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PLASTIC-KINEMATIC vs JOHNSON-COOK MODEL IN FEM TAYLOR TEST SIMULATION

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ABSTRACT

The paper presents some theoretical aspects regarding stress wave propagation on solids and constitutive material models used in FEM Taylor test simulation. Also, in the final part of the paper are presented the results obtained in a LS Dyna simulation of Taylor test for 4340 steel using Plastic-kinematic and Johnson-Cook model.

Key word: numeric simulation, Taylor test, wave stress.

1. THEORETICAL ASPECTS

When a perturbation is induced in a solid automatically some stress waves start traveling along the body. Depending on the intensity of the initial perturbation the traveling waves can be classified as: elastic waves, plastic waves and shock waves.

A characteristic of the elastic wave is the fact that after passing through a solid, the medium presents no residual strain. On the atomic level this property can be easily explained because the atoms tend to return to the initial positions.

In solids there can be identified three types of elastic waves: longitudinal, transversal and surface waves.

When a longitudinal wave travels through a solid the displacement particles vector has the same direction with the wave velocity vector. In solids there can travel compression or tension waves depending on the vector orientation.

The emergence of a transversal wave in a solid leads inevitably to a particle displacement on a perpendicular direction to wave velocity vector, the longitudinal deformation being ignore.

When we speak about surface waves the most eloquent example that anyone can give is sea waves. This particular type of wave presents a strong decrease of the speed particles with the increase of the distance between the surface and the measuring point.

An elastic wave is characterized by a series of particularizations [1]:

o a solid traversed by an elastic wave exhibits an adiabatic and isentropic transformation, the entropy of material element being conserved;

o the wave speed is evaluated by

$$c = \sqrt{\frac{E}{\rho}} \tag{1}$$

where: E – Young modulus;
φ – density.

When the intensity of the perturbation induced in a solid exceeds the specific elastic limit a series of elastic and plastic waves will emerge leading to some permanent deformation of the medium.

The study of plastic waves and their propagation can be approached through one of the following methods:

o tracking in time the evolution of a material particle;

o tracking in time the material flow through a chosen cross section.

The first method is found in T. Von Karman, P. Duwez and K.A. Rakhmatulin's papers regarding the plastic wave theory. Unlike the three scientists above mentioned, G.I. Taylor approaches the theory using the second method the results being identical with the ones obtained by the others.
The plastic wave speed for a constant strain is evaluated by

$$v_p = \sqrt{\frac{\frac{d\sigma}{d\varepsilon}}{\rho_0}} \tag{2}$$

The test performed by G.I. Taylor in the 50's try to explain the way in which a long rod launched against a rigid target deforms, the tests final purpose being the elaboration and validation of a constitutive material model.
During these tests through the use of a gas gun, Taylor succeeds to launch the rod with a speed of 450 m/s which automatically involves a $10^3 \ldots 10^4$ s^{-1} strain rate.[2]
The Taylor test can be used in one of the three configurations:
- *direct Taylor test* in which a rod strikes a rigid fixed plate
- *symmetrical Taylor test* in which a rod is launched against an identical one, the second rod being in repose. The advantage of this particular test is that allows to eliminate the incertitude regarding the friction between rod and target.
- *inverse Taylor test* where the target is launched against the rod. This solution is difficult to be put in practice due to the gun caliber and rod recuperation method. The huge advantage of this particular test is that the one can take in consideration the rod temperature.

At normal impact between the rod and the target a series of stress waves start propagating along the rod. As a result of the impact the elastic waves emerge and travel with a speed equal to the sound speed. Once the elastic waves reach the free surface the reflection induced a tension wave propagating in the opposite direction. When the induce tension exceeds the material elastic limit $\sigma_{e,}$ a plastic wave start traveling along the rod with a considerable lower speed.
The front which separates the undeformed material by the deformed one is called elastoplastic interface.
As a result of the impact the rod will exhibit a decrease in length and an increase in diameter due to the material evacuation on radial direction. This phenomena lead to a shape change and an increase of internal temperature.
Due to the difference between waves velocity the reflected elastic wave interacts with the direct plastic wave. The result is another reflection of elastic wave, the second reflected wave leading to a rod compression.

2. MATERIAL MODELS

FEM is a numerical analyzes technique which allowed obtaining solutions for a large variety of problems and at this moment is the most powerful tool used to investigate complex problems from different fields.
The use of laboratory devices (hydraulics, pneumatics or gas-guns) allowed determining material behavior subjected to a very precise loading. Once that these material models have been determinate, an implementation of these data in different codes can be made, allowing us to predict the response of materials subjected to different loads.

2.1. Johnson-Cook Model

This material model is applicable when the deformations, strain rates and temperatures are characterized by high values. These cases are encountered when the loads have high values (impact at high speed or interaction with blast wave). The expression of the model is given by the relation [3]:

$$\sigma_c = \left[A + B\varepsilon_p^n\right]\left[1 + C\log\varepsilon_p^*\right]\left[1 - T^m\right] \tag{3}$$

where : ε_p – effective plastic strain;

ε_p^* – effective strain rate;

$T = \dfrac{T - T_{mediu}}{T_{topire} - T_{mediu}}$ – temperature function;

A, B, n, C and *m* – material constants.

Material constants given above must be determined experimental through laboratory tests.
On this particular material model, the plasticity is sensitive to strain rate and temperature. The model is used sometimes to solve problems in which the interval variation of strain rate is significant and the temperature rise adiabatic causing material melting.
The Johnson-Cook material model is applicable to the most metallic material.

2.2. Plastic- Kinematic Material Model

The plastic-kinematic model with viscosity is a model used mostly in applications in which the modeling element is *beam, shell and solid*[4].

$$\sigma = \sigma(\varepsilon)\left[1 + \left(\frac{\dot{\varepsilon}}{c}\right)^{\frac{1}{\rho}}\right], \tag{4}$$

where: c, p – material coefficients;
$\sigma(\varepsilon)$ – Static characteristics;
E - Young modulus;
E_T - plasticity modulus;
σ_c - yield stress.

Kinematic hardening, isotropic hardening or a combination kinematic-isotropic can be specified through hardening parameter β between 0 and 1 (0 for kinematic and 1 for isotropic).
In isotropic hardening case, the yield surface rest centered on initial point and increase his dimension with the development of plastic deformation.
In the kinematic hardening case is assumed that the yield surface rest constant and move along the main stress directions while the plasticity process develops.

3. NUMERICAL SIMULATION OF TAYLOR TEST

For the numerical simulation of Taylor test had been chose a metallic material (4340 steel) with the following characteristics [5]: ρ=7840 kg/m^3; E=1,57*10^{5}N/mm^2; σ_c=400N/mm^2; γ=0,26.
LS Dyna code had been used for the numerical simulation. For simulation had been considered a cylinder with a diameter of 7,595 mm, a length of 37,97 mm and three different initial speed: 181 m/s, 224 m/s and 270 m/s.
For the simulation had been considered two material models: plastic-kinematic and Johnson-Cook.

Table 1. Results of simulation

Speed (m/s)	**D_f (mm)**			**L_f (mm)**		
	Plastic-kinematic	**Johnson-Cook**	**Experimental [2]**	**Plastic-cinematic**	**Johnson-Cook**	**Experimental [2]**
181	11,2	9,52	9,5	34,6	34,47	34,6
224	12,9	10,64	10,5	33,7	33,11	33
270	14,7	12,18	12,1	32,8	31,2	31,3

In the figure 1 and figure 2 are presented the rode profile obtained for the two models considering a 270 m/s speed:

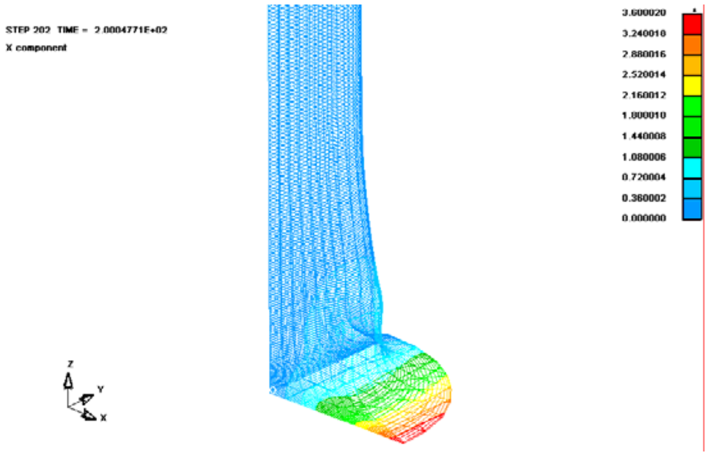

Figure 1. Plastic-kinematic model

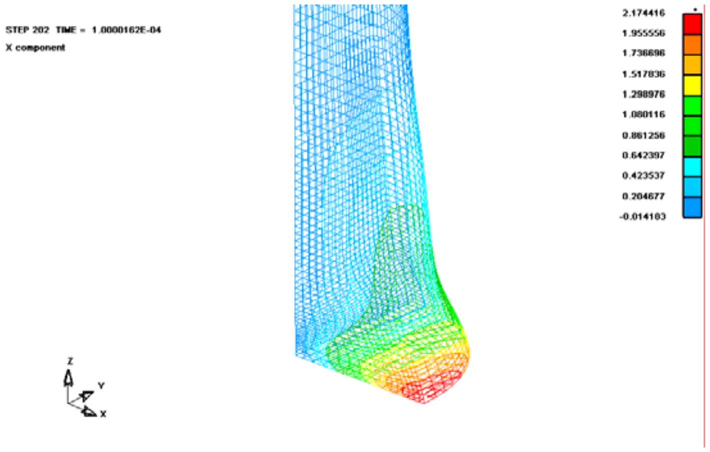

Figure 2. Johnson-Cook model

4. CONCLUSIONS

The numerical simulation of Taylor test for 4340 steel shows that:

- the results obtained for Johnson-Cook model prove that the errors between the calculated rode dimensions and the measured dimensions (mushroom diameter D_f and final length L_f) are bellow 5% and have a decreasing tendency with the increase of speed;
- the high values for stress and the unsatisfactory shape of cylinder obtained prove that for this particular test the plastic-kinematic model don't lead to good results.

5. REFERENCES

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