

A study on the performance of ductile failure models under different range of stress triaxiality states with experimental validation

Rui Amaral¹, Pedro Teixeira², Erfan Azinpour¹, Abel D Santos^{1,2}, J César de Sá^{1,2}

¹INEGI, Institute of Science and Innovation in Mechanical and Industrial Engineering, R. Dr. Roberto Frias, 400, 4200-465, Porto, Portugal

²FEUP, Faculty of Engineering, University of Porto, R. Dr. Roberto Frias, 4200-465, Porto, Portugal

ramaral@inegi.up.pt, pmcteix@gmail.com, abel@fe.up.pt, cesarsa@fe.up.pt

Abstract. In this work, experimental tests were carried out, under different loading conditions, in order to assess different ductile failure criteria, namely based on GTN, Johnson-Cook or Lemaitre models and to establish new proposals for improvement. Corresponding characterization for damage parameters is performed by an inverse analysis procedure, using reference experimental tests. Numerical simulations of a cross-shaped component are considered for the damage models, and results show a similar trend related with the experimental fracture evidence.

1. Introduction

Sheet metal forming processes are used in several manufacturing areas, including aeronautical and automotive body components. The processing may include different loading paths and operations like drawing, bending and stamping, in which the sheet metal can be subjected to large localized deformations with significant through-thickness necking, thus developing 3D stress states and promoting the fracture event of the metal blank.

The possibility to analyse larger and complex deformations to which the sheet metal can be subjected during stamping or deep-drawing operations, up to damage and fracture, is nowadays enhanced by using numerical methods (e.g., Finite Element Method) [1], which are still evolving continuously.

Under current work, the aluminium alloy AA5182-O is studied using three damage models: Johnson-Cook model, Gurson-Tvergaard-Needleman (GTN) model and Lemaitre's ductile damage model. The Johnson-Cook and GTN models are implemented in FE package Abaqus, but the corresponding damage parameters are obtained by an inverse analysis procedure using reference experimental tests. In the framework of Continuous Damage Mechanics, Lemaitre's local damage evolution model is implemented in a user material subroutine [2], which was developed to be incorporated and integrated in the FE package Abaqus.

A cross-shaped component is analysed using numerical simulation and the obtained results for the damage models are compared with the experimental ones, in order to evaluate their ability to predict damage and fracture initiation.



2. Material and damage model parameters

In this paper, a mechanical characterization of the aluminium alloy AA5182-O, with 1 mm thickness, was performed [3]. Tensile tests of AA5182-O specimens were performed for different angles relative to the rolling direction. The corresponding flow curves are shown in Fig.1.

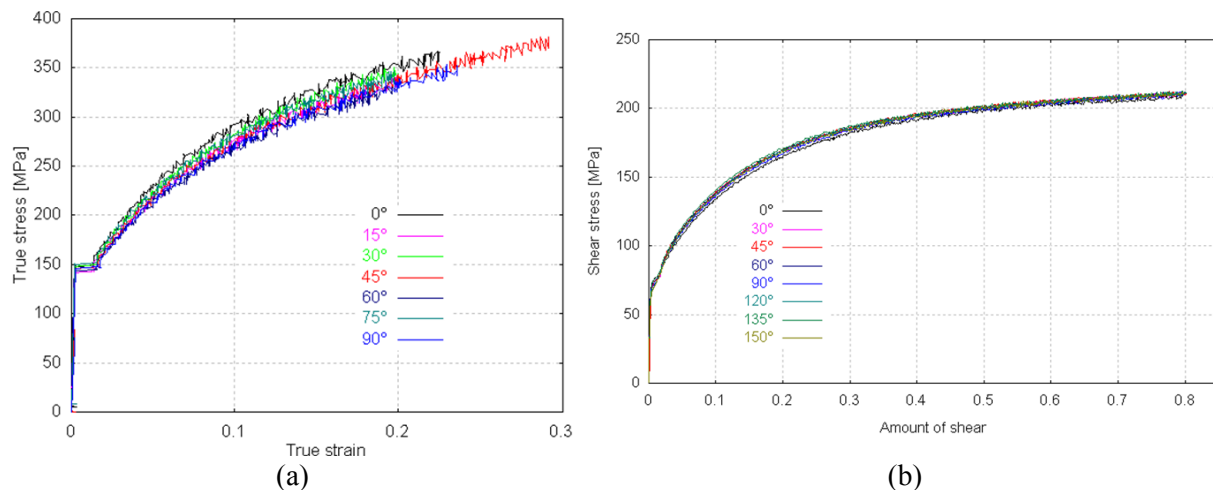


Figure 1. Flow curves obtained from uniaxial tensile test (a) and from monotonic simple shear test (b) for AA5182-O, according to different directions relative to the rolling direction [3].

Table 1 contains the main mechanical properties of AA5182-O material and the parameters for hardening behaviour when modelled by Voce law.

Table 1. Mechanical properties for the aluminium alloy AA5182-O.

Property	Value	Voce Law
Young modulus [GPa]	69	$Y = Y_0 + R_{sat} \left[1 - \exp(-C_r \cdot \bar{\epsilon}^p) \right]$
Poisson coefficient	0.3	
Yield stress [MPa]	149.5	
Ultimate tensile strength [MPa]	283.8	
Total elongation [%]	24.4	Y0 [MPa] 149
r_0, r_{45}, r_{90}	0.79, 0.85, 0.7	Rsat [MPa] 208.7
		Cr 12.1

An inverse numerical analysis, based on optimization algorithms, was used to obtain the parameters for each damage model. Corresponding parameters are presented in table 2 and they show being very similar to those identified by Sun *et al* [1], also for AA5182-O.

Table 2. AA5182-O parameters for selected damage models.

Johnson-Cook damage model									
Parameter	d_1		d_2		d_3		d_4, d_5		
Value	0.024		0.38		1.5		0		
GTN damage model									
Parameter	q1	q2	q3	f ₀	f _C	f _F	ε _N	S _N	f _N
Value	1.5	1	2.25	0.01	0.021	0.04	0.3	0.1	0.001
Lemaitre damage model [4]									
Parameter	Damage exponent - s			Damage denominator $-S$			Damage closure effect		
Value	1.0			1.25 [MPa]			0.2		

3. Results and discussion

The application of selected damage models is illustrated by means of an experimental deep drawing failure case of a cross-shaped sheet metal component. Figure 2(a) shows the selected experimental component after failure, using AA5182-O sheet with 1 mm thickness.

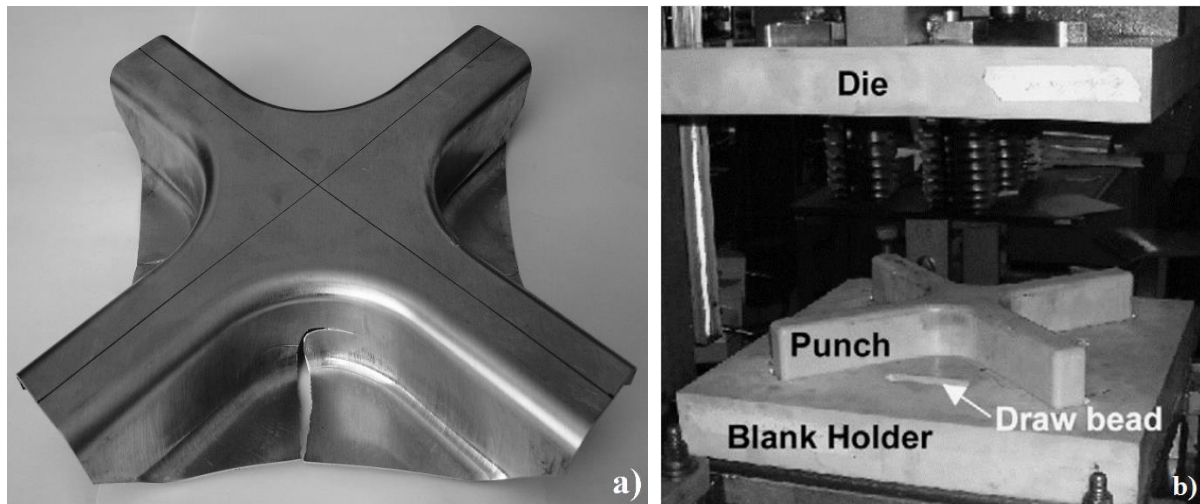


Figure 2. (a) Cross-shaped component with breakage. (b) Tool geometry and active parts (the punch cross geometry has 487 mm length).

A 3D FEM explicit analysis (Abaqus/Explicit) model is considered with one quarter of the experimental setup, due to symmetry. The tools are modelled as fully rigid surfaces with discretization performed by three noded rigid elements. The blank discretization uses a double layer of deformable eight noded solid elements with reduced integration. Regarding the material behaviour, the blank was modelled as an elasto-plastic material with hardening described by Voce Law, as already presented in section 2.

3.1. Results

Figures 3 and 4 present the contours of the equivalent plastic strain as well as the corresponding damage value for the three considered damage models, respectively, Johnson-Cook, GTN and Lemaitre.

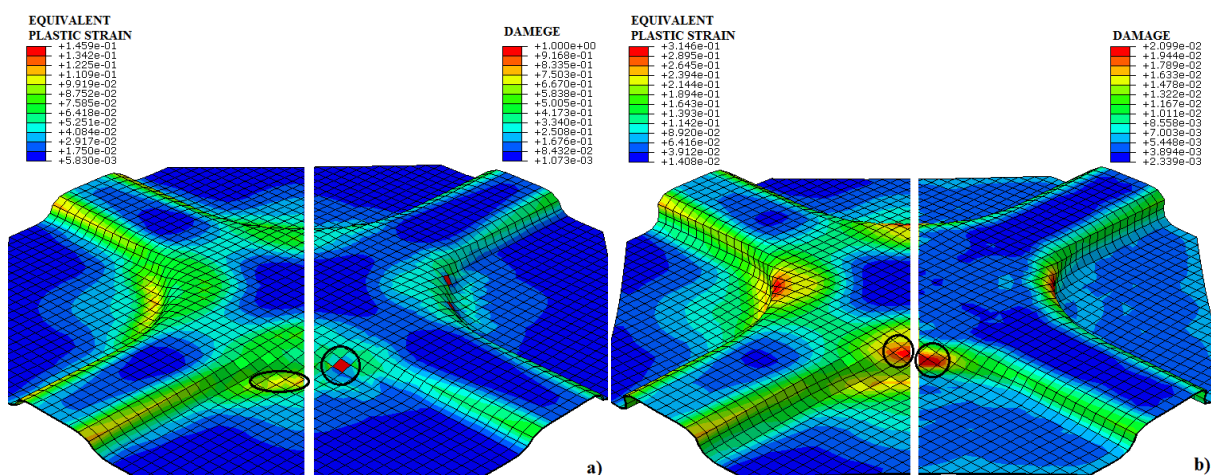


Figure 3. Numerical results of cross –shape component. (a) Johnson-Cook model; (b) GTN model.

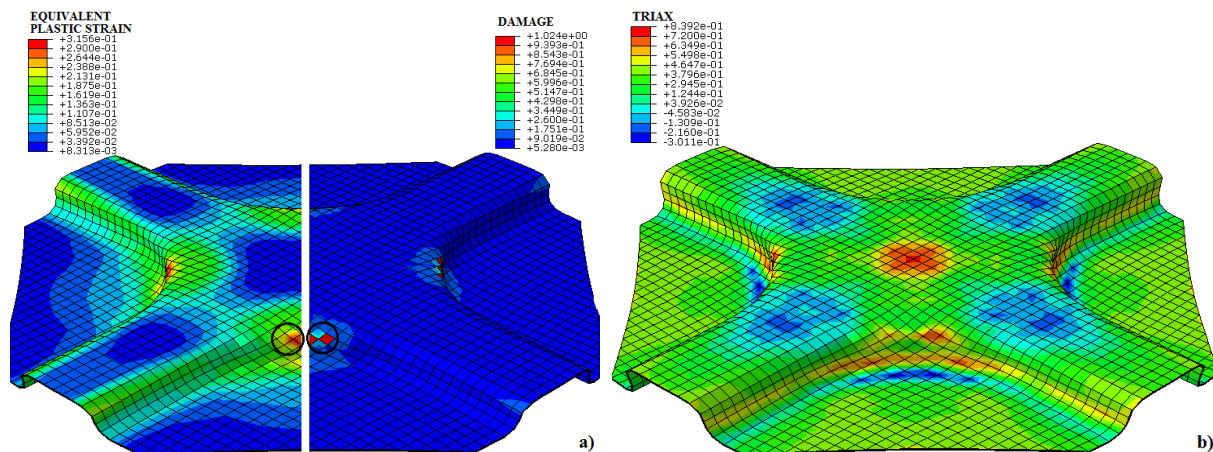


Figure 4. Numerical results of cross –shape component. (a) Lemaître model; (b) stress triaxiality levels before failure.

It is also possible to see the prediction of fracture initiation for each model. For this experimental component, both maximum strain and damage variable have very close locations (at the vertical wall of cross-centre geometry). All damage models in this study show similar trend, which is in accordance with experimental evidence. However, the punch displacement to failure and maximum strain are different. Although GTN and Lemaître models predict fracture initiation at the same punch displacement, Johnson-Cook model predicts failure at lower punch displacement and lower plastic strain. A reason for such difference can be due to the base of parameter identification for the studied damage models, which in turn is related with the triaxiality levels.

4. Conclusions

Three different ductile damage models, Johnson-Cook, GTN and Lemaître were tested and compared in this paper to predict damage in sheet metal forming processes. A FE analysis of a cross-shaped component, using the parameters evaluated for the AA5182-O, has been taken as a basis of comparison between the damage models, in order to assess the accuracy of the results.

For this particular case, the simulations of GTN and Lemaître show a good agreement with the damage location observed in the experimental component. Johnson-Cook damage model shows to overestimate the development of damage at high triaxialities. However, the range of relations between stress triaxiality and strain at failure, namely on low stress triaxiality states, is not completely incorporated for particular damage models [5], which may give directions for further developments and testing.

References

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