Effective Flow Curves of Ferrite/Pearlite Microstructures and their Use in Cutting Simulations of Steel Gears

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ABSTRACT

Hot-forged steel gear wheels are widely used e.g. in wind energy converters. Their manufacturing process chain involves various process steps such as continuous casting, hot rod rolling and forging, followed by a direct annealing to produce a ferrite-pearlite microstructure suitable for machining the gear preform. After cutting, this preform is milled and then hardened via carburising. In this study two gear steel grades are retained: the reference 18CrNiMo7-6 alloy and a variant [1], where Ni is substituted by Mn and Mo and Nb is added to carburise at higher temperatures. In order to analyse the influence of their ferrite/pearlite microstructure on the cutting process, a multi-scale approach is presented here. For the selected steel grade, three different scales are distinguished: the micro-scale with the bi-lamellas of pearlite, the meso-scale, which corresponds to a Representative Volume Element (RVE) of the ferrite/pearlite microstructure, doted with MnS inclusions, and the macro-scale. In order to derive the effective flow behaviour of pearlite phase, uniaxial tensile and shear tests of the bi-lamella are performed at the microscale. The orthorhombic cementite phase has an elasto-plastic behaviour [2], whose yield curve is deduced from nano-identation tests. At the mesoscale, the ferrite matrix, the pearlite phase and the softer MnS inclusions deform elasto-plastically. The yield stress of the ferrite phase is function of the grain size and of the chemical composition of both steel variants according to the Gutierrez law [3]. In a further step, 3D RVE's of both steel microstructures are generated at the meso-scale with a random distribution of pearlite and MnS inclusions, according to metallographic images. Effective anisotropic hardening curves for both steel grades are determined at room temperature by adopting a mean lamella spacing. These curves are used to derive microstructure dependent strain hardening parameters of the Johnson-Cook model used in the cutting simulations. To evaluate and compare the machinability of both alloys, series of orthogonal cutting simulations with the identified constitutive model were performed in a coupled Eulerian-Lagrangian framework. The cutting velocity and the depth of cut were analysed while other cutting parameters, as tool material and geometry, were kept fixed. At the end, the comparison of numerical predictions with experimental results allows to validate the derived, microstructure dependent Johnson-Cook material model and to quantify the impact of manganese sulfide inclusions on the machinability of both steel grades.

References

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