

# Equivalent stress for multiphysics - Multiphysic couplings thanks to phase transformation description -

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## **Abstract**

Materials and structures exhibiting coupled behaviors between mechanics and other physics (especially magnetics, electrics and thermics – phase transformation –) and submitted to multiaxial stress are considered.

The most practical applications concern sensors and actuators. The multiaxial stress is usually inherited from forming process or appears in use. In the area of coupling between mechanics and magnetics, one can mention: inertial stresses in high rotating speed systems or new technologies of flywheel, stresses due to binding process (encapsulation), residual stress associated to plastic straining (forming) or cutting process. On the other hand, since the works of Mateucci [1] and Villari [2], mechanical stress is known to change significantly the magnetic behavior of materials (see for instance [3]) as well as their magnetostrictive behavior [4]. The design of electromagnetic systems consequently requires coupled models taking account of multiaxial stress.

One way is to use energy-based models written at an appropriate scale. Indeed the development of fully multiaxial magneto-elastic models following micromagnetics is a promising issue [5–7], but still leads to dissuasive computation times for engineering design applications. The few available and practically implemented models describing the effect of stress on the magnetic behavior are restricted to uniaxial (tensile or compressive) stress. Jiles–Atherton type models [8–9] and Preisach type models [10–11] are the most popular. Indeed the relevant way seems to implement multiaxial stress directly in a uniaxial model. This way supposes to define and calculate a “fictive” uniaxial stress, the equivalent stress that would change the magnetic behavior in a similar manner than the multiaxial one. Such equivalent stress has been proposed recently [12]. It is based on equivalence in magnetization and uses an analytical discretization of bulk in so-called magnetic domains. The free energy of each domain is written allowing calculate their volume fraction thanks to a stochastic approach (calculation thanks to Boltzmann function). Macroscopic magnetization is the average magnetization over the volume.

Since an equilibrium of phases is involved, the approach proposed for magneto-elastic coupling can be extended to ferroelectric media, and other couplings where a form of phase transformation occurs. Application to the modeling of thermo-mechanical behavior of shape memory alloys is finally made.

The talk will be illustrated by experimental results carried out on magnetic materials and shape memory alloys submitted to uniaxial and multiaxial stresses.

**KEYWORDS:** multiphysic couplings, magneto-elasticity, electro-elasticity, phase transformation, equivalent stress.

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