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Influence of martensitic transformation on fracture propagation in austenitic steels operating at cryogenic temperatures

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ABSTRACT

In-depth recognition of how phase transformation occurs in austenitic steel at different ranges of temperatures is crucial to use this material in many branches of industry. Thanks to excellent mechanical properties, this kind of steel is commonly used in cryogenic applications present in medicine, astronomy, and energetics. This work aims to make a complete theoretical description of the transformation paths of Pitsch, Kurdjumov-Sachs, and Nishiyama-Wasserman, which appear the most often during austenite-martensite transformation in austenitic stainless steels. All of them are based on Bain relation through the right stretch tensor. However, they require an additional rotation. The formation of these three different disorientations at the austenite/ martensite boundary can be expressed by correspondence matrices. It has been proven, that Kurdjumov-Sachs misorientation is the beginning of two continuous rotations. They belong to the real and reciprocal space, respectively. The first sequence of rotations is based on the invariance of austenite close-packed direction and it leads to Pitsch misorientation, while the other requires invariance of austenite close-packed plane leading to Nishiyama-Wasserman. Between the above misorientations, there exist infinitely many others. Additionally, applying the Gautam-Howe method the most energetically favorable misorientations at the austenite/ martensite boundary are uncovered. It appears that the energy minimum, to which microstructure tends, is approached at the Kurdjumov-Sachs orientation relationship if the ideal Bain's fraction of lattice constants of the composed phases is preserved. The situation is different if the parameters determined experimentally are taken into account. Then, the energy minimum is provided by Pitsch misorientations.

Theoretical considerations have been supported by experiments of the uniaxial tension and complex loads consisting in tension combined with torsion. Thanks to EBSD maps and the synchrotron measurements, it was possible to describe the participation of individual phases, their orientations, and misorientation at grain boundaries. Under conditions of liquid helium (4 K), the martensite phase is located according to the Pitsch relation, which can be caused by limited atomic movement in the material. In the area of the crack, the proportion of produced final phase is almost 100 %. Despite such a share of the martensite phase, which is more brittle than austenite, the obtained fracture is ductile. The most energetically beneficial is Pitsch misorientation, which is why, very strong bonds are created at the boundaries of the old and new phases, impeding crack propagation. Under room temperature conditions, martensite embeds in austenite also in a non-random manner. It turns out that the secondary phase prefers disorientations belonging to the two uncovered chains of rotations.

Keywords: fracture, eigen problem, martensitic transformation, EBSD, synchrotron radiation.