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The Ductile Fracture of Armor Steel Targets Subjected to Ballistic Impact and Perforation: Calibration of Four Damage Criteria

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Abstract : Over the past two decades, the automotive, aerospace and army industries have been paying an increasing attention to Finite Elements (FE) numerical simulations of the fracture process of their structures. Thanks to the numerical simulations, it is nowadays possible to analyze several problems involving costly and dangerous extreme loadings safely and at a reduced cost such as blast or ballistic impact problems. The present paper is concerned with ballistic impact and perforation problems involving ductile fracture of thin armor steel targets. The target fracture process depends usually on various parameters: the projectile nose shape, the target thickness and its mechanical properties as well as the impact conditions (friction, oblique/normal impact...). In this work, the investigations are concerned with the normal impact of a conical head-shaped projectile on thin armor steel targets. The main aim is to establish a comparative study of four fracture criteria that are commonly used in the fracture process simulations of structures subjected to extreme loadings such as ballistic impact and perforation. Usually, the damage initiation results from a complex physical process that occurs at the micromechanical scale. On a macro scale and according to the following fracture models, the variables on which the fracture depends are mainly the stress triaxiality η, the strain rate, temperature T, and eventually the Lode angle parameter Θ. The four failure criteria are: the critical strain to failure model, the Johnson-Cook model, the Wierzbicki model and the Modified Hosford-Coulomb model MHC. Using the SEM, the observations of the fracture facies of tension specimen and of armor steel targets impacted at low and high incident velocities show that the fracture of the specimens is a ductile fracture. The failure mode of the targets is petalling with crack propagation and the fracture facies are covered with micro-cavities. The parameters of each ductile fracture model have been identified for three armor steels and the applicability of each criterion was evaluated using experimental investigations coupled to numerical simulations. Two loading paths were investigated in this study, under a wide range of strain rates. Namely, quasi-static and intermediate uniaxial tension and quasi-static and dynamic double shear testing allow covering various values of stress triaxiality η and of the Lode angle parameter Θ. All experiments were conducted on three different armor steel specimen under quasi-static strain rates ranging from 10-4 to 10-1 1/s and at three different temperatures ranging from 297K to 500K, allowing drawing the influence of temperature on the fracture process. Intermediate tension testing was coupled to dynamic double shear experiments conducted on the Hopkinson tube device, allowing to spot the effect of high strain rate on the damage evolution and the crack propagation. The aforementioned fracture criteria are implemented into the FE code ABAQUS via VUMAT subroutine and they were coupled to suitable constitutive relations allow having reliable results of ballistic impact problems simulation. The calibration of the four damage criteria as well as a concise evaluation of the applicability of each criterion are detailed in this work.

Keywords : armor steels, ballistic impact, damage criteria, ductile fracture, SEM
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