementary tools (TEM, XRD, neutron/synchrotron methods and modelling), EBSD forms a central pillar of contemporary materials characterization one that continues to enable both fundamental discoveries and targeted materials engineering.