Numerical study of the stress triaxiality distribution: the case of aluminum and steel

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Abstract

This work presents a series of numerical simulation tests using ABAQUS code including compression tests and tensile tests on 2024-T351 aluminum alloy and steel, demonstrating ductility phenomena for a wide range of stress triaxiality. The purpose of this study is to find the average stress triaxiality for different specimen geometries using numerical simulations, and then to compare results with the experimental tests illustrated in other works, by finding the corresponding values of the nominal strains.

***Keywords**:* fracture; stress triaxiality; experiment; numerical simulation

1. Introduction

The paper presents the results of tests for different materials (aluminum and steel) performed using Finite Element code Abaqus. Mainly the distribution of stress triaxiality during compression and tension is taken into consideration.

McClintock in 1986 [1], Rice in 1969 [2], and Atkins in 1996 [3] have shown that fracture of ductile metals is strongly dependent on hydrostatic stress. The growth of long cylindrical and spherical voids and the fracture initiation depend on hydrostatic pressure. Bao and Wierzbicki in 2004 [4] described the relation between the equivalent plastic strain and the stress triaxiality based on the experimental test of the aluminum specimen. They observed that the test type (tension or compression) and the specimen shape (size ratio, notches shapes and sizes) implied the failure criterion.

In this paper we present a validation study in which we compare our numerical results and experimental results obtained by Bao and Wierzbicki [4], using 2024-T351 aluminum alloy. Then we studied the compression and tensile tests of another material (steel used in the works of Jankowiak et al. [5]) with mechanical behavior based on the Johnson–Cook model using numerical simulations in order to find values of the stress triaxiality. Finally, we studied another geometry (SP1, SP2, SP3) using the same steel and we got the same values of the average stress triaxialty as those obtained in Bao and Wierzbicki works (Bao, 2004) [4].

2. Nomenclature

D/H	:	Ratio of initial diameter to initial height
$\bar{\sigma}$	:	Equivalent stress
σ_H	:	Hydrostatic stress
$\sigma_H/\bar{\sigma}$	:	Stress triaxiality

3. Approach

A limiting fracture curve has been found by comparing numerical simulations results using ABAQUS code and experimental results. The following steps have been adopted:

- from the tests it has been determined the location of fracture initiation and displacement to fracture,
- it has been determined the equivalent strain to fracture and the average stress triaxiality for each case,
- The results of the average stress triaxiality obtained from numerical simulations have been plotted and the limiting fracture curve has been constructed.

4. Results

4.1 Compression test of the first specimen for the geometry 1:

For the first simulation we started with the specimen cylinder ratio D/H = 0,5 with the friction coefficient 0.15 +0.50 (surface A + surface B) and we found the stress triaxiality values are similar to those in the works of Bao and Wierzbicki [4], namely -0.33 to -0.12, and that this triaxiality (colored in Fig. 1) changes during compression simulation.

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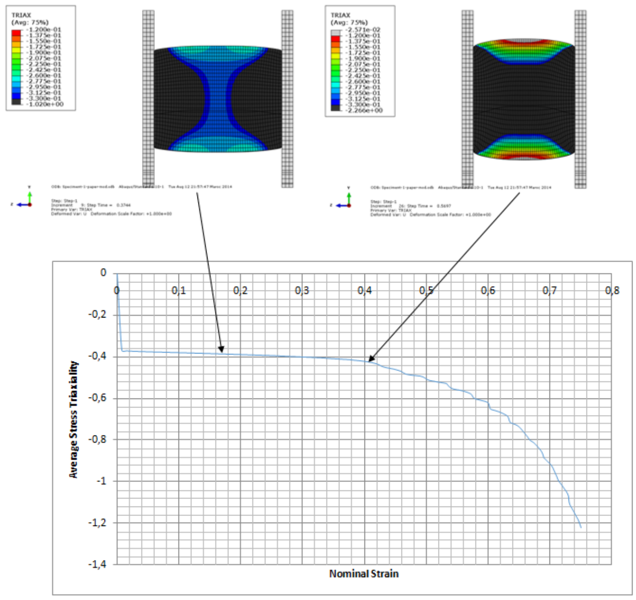

Figure 1: Compression test, specimen 1 (Cylinder D/H = 0.5)

In this curve we plot the average of the stress triaxiality versus the nominal strain at different stage of simulation. The aim of this study was to find the values of stress triaxiality $\sigma_H/\bar{\sigma}$ (-0.33 to -0.12) as illustrated in works of Yingbin Bao [4] obtained in the lab compression tests, The numerical simulations have shown that the stress triaxiality values $\sigma_H/\bar{\sigma}$ (-0.33) corresponds to the nominal strain 0.280, and the same for the stress triaxiality $\sigma_H/\bar{\sigma}$ (-0.12) with the value of 0.427as you can see in Figure 1.

4.2 Force versus displacement with different friction coefficient for geometry 1:

In this graph we have gathered the plots for all simulations and for each specimen with different friction coefficients. We can observe that the friction coefficient plays a key role in relation between force and displacement. If the friction coefficient increases, the specimen resists more against the force and therefore the displacement decreases.

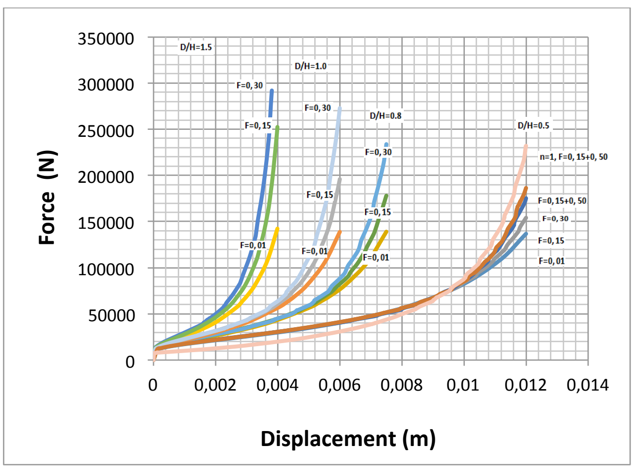

Figure 2: The plot of force versus displacement with different friction coefficients (geometry 1)

4.3 Compression test of the first specimen for the geometry 2:

This compression test simulation has started with a friction coefficient equal to 0.30 and we have reproduced values of the stress triaxiality from the works of Bao and Wierzbicki [4], respectively -0.40 and -0.09.

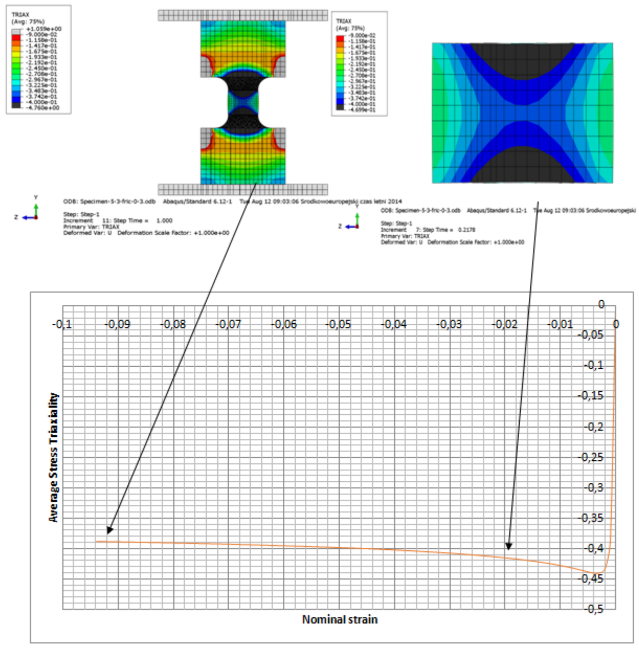

Figure 3: Compression test of the first specimen - geometry 2

In this graph we have the average of the stress triaxiality versus the nominal strain at different stage of simulation. The aim of this study was to find values of the stress triaxiality $\sigma_H/\bar{\sigma}$ (-0.4 to -0.09) as illustrated in the works of Yingbin Bao [4] obtained in the lab compression tests, The numerical simulations have shown that the stress triaxiality values $\sigma_H/\bar{\sigma}$ (-0.4) corresponds to the nominal strain of 0.0204, and the same for the stress triaxiality $\sigma_H/\bar{\sigma}$ (-0.09) with the value of -0.0938 as it can be seen in Figure 3.

4.4 Force versus displacement for different friction coefficients for the second geometry

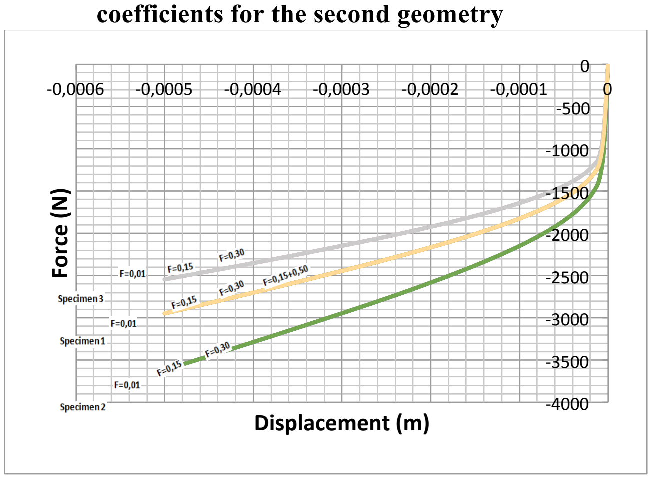

Figure 4: The plot of force versus displacement for different friction coefficients (geometry 2)

Figure 4 presents the plots for all simulations, for each specimen with different friction coefficients and for different materials. We can observe that the friction coefficient is not very important for the force-displacement relation. If the friction coefficient increases, the values of forces and displacements remain stable as you can see at the plots.

4.5 Summary

To sum up, we made a comparison between experiments and numerical tests in the table below:

Table 1: Comparison between experiments and numerical tests:

Loading	Specimen description	Experimental [1] Stress triaxiality $\sigma_H/\bar{\sigma}$	Numerical stress triaxiality $\sigma_H/\bar{\sigma}$
Compression	Cylinder (D/H = 0.5)	-0,33 to -0,12	-0.33 to -0.12
Compression	Cylinder (D/H = 0.8)	-0.32 to -0.05	-0.32 to -0.05
Compression	Cylinder (D/H = 1.0)	-0.32 to -0.05	-0.32 to -0.05
Compression	Cylinder (D/H = 1.5)	-0.32 to -0.05	-0,32 to -0,05
Compression	Asymmetric (Fig. 3)	-0,4 to -0,09	-0.4 to -0.09
Tension	Round, small notch	0,9 to 1	0,9 to 1

In this study we have found exactly the same results of the stress triaxiality. And the results have shown that the material behavior does not depend on the triaxiality distribution but on the specimen's shapes. The compression test simulations using ABAQUS code for the first geometrical category (cylinder factor D/H = 0.5, D/H = 0.8, D/H = 1.0, D/H = 1.5, have shown the same results of stress triaxiality, and also for geometry 2 (SP1, SP2, SP3) and geometry 3 (tension), using the same steel.

5. Further developments

The numerical model has been developed to confirm experimental results, but experimental tests are also envisaged in future at Universiapolis in Agadir in collaboration with Poznań University of Technology (Poland). Both institutes involved in this paper under the guidance of ENIM France have worked on the new test machine, now available in Agadir. It is designed to serve to science and industry by performing different kinds of dynamic tests on material behavior. Compression, shear or perforation tests are of the main interest. The high-pressure gas device is based on the Hopkinson Split Bar concept. Figure 5 presents the new experimental tool located at Universiapolis in Agadir.

6. Conclusions

In this paper, we deal with the problem of the stress triaxiality for different materials (aluminum and steel). In the numerical simulations we have managed to find results similar to works of Yingbin Bao [4] what confirms the correctness of our numerical model. We have also concluded that the material type has little impact on the stress distribution, but specimen shapes as it remains nearly the same, and. Another important observation is that the fracture ductility strongly depends on the stress triaxiality.

Figure 5: High-pressure experimental machine for dynamic tests located at Universiapolis in Agadir

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