Application of combined EBSD/EDX measurements to microstructure analysis of White Etching Areas in 100Cr6 steel

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Early failures of 100Cr6 roller and ball bearings, which are caused by microstructural changes and material degradation leading to the formation of white etching areas (WEA) in the subsurface have become a serious problem in many technological applications, the most prominent example being wind turbines. Along with WEA formation, systems of cracks are formed and extend to the surface resulting in catastrophic bearing failure as a consequence of massive pitting at the bearing raceway. [1]

Based on previous TEM investigations, which can only cover information for small regions, the microstructure of WEA was assumed to be carbide-free, homogenous and nanocrystalline with grain sizes of 10-50nm. [2, 3]

These grain sizes imply that only the larger grains can be measured with conventional EBSD. However, this partial measurability can be used to contrast different grain size fractions, e.g. in Image Quality maps, thus combined EBSD/EDX measurements were used the first time for a detailed characterization of WEA and to reveal a quite inhomogeneous microstructure and chemistry within the WEA (cf. Fig.1a). Larger needle-shaped grains, often growing into preferred directions from the crack, can be found in fully developed WEA. These grains usually show a lower misorientation than the initial martensitic/bainitic matrix, thus indicating recrystallization and grain growth processes at the late stages of the WEA formation (cf. Fig.1b). Besides this, they often show preferred crystal orientations giving indication for a temperature controlled grain growth (cf. Fig.1c and Fig.2).

Simultaneous EDX measurements reveal, that positions of former $(Fe,Cr)_3C$-particles in the nanocrystalline WEA can still be identified by an elevated Cr content, but do not show any EBSD pattern, especially no carbide pattern, any longer. These positions with elevated Cr concentration, appear usually smeared out into preferred directions. By comparison to the IQ map, the finest-grained fractions within the WEA can be thus interpreted as traces of severe plastic flow transporting the Cr from the former carbides into and within the WEA (cf.Fig.1a).

Large-area IPF maps show that WEA and connected cracks are not running along grain boundaries. This can be an indication, that the chemical weakening of grain boundaries does not play the major role in WEA and accompanying crack formation.

In conclusion, combined EBSD/EDX measurements provide information about the microstructure during WEA formation in relation to the material chemistry, which is important in the field of WEA-research in order to analyze processes such as the dissolution of carbides. These analyzes can be performed on large areas and thus statistically relevant information can be obtained. This allows to apply further preparation methods and characterization techniques such as TEM and APT for local investigations.

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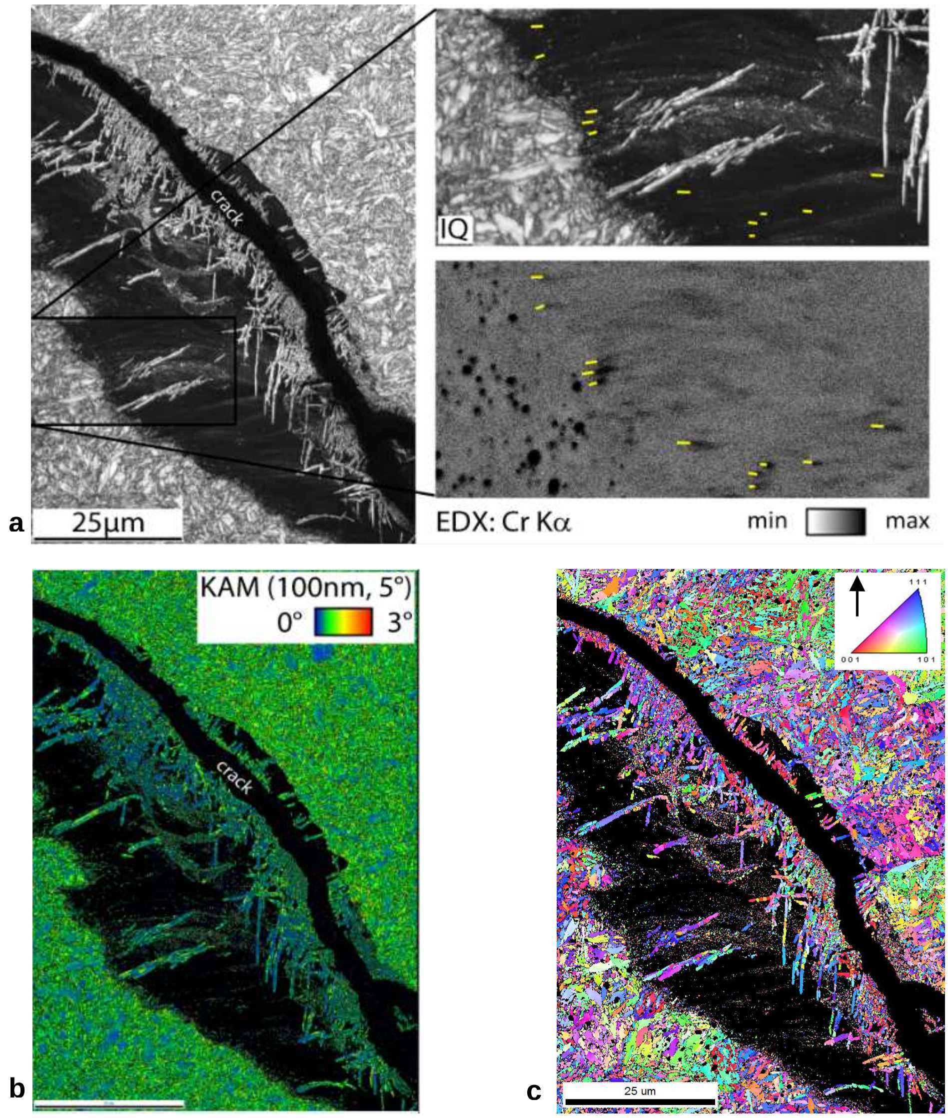

Fig.1: a) Combined EBSD/EDX results of a WEA region. Finest WEA fractions and crack appear dark in the IQ map. Grain structures can be identified within the WEA. Example high-Cr regions in the WEA are marked in yellow in the enlarged IQ and EDX map. b) The KAM map shows that the larger needles have lower misorientations than the matrix. c) IPF-Map of the α-iron phase in a region damaged with WEA and cracks showing parallel grain structures next to the crack with similar orientations.

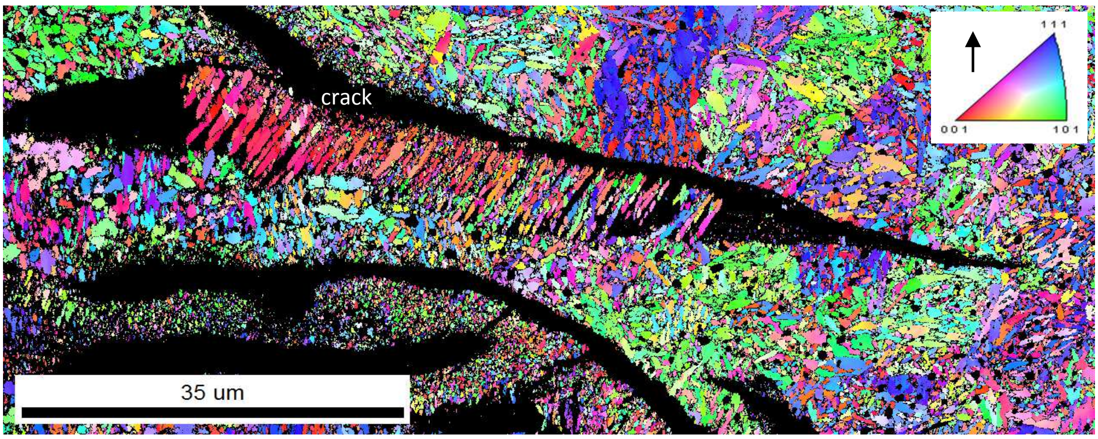

Fig.2: IPF-Map of the α-iron phase in a region damaged with WEA and cracks showing parallel grain structures next to the crack with similar orientation.