PHASE TRANSFORMATION INVOLVING RESIDUAL STRESSES DURING GASEOUS NITRIDING OF STEEL

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Nitriding is a thermochemical surface treatment involving the diffusion of nitrogen and generating a hardening effect combined to compressive residual stresses. This process is often used to improve fatigue life, tribological and anti-corrosion properties of iron-based alloys.
Hardening mechanisms are mainly associated to the precipitation of complex nano MN precipitates (M=Cr,V,Mo...). Residual stresses are explained by the volume variation accompanying precipitation during the treatment. In both cases, relationships with the nitrogen concentration are strongly dependant of alloying elements' concentration as well as nitriding time and temperature.
In case of iron-based alloys, two kinds of precipitation mechanisms occur due to the presence of carbon. First, nitrogen interacts with alloying elements initially present in solid solution in the martensite. It results in the precipitation of nano semi-coherent MN nitrides. Secondly, due to a better affinity of alloying elements with nitrogen than with carbon, carbides from earlier annealing steps are transformed into incoherent nitrides. Consequently, the released carbon diffuses either towards the surface or backward the core, driving cementite M_3C precipitation at grain boundaries. Moreover cementite is stress-driven as it precipitates oriented by the plane stress state parallel to the nitriding surface. Therefore, in parallel to the metallurgical and microstructural changes caused by nitrogen diffusion, the resulting carbon diffusion also generates secondary phases and microstructure gradients. The purpose of this study is to study the importance of carbon in case of residual stresses understanding.
This work deals with the study of residual stresses in relation with phase transformations during nitriding. Materials investigated in this work are an industrial steel 32CrMoV13 and a ternary alloy (Fe-0,37wt.%C-3wt.%Cr) manufactured by Aubert & Duval (heated, quenched then annealed). They were nitrided during 48h at 520˚C and 100h at 550˚C respectively. A characterization of the cementite along side of a nitrided surface is presented using image analysis coupled with optical and SEM observations. The in-depth cementite quantification profiles are then compared to the in-depth stress profiles of ferrite. Residual stresses in the ferritic matrix are analyzed using X-ray diffraction. Phase identification are also carried out using X-ray diffractometer at some pertinent depths chosen according to nitrogen and carbon concentration profiles.
In order to understand the link between phase transformations and the development of residual stresses, experimental characterization are compared to a simulation of nitriding. It is based on thermochemical simulation using Thermo-Calc software and a self-consistent micromechanical model considering elastic precipitates exhibiting a volume variation embedded in an infinite ferritic matrix. The volume variation for a given depth is calculated based on the volume fraction and chemical composition of each identified phase. The mechanical behavior of the ferritic matrix is taken as elastoplastic.
Experiments and simulations suggest that residual stresses development is partially attributed to a carbon redistribution. Carbon diffusion is responsible for an additional volume variation to the one associated with nitrogen diffusion. Finally, it can explain the typical growth of nitrides when getting away from the surface.