Yielding and Plastic Flow of Prestrained Rolled Sheet-Steel

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Summary

The aim of this work is to develop a consistent theoretical and experimental study of the constitutive relations for anisotropic hardening metals. Attention is stressed on the anisotropic evolution of the yield condition and the plastic flow law during irreversible deformations. Special emphasis is laid on possible connections between anisotropic criteria and kinematic laws. The theoretical approach is developed within the framework of tensor functions representations, which furnishes the general invariant forms of anisotropic constitutive laws within Non-Linear Continuum Mechanics. An adequate experimental program on rolled sheet-steel is developed, in order to determine the specific forms and the evolution of the anisotropic yield criterion and flow law for soft steel subjected to different prestrainings.

The proper description and a reliable assessment of anisotropic hardening of prestrained sheet-steel are of importance when developing materials with adequate mechanical properties and when designing engineering structures. An objective and unified formulation of the mechanical behavior of anisotropic plastic flow laws and their evolution during irreversible deformations are presented. In our approach, stress is considered as a tensor-valued function of the rate-of-deformation tensor, the prestraining tensor and other tensor parameters accounting for the anisotropy of the material. By application of the theorems of representations for anisotropic tensor functions, we obtain the most general invariant and irreductible form of the constitutive relation for anisotropic materials, whose mechanical behavior depends on the deformation history through the prestraining tensor. The anisotropic tensor generators, as well as the minimal number and the type of basic stress and mixed stress-prestraining and stress-anisotropy invariants involved in the general constitutive law are thus entirely determined. Consequently, the essential independent variables to be observed in experiments are specified.

Plastic behavior is introduced in the general constitutive relation by the homogeneity condition of order zero with respect to time. The general invariant forms of both the yield condition and the plastic flow law for anisotropic hardening materials are thus derived. In this approach, associated flow laws appear as a special case of the developed theory. From the obtained general invariant forms, a new generalization of the Von Mises condition and different associated and non-associated flow laws, taking into account isotropic and anisotropic hardening, are proposed. Each proposed flow law, even if non-associated, has some connec-

tions with the yield condition, at least through the fact that they involve the same set of independent anisotropic hardening parameters.

A first experimental program was developed, in order to assess the directional tensile strengths of sheet-steel subjected to different prestrainings. The initial values and the evolution of the anisotropic material constants involved in the proposed yield condition and flow laws were thus determined. The obtained experimental data are in good agreement with the previsions of the proposed criterion. A second series of tests were performed, in order to obtain experimental data regarding the specification of the kinematic law. The procedure was based on the well-known fact that, for "off-axis" anisotropic specimens, the principal directions of stress and plastic strain tensors are not coincident. Thus, a number of specimens with different inclinations to the axis of prestraining were subjected to tensile deformation, in order to measure, by means of straingauges, the orientation of the developed plastic strain tensor and the values of the principal plastic strains, as well as their evolution with respect to the prestrainings. The obtained data are compared with the previsions of the different proposed anisotropic hardening flow laws. Evidently, the performed tests cannot specify entirely the kinematic law, but they enable us to determine the most probable plastic flow law of prestrained rolled sheet-steel, as well as its connections with the yield condition.

The significant results concern an objective and rational description of anisotropic hardening of rolled sheet-steel and the specification of the yield condition and the most probable flow law, as well as their evolution during irreversible deformations.