Dynamic Recrystallization of Ti-based Materials at Crack Surfaces at Elevated Temperatures - Hybrid Cellular Automata Simulation

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ABSTRACT

Steam turbines are used in various steam power plants (coal, nuclear, oil), combined cycle power plants as well as combined heat and power plants. Titanium alloys are popular as the blade materials in steam turbines, particularly in low pressure steam turbines that are considered to most significantly affect the power output, size and efficiency of steam turbines. The most promising ways of further increasing the efficiency of steam turbines is by extending the lengths of low pressure steam turbine blades and by increasing the steam reheat temperature. However, these results in substantial centrifugal stresses on blades and rotors and creep effect. As a consequence, advanced titanium alloys and manufacturing processes are needed to design the blades with sufficient reserve strength. Moreover, one of the most significant tasks is the coupled problem of cracking and the simultaneous recrystallization process under heat loading.

In our current research the authors propose a Hybrid discrete-continuum Cellular Automata approach (HCA) based on coupling of classical thermomechanics and logics of CA-switching to simulate new phase generation and grain growth [1]. On the base of HCA the numerical experiment for thermal-activated recrystallization of titanium near the crack edges was conducted. 3D cellular automaton simulates the area of the specimen with V-notch imitating the vicinity of the crack. In this numerical experiment heat expansion of the material was taken into account along with thermal stresses accumulation and microrotation initiation. Microrotation appearance leads to new defects generation and local entropy increase. Every "new-born" grain has zero dislocation density, so the dislocation density gradient initiates additional driving force of new grains growth (along with thermal gradient).

The specimen was simulated by cellular automata consisting of active elements with characteristic size of 1 µm. The specimen dimensions were $80 \times 120 \times 10$ µm^3. The initial temperature of each element was set at 300 K, the initial values of strains and stresses were equal to zero. The time step was set at 1 ns. For numeric calculation the materials constants were for a typical Ti. During all numerical experiments the inner surface of the notch has 1800K.

It was shown that the material adjacent to the crack sides undergoes a change of its crystal structure. The new grains are generated at the crack sides and grow to form column-like patterns and replace the old grain structure. This fact leads to significant local change of all mechanical properties of the material. This study should be a starting point to reveal the reasons of a so far unpredictable behavior of materials with fatigue cracks in turbine blades.

REFERENCES

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