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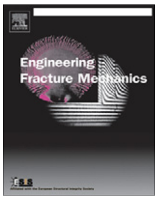

Flow and fracture behaviour of FV535 steel at different triaxialities, strain rates and temperatures

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ABSTRACT

The new generation jet engines operate at highly demanding working conditions. Such conditions need very precise design which implies an exhaustive study of the engine materials and behaviour in their extreme working conditions. With this purpose, this work intends to describe a numerically-based calibration of the widely-used Johnson–Cook fracture model, as well as its validation through high temperature ballistic impact tests. To do so, a widely-used turbine casing material is studied. This material is the Firth Vickers 535 martensitic stainless steel. Quasi-static tensile tests at various temperatures in a universal testing machine, as well as dynamic tests in a Split Hopkinson Pressure Bar, are carried out at different triaxialities. Using ABAQUS/Standard and LS-DYNA numerical codes, experimental data are matched. This method allows the researcher to obtain critical data of equivalent plastic strain and triaxility, which allows for more precise calibration of the Johnson–Cook fracture model. Such enhancement allows study of the fracture behaviour of the material across its usage temperature range.

1. Introduction

Jet engine certification involves assuring the manufacturer that in the case of an accidental blade-off event inside the turbine, any spoiled component as a consequence of this event, must be contained by the casing. This certification needs to pass an experimental procedure. This procedure is a real scale containment test, in which one turbine blade is intentionally manipulated to fail. These kinds of experimental procedures present financial difficulties. Many resources are focussed on improving and minimising the costs of such tests, so much that a future objective is to minimise costs by performing numerical simulations of these containment tests. Besides economic considerations, technical ones must also be taken into account. The aerospace industry requires lightweight materials with high strength: in other words, a high strength to weight ratio. The material used in a turbine casing, as well as the afore-mentioned characteristics, must have a high temperature resistance.

One of the most common materials used for jet engine turbine casings is 9–12% high chromium martensitic stainless steel, which has excellent mechanical properties at relatively high temperatures and good corrosion resistance. The exact material analysed in this study is the Firth-Vickers FV535 stainless steel. Unfortunately, the steel is not one of the most lightweight of materials. Numerical simulations of containment tests could help to optimise the thickness of these casings in order to reduce weight causing a great weight saving and thus reducing cost. In order to simulate with fidelity the real behaviour of the materials involved in the containment tests complete material model characterisation is mandatory.

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Nomenclature

$\bar{\sigma}$	equivalent Von Misses stress
A	material constant of Johnson–Cook constitutive relation
B	material constant of Johnson–Cook constitutive relation
n	material constant of Johnson–Cook constitutive relation
C	material constant of Johnson–Cook constitutive relation
m	material constant of Johnson–Cook constitutive relation
$\bar{\varepsilon}_p$	equivalent or Von Misses plastic strain
$\dot{\bar{\varepsilon}}_p^*$	dimensionless plastic strain rate
$\dot{\varepsilon}_0$	user defined strain rate
$\dot{\bar{\varepsilon}}_p$	plastic strain rate
T^*	homologous temperature
T_r	room temperature
T_m	melting temperature
β	Taylor–Quinney coefficient
ρ	density
C_p	specific heat
D	damage parameter or indicator
$\bar{\varepsilon}_p^f$	equivalent plastic strain to fracture
σ^*	stress triaxiality
σ_H	hydrostatic stress
D_1	material constant of Johnson–Cook fracture criterion
D_2	material constant of Johnson–Cook fracture criterion
D_3	material constant of Johnson–Cook fracture criterion
D_4	material constant of Johnson–Cook fracture criterion
D_5	material constant of Johnson–Cook fracture criterion
r	axisymmetric specimen initial radius
R	axisymmetric specimen notch radius
d	axisymmetric specimen diameter
d_0	axisymmetric specimen initial diameter
d_f	axisymmetric specimen final or fracture diameter
A	specimen cross section area
A_0	specimen initial cross section area
A_f	specimen final or fracture cross section area
ε_i	incident strain
ε_r	reflected strain
ε_t	transmitted strain
σ_s	specimen engineering stress
F_s	force applied by the Split Hopkinson Pressure Bar over the specimen
E_b	SHPB input and output bar elastic modulus
A_b	SHPB input and output bar cross section area
ε_s	specimen engineering strain
C_0	elastic wave propagation velocity inside SHPB input and output bar
l_s	specimen initial length

Numerical simulations with a real jet engine model are carried out at the Department of Materials Science at the UPM. The non-linear explicit numerical code chosen for such a purpose is LS-DYNA in its 971 version. For the correct simulation of the complete impact phenomena produced inside the engine, it is necessary to include a material model that reproduces the blade-off event in the most accurate way possible. Previous works [1,2] have shown that the Johnson–Cook material model [3], already implemented in the LS-DYNA numerical code, works reasonably well. This work is focused on obtaining a valid Johnson–Cook model for the material proposed.

The accumulation of plastic strain is the basis of the majority of the fracture criteria. The Johnson–Cook (JC) failure criterion is also based on the same principle. The standard procedure to obtain the Johnson–Cook fracture model is detailed in [3] and has been used by Clausen et al. [4] and Børvik et al. [5], among others. This procedure is based on obtaining an equivalent plastic strain fracture envelope as a function of the stress triaxiality, strain rate and temperature. To obtain the JC fracture criterion constants, extensive experimental testing was carried out. This included the following:

- Quasi-static tensile tests of axisymmetric smooth and notched specimens which provided different values of the stress triaxiality.