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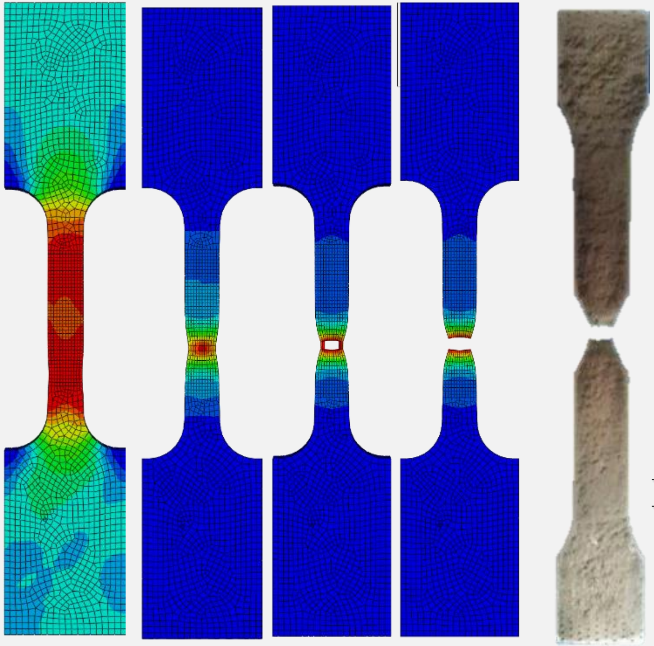
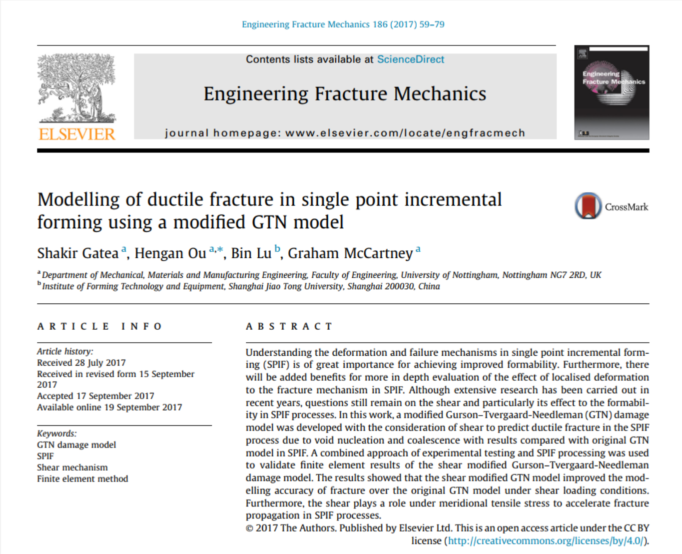
Modified Anisotropic-Shear GTN Damage VUMAT Subroutine



BanuMusa R&D Company



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Modelling of ductile fracture in single point incremental forming using a modified GTN model

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ABSTRACT

Understanding the deformation and failure mechanisms in single point incremental forming (SPIF) is of great importance for achieving improved formability. Furthermore, there will be added benefits for more in depth evaluation of the effect of localised deformation to the fracture mechanism in SPIF. Although extensive research has been carried out in recent years, questions still remain on the shear and particularly its effect to the formability in SPIF processes. In this work, a modified Gurson–Tvergaard–Needleman (GTN) damage model was developed with the consideration of shear to predict ductile fracture in the SPIF process due to void nucleation and coalescence with results compared with original GTN model in SPIF. A combined approach of experimental testing and SPIF processing was used to validate finite element results of the shear modified Gurson–Tvergaard–Needleman damage model. The results showed that the shear modified GTN model improved the modelling accuracy of fracture over the original GTN model under shear loading conditions. Furthermore, the shear plays a role under meridional tensile stress to accelerate fracture propagation in SPIF processes.

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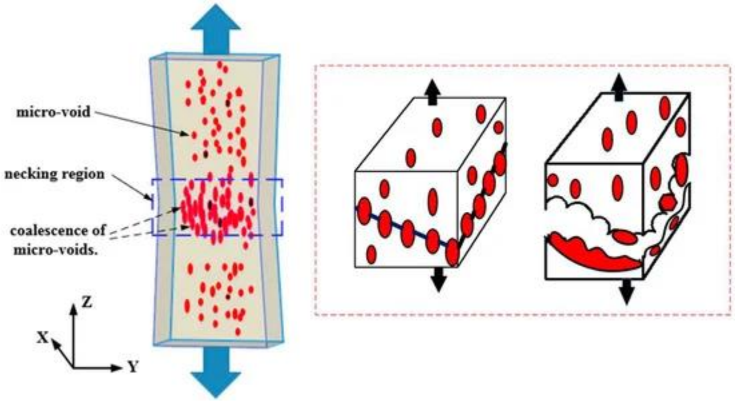
GTN Damage Model

The Gurson-Tvergaard-Needleman (GTN) model is a material plasticity model in which the accumulation of ductile damage is represented by the nucleation, growth, and coalescence of microvoids. The basic yield function of the GTN model is:

$$\varnothing = \left(\frac{\sigma_q}{\sigma_y}\right)^2 + 2q_1 f^* \cosh\left(-\frac{3q_2 p}{2\sigma_y}\right) - (1 + q_3 f^{*2}) = 0$$

The GTN plasticity model is intended for use with mildly voided metals. Even though the material that contains the voids (also known as the matrix material) is assumed to be plastically incompressible, the plastic behavior of the bulk material is pressure-dependent due to the presence of voids.



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Modified GTN Model

- The GTN model has its limitations as it ignores the fracture mechanism due to shear (low stress triaxiality $\eta = -p/\sigma_q$).
- A number of papers have been published recently to develop modified GTN models by adding a function to capture the fracture at low stress triaxiality.
- In this work, Nahshon-Hutchinson's shear mechanism is used.
- The results showed that the shear modified GTN model improved the modelling accuracy of fracture over the original GTN model under shear loading conditions. Furthermore, the shear plays a role under meridional tensile stress to accelerate fracture propagation in SPIF processes.

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A B S T R A C T

Understanding the deformation and failure mechanisms in single point incremental forming (SPIF) is of great importance for achieving improved formability. Furthermore, there will be added benefits for more in depth evaluation of the effect of localised deformation to the fracture mechanism in SPIF. Although extensive research has been carried out in recent years, questions still remain on the shear and particularly its effect to the formability in SPIF processes. In this work, a modified Gurson–Tvergaard-Needleman (GTN) damage model was developed with the consideration of shear to predict ductile fracture in the SPIF process due to void nucleation and coalescence with results compared with original GTN model in SPIF. A combined approach of experimental testing and SPIF processing was used to validate finite element results of the shear modified Gurson–Tvergaard-Needleman damage model. The results showed that the shear modified GTN model improved the modelling accuracy of fracture over the original GTN model under shear loading conditions. Furthermore, the shear plays a role under meridional tensile stress to accelerate fracture propagation in SPIF processes.

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Anisotropic Effect

Adding plastic anisotropy into constitutive equations of the GTN damage model based on the Benzerga and Besson, 2001 paper by Lankford coefficient.

$$\kappa=\sqrt{\left(1.6\left(\frac{h_1+h_2+h_3}{h_1h_2+h_2h_3+h_1h_3}\right)+0.8\left(\frac{1}{h_4}+\frac{1}{h_5}+\frac{1}{h_6}\right)\right)}$$

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European Journal of Mechanics - A/Solids
Volume 20, Issue 3, May 2001, Pages 397-434

Plastic potentials for anisotropic porous solids

Ahmed Amine Benzerga [a, 1], Jacques Besson [b, 1]

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https://doi.org/10.1016/S0997-7538(01)01147-0

Abstract

The aim of this paper is to incorporate plastic anisotropy into constitutive equations of porous ductile metals. It is shown that plastic anisotropy of the matrix surrounding the voids in a ductile material could have an influence on both effective stress–strain relation and damage evolution. Two theoretical frameworks are envisageable to study the influence of plastic flow anisotropy: continuum thermodynamics and micromechanics. By going through the Rousselier thermodynamical formulation, one can account for the overall plastic anisotropy, in a very simple manner. However, since this model is based on a weak coupling between plasticity and damage dissipative processes, it does not predict any influence of plastic anisotropy on cavity growth, unless a more suitable choice of the thermodynamical force associated with the damage parameter is made. Micromechanically-based models are then proposed. They consist of extending the famous Gurson model for spherical and cylindrical voids to the case of an

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Shear Effect

Nahshon and Hutchinson (Nahshon and Hutchinson, 2008) modified the damage law to accommodate the damage contribution from shear since it could play a major role in forming due to the continuous shape changing and load distribution during the deformation.

$$\dot{f} = (1-f)\,tr\left(\dot{\boldsymbol{\varepsilon}}_p\right) + \frac{k_w w(\boldsymbol{\sigma}) f}{\sigma_e}\left(\boldsymbol{\sigma}' : \dot{\boldsymbol{\varepsilon}}_p\right)$$

Where $w(\boldsymbol{\sigma}) = 1 - \left(\frac{27 J_3}{2\sigma_e^3}\right)^2, \quad J_3 = \det\left(\boldsymbol{\sigma}'\right)$

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European Journal of Mechanics - A/Solids

Volume 27, Issue 1, January–February 2008, Pages 1-17

Modification of the Gurson Model for shear failure

K. Nahshon, J.W. Hutchinson

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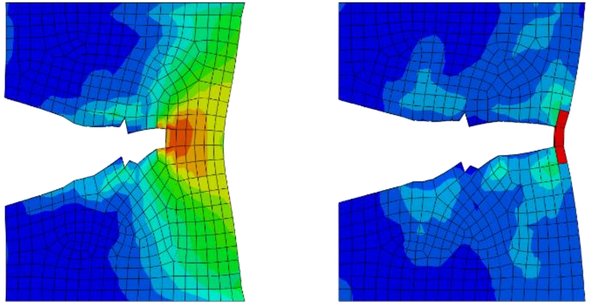
https://doi.org/10.1016/j.euromechsol.2007.08.002 Get rights and content

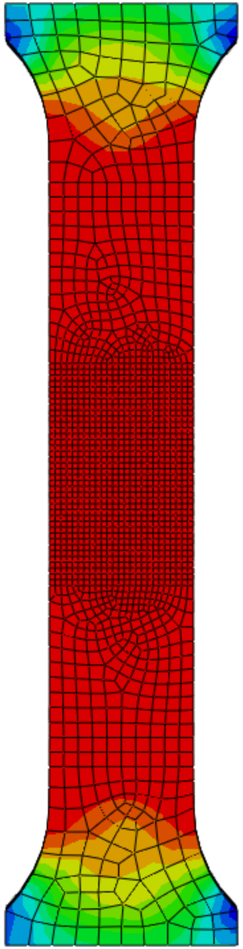
Abstract

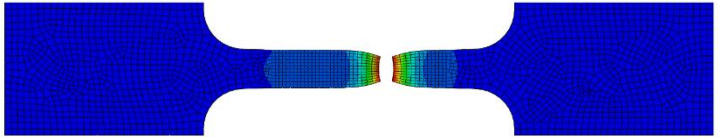
Recent experimental evidence points to limitations in characterizing the critical strain in ductile fracture solely on the basis of stress triaxiality. A second measure of stress state, such as the Lode parameter, is required to discriminate between axisymmetric and shear-dominated stress states. This is brought into the sharpest relief by the fact that many structural metals have a fracture strain in shear, at zero stress triaxiality, that can be well below fracture strains under axisymmetric stressing at significantly higher triaxiality. Moreover, recent theoretical studies of void growth reveal that triaxiality alone is insufficient to characterize important growth and coalescence features. As currently formulated, the Gurson Model of metal plasticity predicts no damage change with strain under zero mean stress, except when voids are nucleated. Consequently, the model excludes shear softening

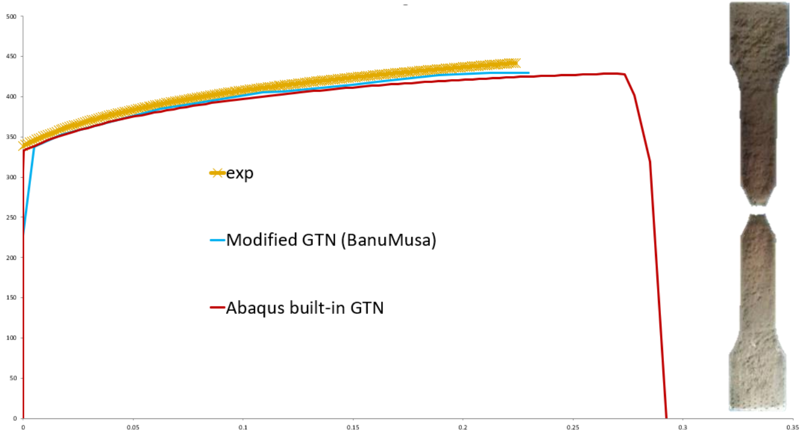
Verification & Validation (V&V)

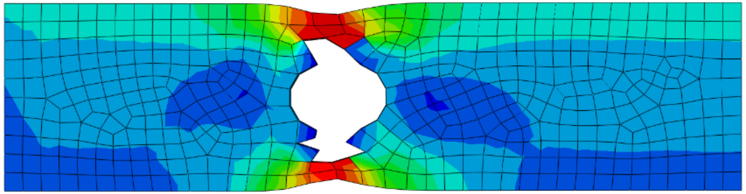
Porous Metal Plasticity
(Abaqus Built-in Material Model)
Vs.
Modified GTN
(Developed by BanuMusa R&D)
Vs.
Experimental Test











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BanuMusa GTN Damage

The code developed by BanuMusa R&D is based on the model provided by Gatea et al. , 2017 and then the anisotropy effect was added. Some important specifications are shown in the table.

Specifications	BanuMusa	Abaqus Built-in
Solver	Abaqus/Explicit	Implicit & Explicit
Subroutine	VUMAT	-
Number of Properties (nprops)	15	12
Number of State Variables (statev)	3	4
Number of Subroutines & Functions	5	Unknown
Integration	Backward Euler method	Backward Euler method
Elements	3D Solid	3D, 2D, 1D
V&V	Gatea et al., 2017	Unknown
Shear Effect	Nahshon and Hutchinson, 2008	No
Anisotropic Effect	Benzerga and Besson, 2001	No
Element Removal	Yes	Yes
CRITERION	Hill & Mises	Mises

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GTN Damage Database

This package contains GTN damage data of +14 materials!

Abaqus Props			1	2	3	4	5	6	7	8	9	10
N	Property	Definition	Al 6061 Khademi	AL 6061-T6 Farahani 2017	AL 6061 Safdarian 2018	Al 6061-T6 Hao,2017	Pure Titanium, Batea, 2017	AA6016-T4 Kami 2014, 2018	AA6111-T4 Chen, 2009	AA5182 Masili, 2016	AA6016 Shahzamanian, 2018	Al5182 Mansouri, 2014
1	Abaqus/Hill/Barlat		1	1		1	1					
2	E		69000	69000		74600	108000	70000	70500	7000	7000	70000
3	Nu		0.33	0.33		0.314	0.34	0.33	0.342	0.33	0.33	0.33
4	q1		1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
5	q2		1	1	1	1	1	1	1	1	1	1
6	q3		2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.15	2.25	2.15
7	f0	void volume fraction	0.01	0.00138	0.0001	0005-0.00	0.00138	0.000242	0	1.00E-02	0.001	0.001
8	fc	Critical F	0.023	0.013	0.02	0.035	0.2593	0.047874	0.15	0.00213	0.0013	0.5
9	ff		0.04	0.04	0.06	0.15	0.3025	0.2		0.15		
10	sn		0.1	0.1	0.1	0.05	0.1	0.1	0.1	0.1	0.01	0.1
11	fn		8.00E-04	8.00E-04	5.00E-04	3.00E-02	0.017	0.041546	0.04	0.035	0	0.25
12	en		0.3	0.3	0.3	0.09	0.3	0.3	0.3	0.27	0.3	0.27
13	r0		0.57			0.55	0.916	0.5529	0.894	0.7	0.7	
14	r45		0.86			0.52	1.214	0.4091	0.611	1	0.7	
15	r90		0.78			0.53	1.824	0.5497	0.66	1	0.7	
16	Sy1 or K		338	297.6		253.652	130.073	525.77		371.2		371.2
17	En1 or eps0		0			0.012012	0.00361	0.011252		0.00324		0.00324
	n		340.3957			256.273	176.367	0.2704		0.17		0.17

Abaqus Props			11	12	13	14	15	16	17	18	19	20	21
N	Property	Definition	Al5754 Mansouri, 2014	Al6016 Mansouri, 2014	Mild steel Mansouri, 2014	XES steel Mansouri, 2014	ULC/Ti Mansouri, 2014	DC 06 steel BenBettaieb, 2011	AA6016-T4 Chalal,2017	AA6016-T4 Banabic,2018	Aluminium Alloy Chen, 2008	DP 600 steel Bettaieb, 2011	
1	Abaqus/Hill/Barlat												
2	E		70000	70000	198000	198000	207836	183053	70000		71000	210000	
3	Nu		0.33	0.33	0.33	0.3	0.3	0.35	0.33		0.33	0.35	
4	q1		1.5	1.5	1.5	1.5	1.5	1.5	1.5		1.5		
5	q2		1	1	1	1	1	1	1		1	1	
6	q3		2.15	2.15	2.15	2.15	2.15	2.25	2.25		2.25		
7	f0	void volume fraction	0.001	0.001	0.001	0.001	0.001	0.002	0.00035		0	0.001	
8	fc	Critical F	0.00284	0.0152	0.0801	0.04	0.04		0.05		0.15		
9	ff								0.15				
10	sn		0.1	0.1	0.1	0.1	0.1		0.1		0.1		
11	fn		0.034	0.036	0.039	0.04	0.04		0.05		0.04		
12	en		0.32	0.276	0.21	0.5	0.5		0.3		0.3		
13	r0							1.98	0.5529	0.724	0.71	0.85	
14	r45							2.56	0.4091	0.547	0.58	1.04	
15	r90							1.67	0.5497	0.602	0.7	0.94	
16	Sy1 or K		309.1	388.3	551.1	551.1	599.3	500	525.77		137	891	
17	En1 or eps0		0.00173	0.00975	0.00954	0.00954	0.00352	0.0063	0.011252			0.02	
	n		0.177	0.22	0.279	0.28	0.26	0.25	0.2704			0.245	

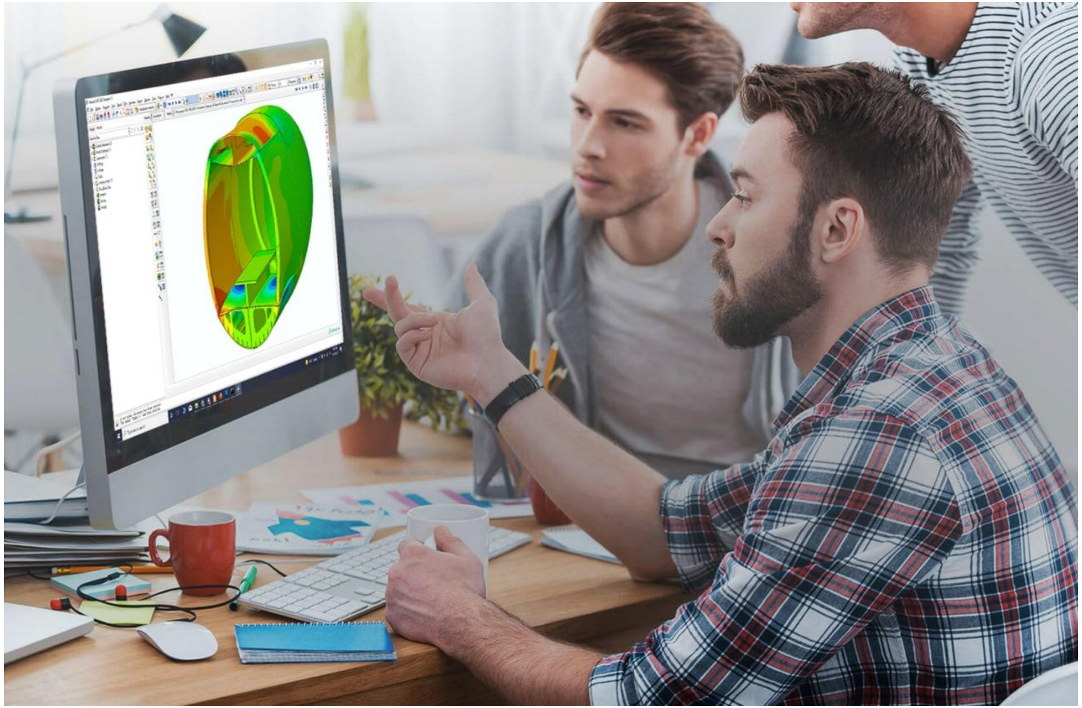
Al 6061 Khademi
AL 6061-T6 Farahani 2017
AL 6061 Safdarian 2018
Al 6061-T6
Pure Titanium
AA 6016-T4
AA 6111-T4
AA 5182
AA 6016
Al 5182
Al 5754
Mild steel
XES steel
ULC/Ti
DC 06 steel
AA 6016-T4
DP 600 steel

Material Database
Al 6061-T6
Pure Titanium
AA 6016-T4
AA 6111-T4
AA 5182
AA 6016
Al 5182
Al 5754
Mild steel
XES steel
ULC/Ti
DC 06 steel
AA 6016-T4
DP 600 steel

Users

This code is useful for all those working on material damage models and they care about more accuracy of FEA simulation.

- Developers
- Abaqus Application Engineers
- Graduate Students
- FEA Analysts
- CAE Engineers



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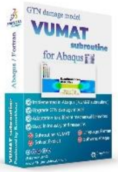
Thank you

Feel free to contact us!



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