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Impact analysis of a turbomachine with composite blades

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ABSTRACT. This study is about the development of a material law taking in account the strain rate effect. The aim is to get finite element simulations that could better predict the behaviour of composites blades under impact. The context of the study is the development of new jet engine composite fan blades that will have to withstand bird or ice strikes and fan blade off tests.

SNECMA and General Electrics are developing together the successor of the CFM56 engine, and aim to use a specific composite material for fan blades. It handles with a woven carbon fibre preform which is moulded by using RTM (Resin Transfer Moulding) process. The composite is considered as having two fibre directions. In order to meet the conditions for the airworthiness certification, the authorities such as the Federal Aviation Administration in the U.S. impose the engine to withstand to bird or ice strike and fan blade off. In this framework Snecma needs to rely on simulation tools, efficient and reliable, which will be used during the design process. This paper describes the methodology developed in order to achieve this goal. It comprises several steps: the material characterization through experimental tests, the modeling of its behavior using continuum damage mechanics, its numerical implementation in a commercial finite element software, and lastly the structural computations performed on the engine.

Through loading/unloading quasistatic tests on composite specimens in each fiber direction, both curves being similar to the one shown figure 1, two main non-linear mechanisms have been underlined: the simultaneous growth of damage, due to stiffness loss, and the presence of inelastic strain. Another feature to take into account is the microcrack closure effect which enables the material to recover its undamaged elastic properties during compressive loads. A model developed by the French Aerospace Lab (ONERA) [1] is dedicated to the modelling of such composite materials. It gives a good correlation between simulation and experiment. We also developed a simplified model that includes the same non-linear effects. Damage acts only on the Young's modulus in the diagonal terms. Upgrades are possible by adding damage on the shear modulus, as soon as some tests will be performed. Damage is calculated from the thermodynamic forces (see [2], [3], [4]) and a delay damage model is available [5] to avoid mesh dependency. Besides, a fast identification process is proposed for the new model. Both models were implemented in the commercial finite element software LS-Dyna, and their strengths and limitations are discussed by comparing the simulation results to the quasistatic test results.

Then both models are used to perform two bird strike and one fan blade off calculations, corresponding to industrial tests. The first bird strike calculation handles with a static composite panel standing for a composite blade. This experimental test shows different damage levels all over the panel, which allows us to associate the numerical damage level with experimental observations. Two areas are especially pointed out: one with widespread and small damage, and one with higher damage level where failure occurs. Even if fracture and crack propagation are not included in our damage models, a good agreement was found between the calculation and the test. The second bird strike calculation aims at simulating a test on rotating composite blades. Only three blades are modelled, one being used as a timeline reference and the two other blades being stroken. Only qualitative results can be pointed out, especially for the position of the peak of damage compared to the zones where failure occurs during the test.

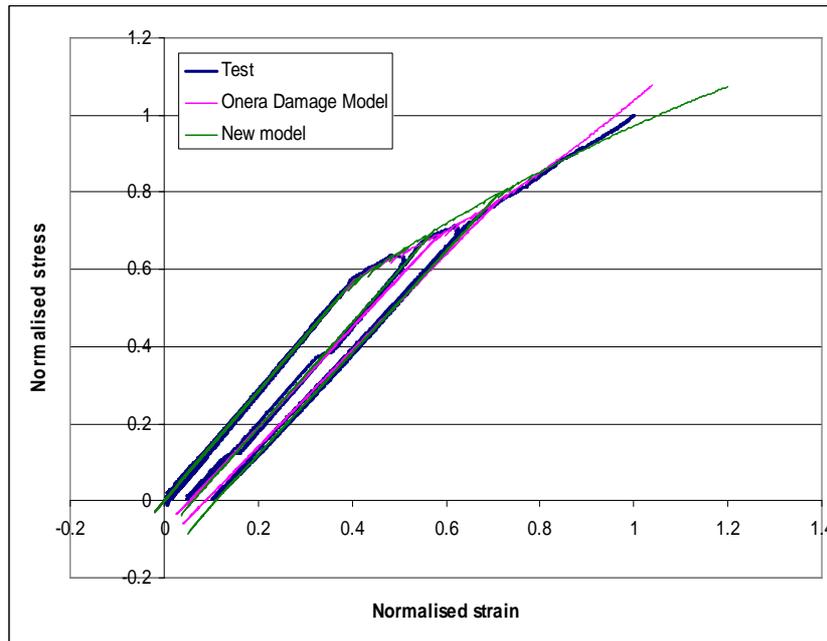


Figure 1: Load/unload test and simulation in the warp direction

Finally, both damage models are used to calculate a fan blade off. This kind of calculation shows clearly the limitations of the models, as failure occurs and leads to break the blades in several fragments which impact the casing simultaneously. The size of the fragments, and therefore their mass, is an important data to know in order to be able to predict the damage level on the casing, in term of cumulated plastic strain. Our models don't include crack initiation or propagation, so the only tool we can use is the automatic erosion of the elements where a failure criterion (based on damage or strain) is reached.

To conclude, the behaviour of a woven-composite used for designing fan blade has been characterized through different tests. These tests show that damage occurs in the material as well as inelastic strain. Thus, a constitutive law is proposed, in order to describe accurately the material behaviour. The model chosen is as simple as possible, in order to save computational cost, and to make easy the calibration of the material parameters. The first results obtained for structural applications are encouraging.

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