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INFLUENCE OF ELEMENT SIZE IN A CASE OF IMPACT SIMULATION

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ABSTRACT

This paper presents an analysis of data resulting from the same material constitutive model, based on experimental data and model developed by Johnson and Cook. The same case of impacting a cylindrical body on a perfectly rigid target was run with four different mesh size (2 mm, 1 mm, 0.5 mm and 0.25 mm). Here, the comparing criterion was the maximum value of von Mises stress and the authors pointed out that the finest mesh here presented is closer to reality. Depending on the case application the engineers could adopt a finer or coarse mesh, but not so coarse to denaturate the reality of body deformation and failure. How to decide? Having performant computer resources (hardware and software) and running several mesh in order to notice the convergence of one parameter or, more reliable, a set of criteria that could include qualitative resemblance with actual bodies as concerning failure and deformation, experimental dat on strain, yield and failure of the involved materials, values of stress and strain, at the same time moments. From this study the following conclusions were formulated: finer mesh presents a earlier failure in time and calculated a higher stress for these moment.

Keywords: Impact simulation, constitutive model of the material, element size

1. INTRODUCTION

In 1983, Johnson and Cook published a paper proposing a constitutive material model, based on cylinder impact tests with strain rate greater than 10^5 s^{-1} and strains greater than 2. Hooke proposed the simplest dependence in the elastic field, . This model evaluated the von Mises yield stress, σ

$$\sigma = \left[A + B \cdot \varepsilon^n\right]\left[1 + C \ln \dot{\varepsilon}^*\right]\left[1 - T^{*m}\right] \tag{1}$$

where ε is the equivalent plastic strain, $\dot{\varepsilon}^* = \dot{\varepsilon} / \dot{\varepsilon}_0$ is adimensional plastic strain rate for $\dot{\varepsilon}_0 = 1.0\,s^{-1}$ and T^* is a adimensional parameter for temperature. A, B, C, n and m are material constants. First brakets reflect the effect of strain on stress for ε_0=1.0 s^{-1}, The second ones gives the effects of strain rate and the third modify the stress due to temperature change. The homologous temperature was expressed as

$$T^* = \frac{T - T_R}{T_M - T_R} \tag{2}$$

where T_M is the melting temperature, T_R is the reference temperature for determining constants A, B and n. $T = T_R + \Delta T$, with

$$\Delta T = \frac{1}{\rho C_p} \int \sigma d\varepsilon \tag{3}$$

ρ being the density of the material and C_p is the specific heat of the material.
Thus, this model could be easily introduced in computer codes as $\sigma = \sigma\left(\varepsilon, \dot{\varepsilon}^*, T^*\right)$ #
The results for OFHC copper offered the lowest agreement, yet acceptable

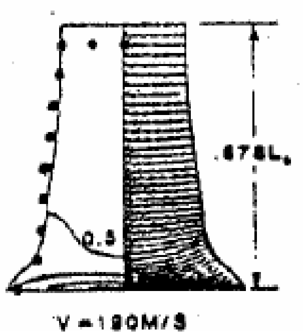


Fig. 1. OFHC copper, impact velocity 180 m/s [1]

In 2007, Schwer [2] presented several expressions for strain rate dependence of constitutive model for

Table 1. Constants in Johnson-Cook model for OFHC copper

Characteristics				Material constants				
Hardness Rockwell	Density [kgm-3]	Specific heat [Jkg^{-1}K^{-1}]	Melting temperature [K]	A [MPa]	B	n	C	m
F30	8960	383	1356	90	292	0.31	0.025	1.09

a steel grade A36, based on experimental data. The author compared three other constitutive models (Huh-Kang [3], Allen-Rule-Jones [4] and Cowper-Symonds[5]), The conclusion was that the effective stress as a function of effective plastic strain is preferred to be introduced by the help of Johnson Cook model, even classic, but also Allen Rule Jones is adequate. This recommendation is argued by the fact that yield and hardening parameters are calibrated from a dependence stress-strain obtained in cvasi-statical conditions and not by using a calibration depending on the strain rate of 1.0 s^{-1}.

Burley et al. [6] presented a methodology for evaluating a strain rate sensitivity parameter for plastic deformation of bulk metallic materials. It involves ballistic impact with a hard spherical projectile, followed by repeated FEM modelling, with predicted outcomes (displacement-time plots and/or residual indent shapes) being compared to experiment. The "correct" parameter value is found by seeking to maximize the value of a "goodness of fit" parameter (g) characterizing the agreement between experimental and predicted outcomes.

Input for the FEM model includes data characterizing the (temperature-dependent) quasi-static plasticity. Since the strain rate sensitivity is characterised by a single parameter value (C in the Johnson–Cook formulation), convergence on its optimum value is straightforward, although a parameter characterizing interfacial friction is also required. Using experimental data from (both work-hardened and annealed) copper samples, this procedure has been carried out and best-fit values of C (~0.016 and ~0.030) have been obtained. The strain rates operative during these experiments were ~10^4–10^6 s^{-1}. Software packages allowing automated extraction of such values from sets of experimental data are currently under development.

Sjöberg, Kajberg and Oldenburg [7] presented a methodology for fracture characterisation at varying strain rates, temperatures and stress triaxialities, at strain rates from 1 to 1000 s^{-1}, and elevated temperatures up to 650 °C. Four specimen geometries were used in order to obtain a wide range of stress triaxialities at fracture. The results showed that Alloy 718 exhibits an evident stress dependency on the failure strain, with lower failure strains observed at higher stress triaxialities for all combinations of temperatures and strain rates. The material exibits a relationship between temperature and stress triaxiality controlling the fracture strain. Any clear tendencies were hard to find for strain rate dependency. Although the strain at failure does vary with strain rate, the only specimen where a kind of pattern could be observed was the shear specimen, where the fracture strain decreases as the strain rate increases. Even though any clear pattern in the strain rate dependency could not be established from the results, it is apparent that strain rate does influence the strain at fracture, especially when considering the results from shear tests.

This paper presents the influence of element size for establishing an adequate meshing for a particular application.

2. THE MODEL

A cylindrical projectile, with a diameter of 7.52 mm and a length of 25.4 mm, hits a squared rigid plate.

The authors selected the following values for the element size: 0.25 mm, 0.5 mm, 1 mm and 2 mm.

Burley [6] considered the projectile to remain elastic throughout, although it can be important in high precision work of this nature not to treat it as a rigid body. All material properties were assumed to be isotropic. The impact velocity was set at 70 m s^{-1}, but in this model the velocity just before the impact was considered 300 m s^{-1}. End time was set for $1x10^{-4}$ s.

The following parameters of the simulations are kept constant: growth rate fixed for 1.2, transition ratio is 0.272, maximum energy error is 0.1, time step safety factor is 0.9, growth rate being 1.2. All cases are considered isothermal, at 22 °C.

There is also the issue of the frictional contact between projectile and target during the impact. The standard representation of this effect (within Ansys) is to ascribe a coefficient of friction, μ, to the interfacial contact, such that sliding between the two surfaces requires a shear stress, τ, given by

$$\tau = -\mu \cdot \sigma_n \qquad (4)$$

where σ_n is the normal stress at the interface. The value of μ is clearly expected to depend on the surface roughness (of projectile and target), stress and on other factors, and so it is hard to be predicted a priori. Since both surfaces are smooth, a relatively low value (<~0.2) is considered to be appropriate by Burley [6]. In this study, the friction is neglected

Table 2. Mesh sizes and numbers of nodes and elements

	Mesh size [mm]			
Case	**2**	**1**	**0.5**	**0.25**
Nodes	1729	5049	27588	148066
Elements	1086	4102	25550	142400

Table 3. Material characteristics

Characteristic	**Value**
Density, kg m^-3	8960
Specific Heat, J kg^{-1} C^{-1}	383
Bulk Modulus Pa	1.29e+011
Shear Modulus Pa	4.6e+010

Table 4. Constants for Jonhson-Cook constitutive model for strength for-OFHC-F copper (from [1])

Initial Yield Stress Pa	Hardening Constant Pa	Hardening Exponent	Strain Rate Constant	Thermal Softening Exponent	Melting Temperature C	Reference Strain Rate (/sec)
9.0e+007	2.92e+008	0,31	2.5e-002	1.09	1082.8	1

Table 5. Johnson Cook failure criterion for-OFHC-F copper

Damage Constant D1	Damage Constant D2	Damage Constant D3	Damage Constant D4	Damage Constant D5	Melting Temperature C	Reference Strain Rate (/sec)
0.54	4.89	-3.03	1.4e-002	1.12	1082.8	1

3. RESULTS

Figures 2 and 3 present the projectile after touching the target, for two different moments, $t=1x10^{-5}$ s and $t=1x10^{-4}$ s. The time step is very important in simulating the impact, that a too large steps could hide peaks of stress, implying high values for stress and strain rate are not introduced to be further processed.

For instance, at the moment $t=1x10^{-5}$ s, there were obtained the following values for the maximum von Mises stress: $\sigma_{(mesh\ 2)} = 373.6$ MPa, $\sigma_{(mesh\ 1)} = 401.1$ MPa, $\sigma_{(mesh\ 0.5)} = 424.3$ MPa and $\sigma_{(mesh\ 0.25)} = 439.2$ MPa. The difference, taking into account $\sigma_{(mesh\ 0.25)}$, is -14.9% for $\sigma_{(mesh\ 2)}$ and only -3.4%, meaning that only for this moment, mesh 0.5 and 0.25 could be accepted for further realistic simulations. But at $t=2x10^{-5}$ s, these values are differently spread:

$\sigma_{(mesh\ 2)} = 428.3$ MPa,

$\sigma_{(mesh\ 1)} = 448$ MPa,

$\sigma_{(mesh\ 0.5)} = 451.1$ MPa and

$\sigma_{(mesh\ 0.25)} = 627.4$ MPa.

The difference among the coarse meshes could be considered acceptable, but for the mesh with 0.25 mm, the value rises at 624.7 MPa, meaning a percentage of +31.4% as compared to the value for the mesh of 2 mm.

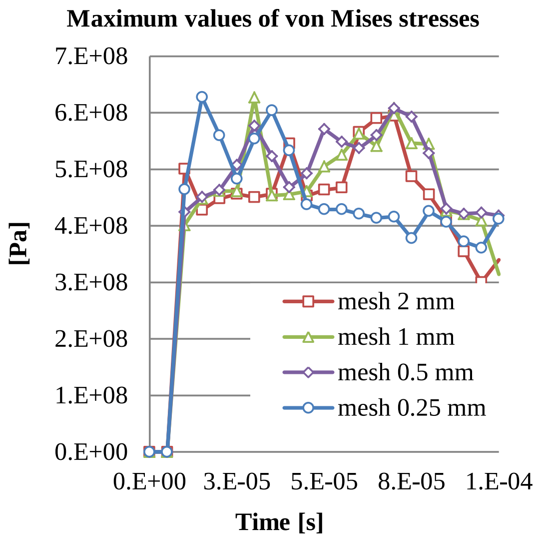
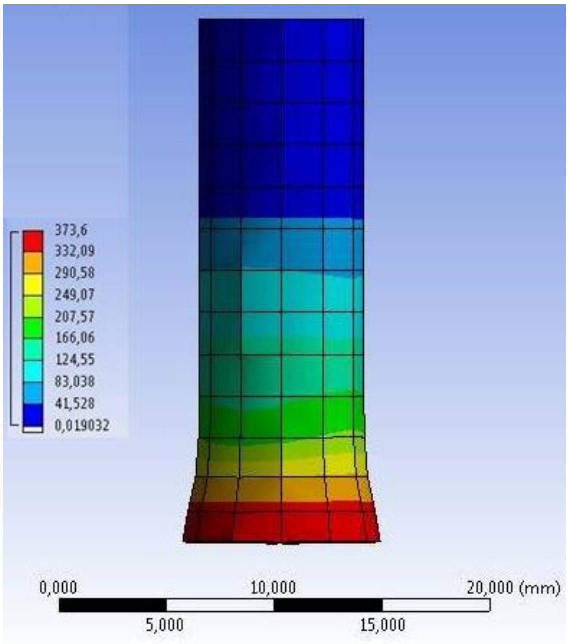


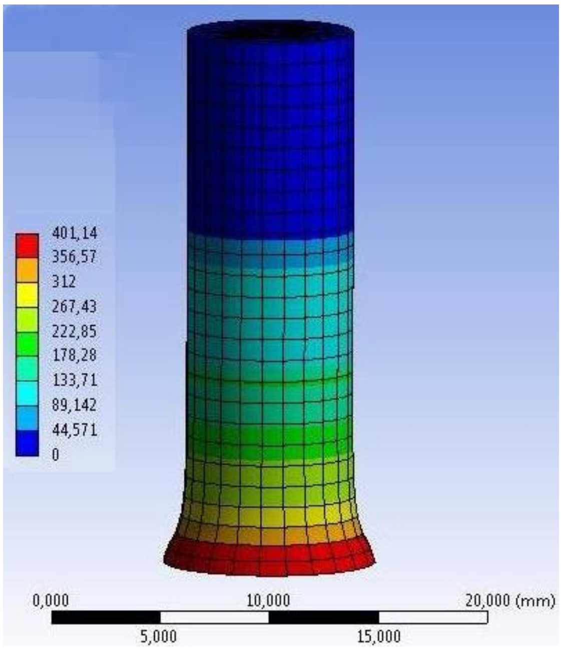
Fig. 4. Maximum values of von Mises stress for all tried discretizations

If one compare the images in Fig. 3, mesh=2 mm does not offer a realistic simulation, the case with mesh 1 mm have no failure at the mashroom edge, but break is present for the finer mesh (0.5 mm and 0.25 mm).

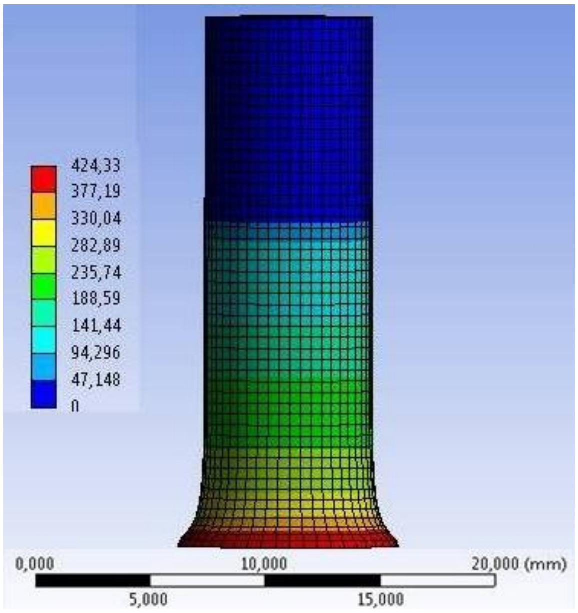
There were analyzed the von Mises stress distribution and maximum values.



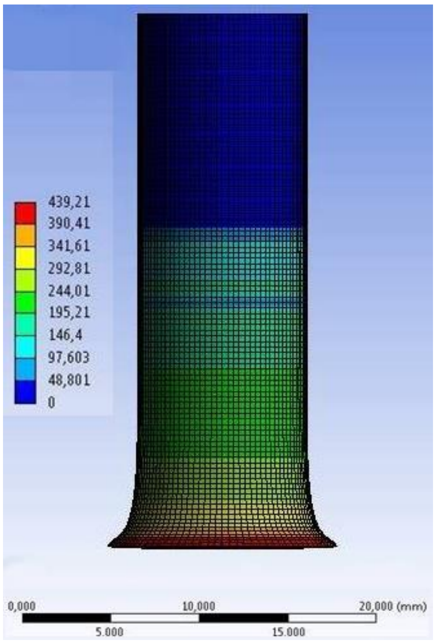
a) mesh size=2 mm



b) mesh size=1 mm



c) mesh size=0.5 mm

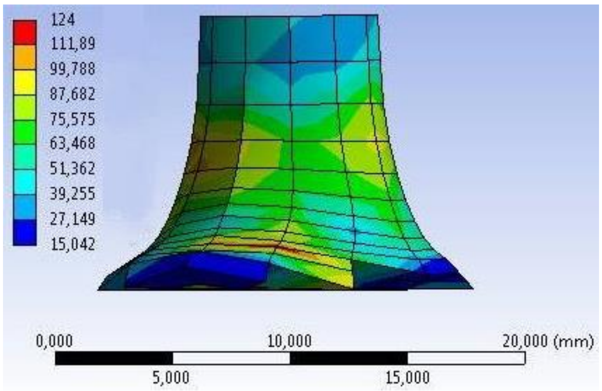


d) mesh size=0.25 mm

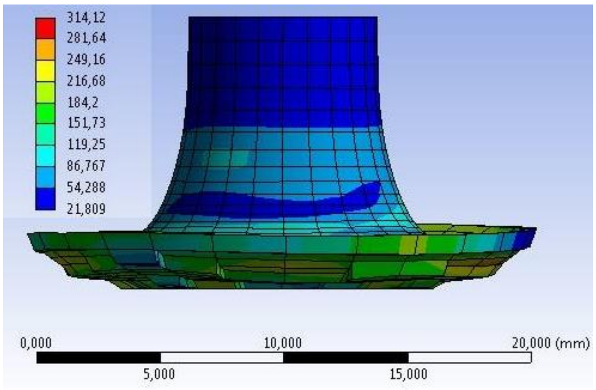
Fig. 2. Influence of mesh size on von Mises stress distribution and projectile shape, at time moment $t=1x10^{-5}$ s

Even if the slope to moment $t=1x10^{-5}$ s is almost the same, then the values for maximum von Mises stress evolve very differently. For the coarsest mesh (2 mm), this value is rising to 501 MPa, but then it follows a plateau around 450 MPa, with a peak of 545 MPa at $t=4x10^{-5}$ s, the highest values (around 600 MPa) being obtained only at $t=6.5x10^{-5}...7x10^{-5}$ s. The highest value was obtained for the finest mesh, meaning that this mesh produces more quickly the material fracture than the other meshes. The peaks around 500...600 MPa means the material is fractured in different places on the peripheral “mashrooms”.

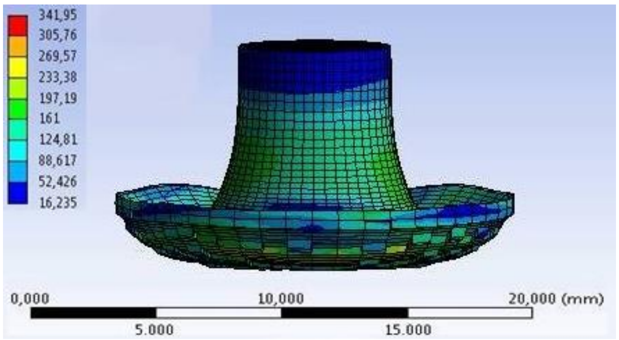
The coarsest mesh (2 mm) generates stress peaks with a delay of $5x10^{-5}$ s. No dependence between mesh size and the occurrence of the stress peaks. The conclusion is that a convergence should be established also for the evolution of the maximum stress in time.



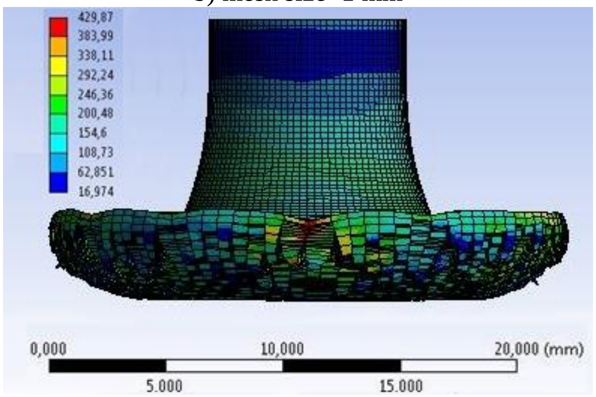
a) mesh size=2 mm



b) mesh size=1 mm



c) mesh size=0.5 mm



d) mesh size=0.25 mm

Fig. 3. Influence of mesh size on von Mises stress distribution and projectile shape, at time moment t=1x10^{-4} s

First rupture noticed during the simulation occurs earlier for the finer meshes (0.5 mm and 0.25 mm) and it is deeper toward the axes of the body, the second or even the third being more superficial. Analyzing the actual failure of three 9 mm FMJ projectiles, after being arrested in a panel made of aramid fabrics (Fig. 6), the mushroom shape is visible and also three or four fractures of the edge, not equal as deepness and opening. Of course, the conditions are not similar to this simulation (impact velocity was around 400 m/s, the panel is made of elasto-plastic materials and the projectile are constrained to deformed within the panel), but one may also notice the resemblance of the edge deformation and fracture.

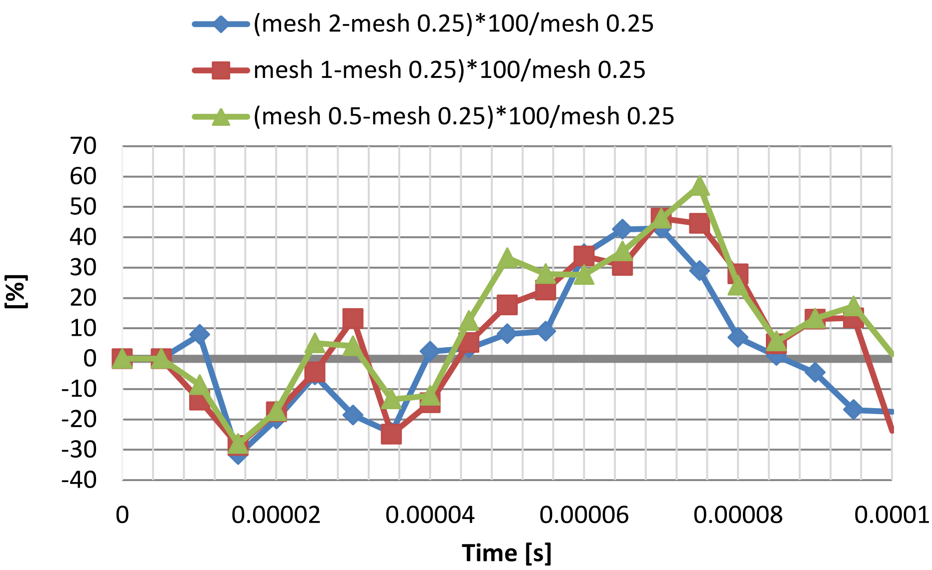


Fig. 5. Percentage difference for the maximum von Mises stress in each analyzed moment, taking as reference the maximum value obtained for a mesh size of 0.25 mm.

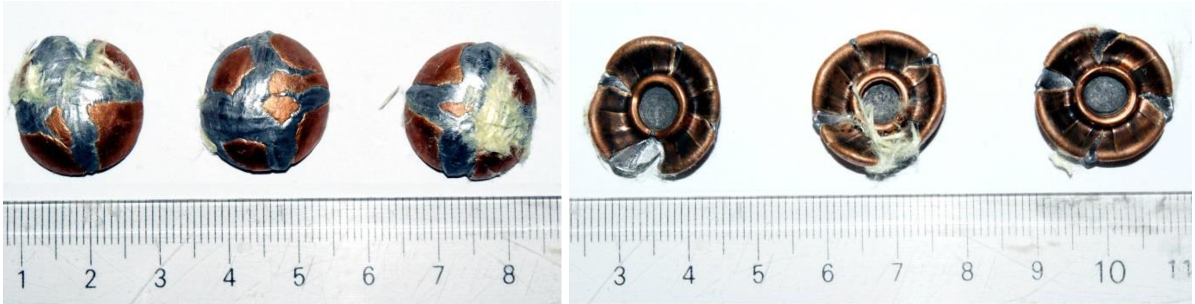


Fig. 6. Bullets extracted from an aramid fabrics panels (the panels were not penetrated, and fire were in agreement with ISO/FDIS 14876-2 Protective clothing - Body armor - Part 2: Bullet resistance; Requirements and test methods, 2002 and NIJ 0101.04/2000 Ballistic Resistance of Personal Body Armor) [8]

CONCLUSIONS

Depending on the case application the engineers could adopt a finer or coarse mesh, but not so coarse to denaturate the reality of body deformation and failure. How to decide? Having performant computer resources (hardware and software) and running several mesh in order to notice the convergence of one parameter or, more reliable, a set of criteria that could include qualitative resemblance with actual bodies as concerning failure and deformation, experimental data on strain, yield and failure of the involved materials, values of stress and strain, at the same time moments. From this study the following conclusions were formulated: finer mesh presents an earlier failure in time and calculated a higher stress for these moments.

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