## A constitutive model for the anelastic behavior of Advanced High Strength Steels

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## ABSTRACT

Automotive industry is increasing the use of Advanced High Strength Steels (AHSS) to reduce the weight of vehicles. The major hurdle in employing AHSS is not the limited formability but the dimensional control. This is mainly due to a phenomena so called springback: a deformation resulted from finding a new force equilibrium during unloading. The accuracy of springback prediction can be improved by a better prediction of the stress states in the part during the deformation and the material behaviour during the unloading when the forming tools are removed [1]. While most researchers have been trying to improve the former by introducing and employing novel plasticity models, little attention has been paid to the latter. Historically, in classic elasto-plastic modelling, the unloading of the material is assumed to be linearly elastic (Hooke's law) with a slope equal to the handbook value of the E-modulus (e.g. 210 GPa for steel). However, experimental observations have shown that this assumption is far from reality. It has been widely observed that the loading/unloading stress-strain curves of plastically deformed metals are in fact not linear but slightly curved, showing a hysteresis behaviour during loading/unloading cycles [2-4]. Additionally, the effective unloading modulus, the slope of the straight line connecting the stress point at the start of unloading to the point at zero stress, decreases. As a result, the springback would be larger than that predicted by FEM using the initial E-modulus to model the unloading behaviour. This has been commonly attributed to 'E-modulus degradation' in the literature; even though, 'E-modulus degradation' or similar terms are inaccurate denominations since the elastic modulus is a result of interatomic interactions and a fundamental material property which is independent from the plastic strain. Anelasticity mechanisms and springback in metals have been studied independently for the past years. However, no anelastic material model for springback simulations pre-exists.

The dislocation based anelasticity is known to be the root cause of such phenomena [2, 5, 6]; as a matter of fact, in addition to the purely elastic strain, extra dislocation based micro-mechanisms are contributing to the reversible strain of the material which results in the nonlinear unloading/reloading behaviour and the reduction of the effective unloading/reloading modulus. This extra reversible strain is the so called anelastic strain. In this work, an anelastic model is proposed to describe the nonlinear unloading behaviour after plastic deformation. In this framework, the total reversible strain is assumed to be partially elastic and partially anelastic. The anelastic strain recovered upon unloading is measured by subtracting the purely elastic strain (obtained by Hooke's law) from the total recovered strain. Based on that, a model is developed that predicts the magnitude of the recovered anelastic strain upon unloading at each stress as a function of the equivalent plastic strain. The model is parameterized for an IF steel (DC06) and a dual-phase high strength steel (DP1000), based on uni-axial experiments.

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