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TEST OF THE NEW IMPLEMENTATION OF THE JOHNSON-COOK MODEL IN AUTODYN

Abstract (not more than 200 words)

In the Autodyn code version 4.2 there is a new option for treating strain rate dependent constitutive models. This so-called visco-plastic correction is available for the Johnson-Cook model. In this report, we test this option on a simple problem, namely, a simulated tensile test. Transient numerical oscillations do occur. For reasonable parameters, however, they are small and have short duration in the tested cases. We also compare the new option to a user implementation of the same constitutive model, where the implicit probelm is solved by iteration. Autodyn is believed to use an approximation, a first order correction, for efficiency reasons. The user implementation produces smooth curves for the stresses.

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Autodyn; Strain rate dependence;

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TEST AV DEN NYA IMPLEMENTERINGEN AV JOHNSON-COOKS MODELL I AUTODYN

Sammanfattning (högst 200 ord)
I programmet Autodyn version 4.2 har man introducerat en ny metod för att behandla töjningshastighetsberoende konstitutiva materialmodeller. Denna så kallade visko-plastiska korrektion finns för Johnson-Cooks modell. I denna rapport testar vi denna nya metod på ett enkelt probelm, nämligen ett simulerat dragprov. Transienta numeriska oscillationer förekommer. För fysikaliskt rimliga parametrar blir de däremot små och får kort varaktighet i de testade fallen. Vi jämför också den nya metoden med en egen metod (user subroutine) för samma konstitutiva modell, där det implicita problemet löses iterativt. Autodyn använder antagligen en approximation (en första ordningens korrektion) av effektivitetsskäl. Vår egna metod ger snygga jämna kurvor utan oscillationer.

Nyckelord
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CONTENTS

1. INTRODUCTION

In Autodyn [1,2] version 4.2, a new option for the strain rate dependent constitutive model by Johnson and Cook [3] was introduced. The option, called “viscoplastic correction”, was needed because the old implementation could lead to unphysical oscillations and under-estimation of strain rate effects [4]. Here, we will test this new standard model for a simulated tensile test, and also compare it to our own user model.

In the Johnson-Cook model the yield stress

$$\sigma_{\mathrm{Y}} = \left(A + B\varepsilon_{\mathrm{p}}^{\mathrm{n}}\right)\left(1 + C\ln(\dot{\varepsilon}_p^*)\right)\left(1 - T_{\mathrm{H}}{}^{m}\right) \tag{1}$$

depends on the plastic strain ε_{p}, plastic strain rate $\dot{\varepsilon}_{\mathrm{p}}$, and the temperature T. Here *A*, *B*, *n*, *C*, and *m* are parameters. T_{H} (homologous temperature) is a linear function of the temperature T, scaled so that it is equal to zero at room temperature and equal to one at melting temperature. Here it is limited to the interval $0 \le T_{\mathrm{H}} \le 1$. The dimensionless variable $\dot{\varepsilon}_p^*$ is the quotient of the plastic strain rate $\dot{\varepsilon}_p$ and a constant $\dot{\varepsilon}_0$, which is usually set to 1 s^{-1}. The logarithm in the formula should be set to zero if $\dot{\varepsilon}_p^* < 1$, i.e. if the plastic strain rate is less than $\dot{\varepsilon}_0$.

2. TEST RUNS

The test problem consists of a tensile test of a cylindrical rod with length and diameter equal to 0.004 m and 0.002 m, respectively. One end was fixed and the other was pulled with the constant velocity 0.4 m/s, corresponding to the strain rate 100 s^{-1}. The two-dimensional version of Autodyn with cylindrical symmetry was used for the simulations. The Lagrangian grid consisted of square cells, 20 cells axially and 5 radially . One radial row of five target points was defined in the middle of the rod, see Figure 1.

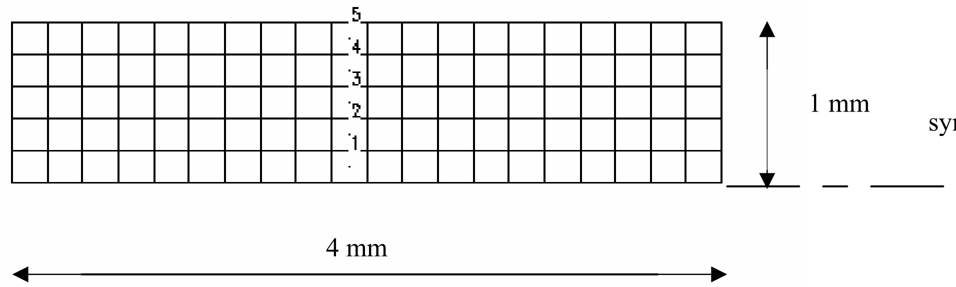

Figure 1. The grid and target points. Data from target point number 4 in the second outermost cell are used in the post processing.

In order to simplify the analysis we limit our self to the special case with only strain rate dependence, i.e.

$$\sigma_{\mathrm{Y}} = A\left(1 + C\ln(\dot{\varepsilon}_p^*)\right), \tag{2}$$

and we use fictitious material parameters according to Table 1.

Table 1. Material parameters.

Parameter	Notation	Value
Bulk modulus (GPa)	K	200
Shear modulus (GPa)	G	100
Static yield stress (GPa)	A	1
Strain rate coeff.	C	See Table 2

The strain rate sensitivity *C* is found in Table 2, where all the test runs are summarised. These *C*-values might be compared to the value for 4340 steel, which is 0.014.

We also compared the results to those obtained with our own implementation (the user model) of the constitutive model as a so-called user subroutine [4]. Finally, we checked the influence of the time step size.

Table 2. Test runs.

Case no.	Run ID	C	Nominal strain rate (s^{-1})	Time step (ns)
1	T01JCB	0.001	100	16
2	T02JCB	0.01	100	16
3	T03JCB	0.1	100	16
4	T01JCC, user routine	0.001	100	16
5	T02JCC, user routine	0.01	100	16
6	T03JCC, user routine	0.1	100	16
7	T04JCB	0.001	100	1.6
8	T05JCB	0.001	100	0.16

3. RESULTS AND DISCUSSION

All results are from a cell, which is situated in the middle of the rod axially and which is the second outermost from the cylindrical surface (target point 4). The interpretation of the somewhat bad quality figures might be helped by knowing that they consist of different combinations of time plots of von Mises effective stress (called `MIS.STRESS` in the figures) and yield stress (`YLD.STRESS`). The yield stress should always be greater than or equal to the effective stress, which also is the case in the figures.

Figure 2 shows the effective stress and the yield stress vs. time for three cases with different values of the parameter *C* (case 1-3). The curves for $C = 0.001$ look smooth. For $C = 0.01$, small oscillations can be seen at onset of plastic deformation. For the highest value of *C*, namely, $C = 0.1$, these oscillations are quite large. However, the oscillations persist only for a short time.

From Figure 3, showing magnifications of small parts of the curves in the previous figure, it is seen that oscillations occur also for C=0.001. As expected, the effective stress is always less than or equal to the yield stress. One might also expect these stresses to coincide after onset of plastic deformation, since the rod is continuously strained (with no unloading). However, this is not the case for the oscillating curves. Another unexpected property of these curves is that the yield stress sometimes is less then the static one, which here is $A = 1.0$ GPa.

The three cases with different values of C were also run with the user model (case 4-6), and results from the three cases are shown in Figure 4(a-c), respectively. These diagrams also contain the effective stress from the original runs with the standard model (case 1-3). The results from the two models coincide except for oscillations in the curve from the standard model, which occur at onset of plastic deformation in the cases with the two highest C values. The diagrams in Figure 5 show enlarged details of the curves from the previous figure, and here small oscillations are seen even for the lowest value of C.

Case 1 ($C = 0.001$) was also simulated with smaller time step sizes, namely 1.6 ns (case 7) and 0.16 ns (case 8), achieved by lowering the time step safety factor. The default time step used in case 1 was 16 ns. The results are shown in Figure 6, where effective stress is plotted versus time. In normal scale, shown in Figure 6(a), the curves for the three different time step sizes coincide and no oscillations are visible. Figure 6(b) shows a large magnification of a part of Figure 6(a), and there small oscillations are seen for all three time step sizes.

Finally, we mention a couple of observations, which perhaps can give some insight in the algorithmic details. Oscillations of the same type as those described in Ref. [4] for the old implementation in Autodyn could also be seen here, see for example Figure 7, which shows a magnification of a small part of the curves in Figure 2(c). In Figure 8 it is seen that the maxima of the effective stress calculated by the standard model tend to lie on the corresponding smooth curve from the user model.

Without fully knowing how the new standard model in Autodyn works, we still believe that we can draw the following conclusions about the model:

(i) If the trial stress is less than the yield stress, based on the strain rate from the previous time step, the material is considered elastic.

(ii) In the opposite case, a new yield stress is calculated by an algorithm, which most probably uses the slope of the logarithmic curve in equation (2).

The problem with (i) is that it classifies the material as elastic too easily. The material should be plastic if the trial stress is greater than the static yield stress, because then there is an overstress present that will drive the plastic deformation. In our simplified constitutive model (1) the static yield stress is equal to A. In the general case, when equation (1) is used, the "static yield stress" should here be interpreted as the yield stress that corresponds to zero plastic strain rate, i.e. the product of the first and last parentheses in equation (1).

In case (ii) it seems that the algorithm is missing the threshold for the logarithmic curve and therefore may return a yield stress, which is less than the static one ($A = 1\ \mathrm{s}^{-1}$).

4. CONCLUDING REMARKS

The new standard implementation in Autodyn of the JC-model, which was introduced in order to cure some problems with oscillations in the old implementation, still suffers from small oscillations. However, in the tested cases they persist only for a very short time, and their amplitude is small except for the largest strain rate sensitivity $C = 0.1$, which is about seven times larger than that for 4340-steel.

In our own user model, which gives rather smooth curves, the equation for the strain rate is solved by iteration every time step. Normally, only a few iterations are needed due to a good initial guess (taken from the previous time step) and the fast convergence properties of the Newton-Raphson method. The implementation in Autodyn that we have tested probably uses a more computationally efficient method without iterations. Computational efficiency is important in these types of simulations, so one obviously has to do a trade off between efficiency and accuracy. On the other hand, we think it would be worthwhile investigating if (small) changes in the implementation could increase the accuracy with little or no loss of efficiency.

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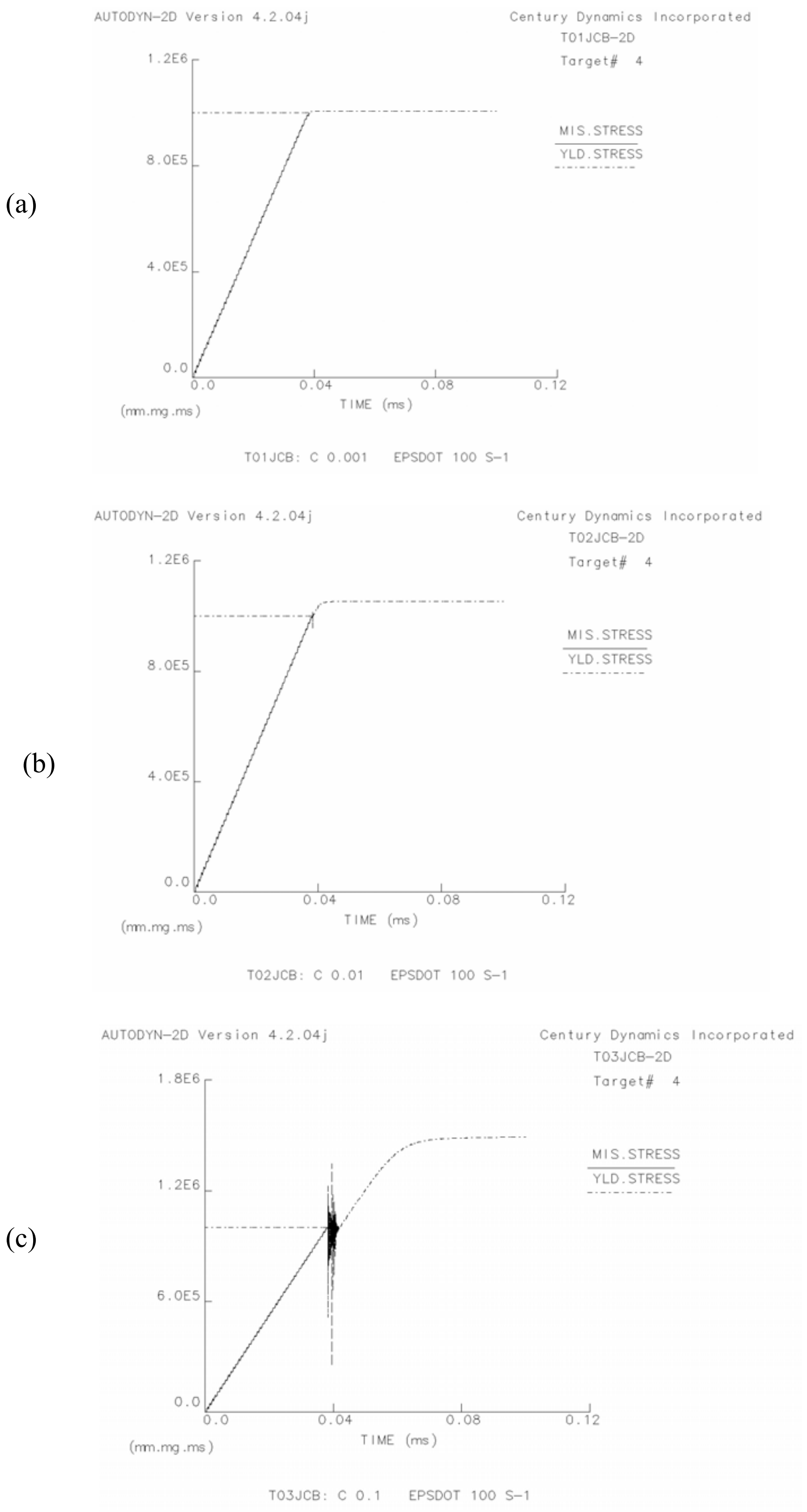

Figure 2. Effective stress and yield stress vs. time computed by the standard model. Nominal strain rate is 100 s^{-1}. The strain rate sensitivity is (a) $C = 0.001$, (b) $C = 0.01$, (c) $C = 0.1$.

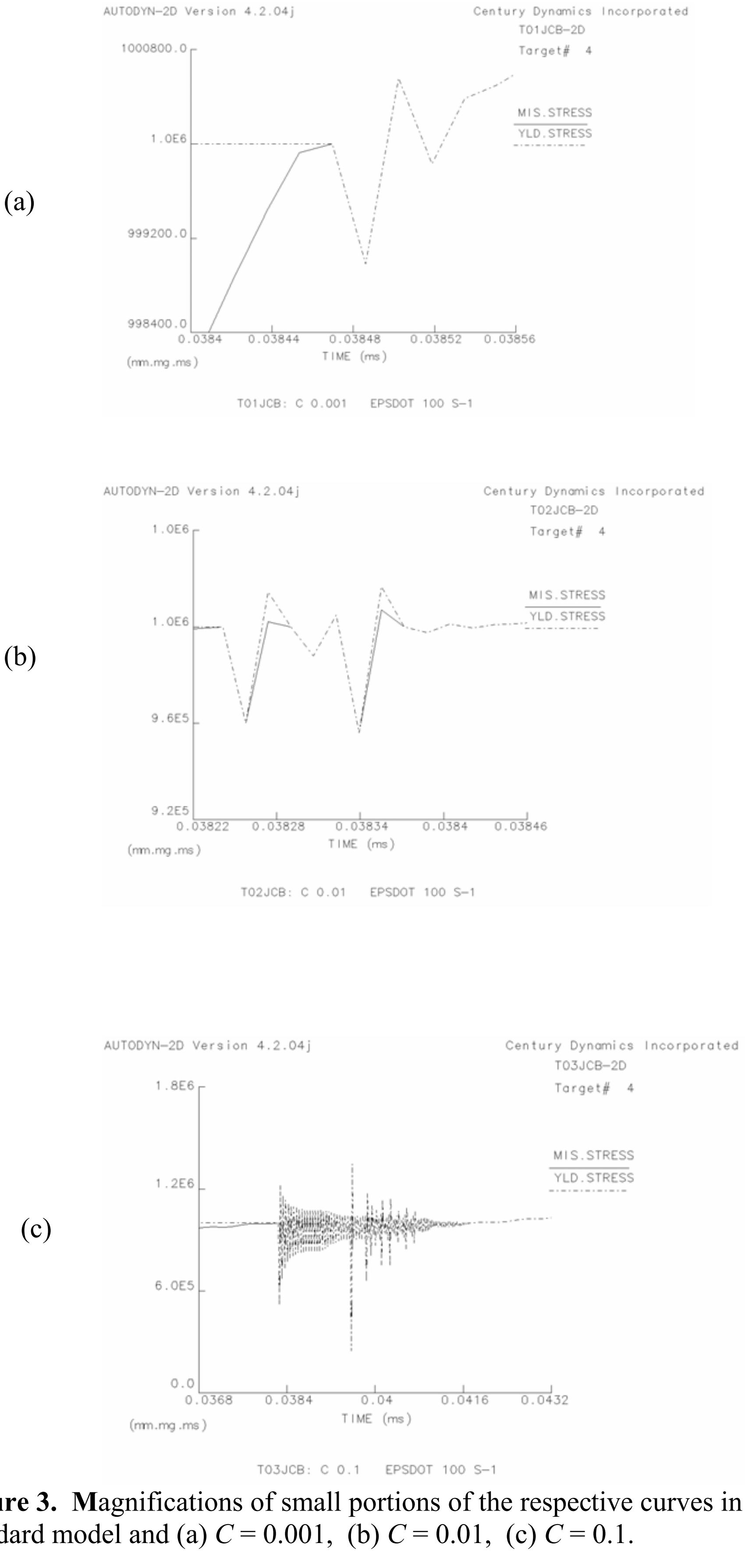

Figure 3. **M**agnifications of small portions of the respective curves in the previous figure, i.e. standard model and (a) $C = 0.001$, (b) $C = 0.01$, (c) $C = 0.1$.

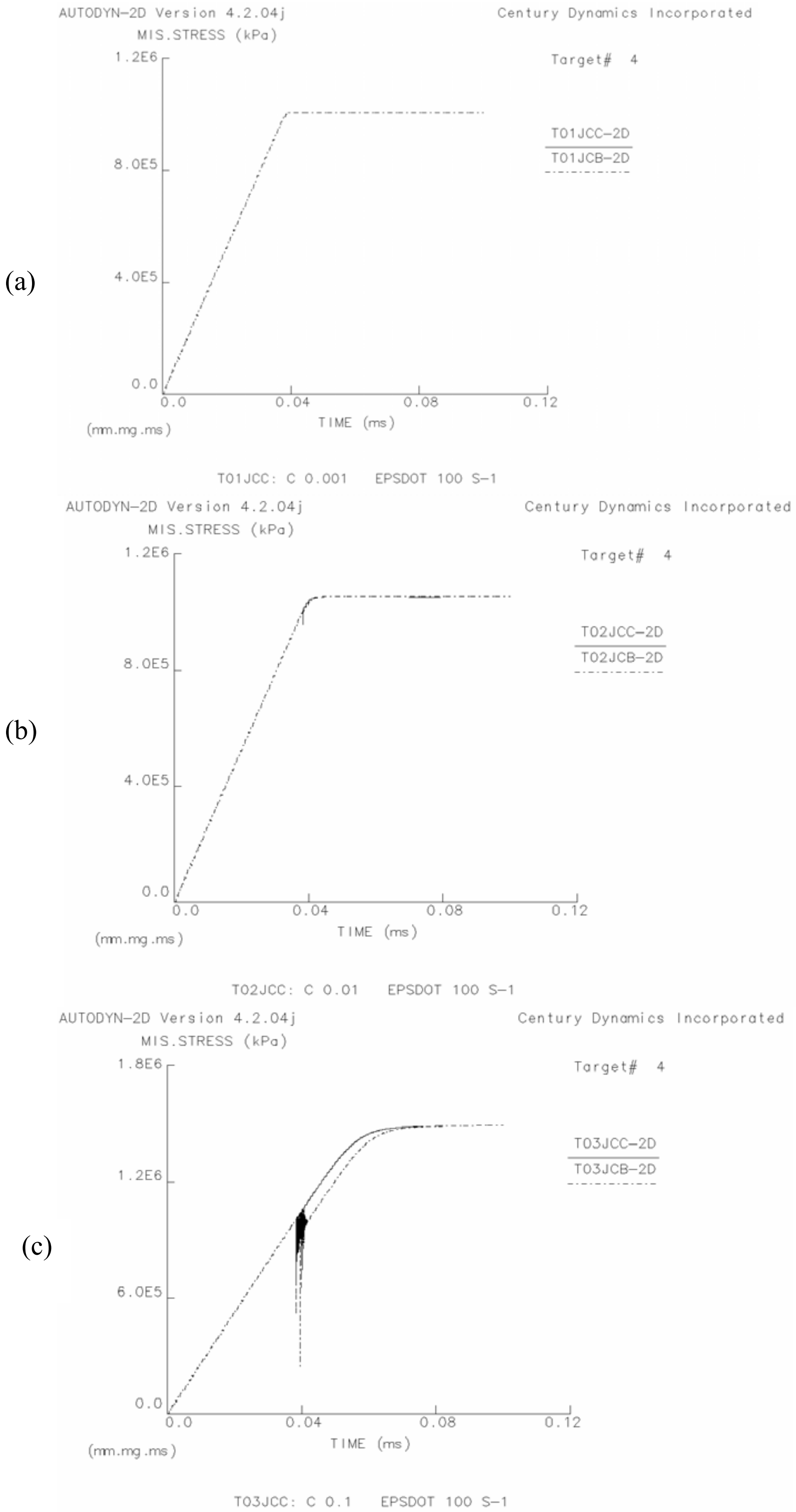

Figure 4. Effective stress vs. time. Comparison between the standard model and user model. The smooth curve, often lying above the other one, is from the user model. (a) *C* = 0.001, (b) *C* = 0.01, (c) *C* = 0.1.

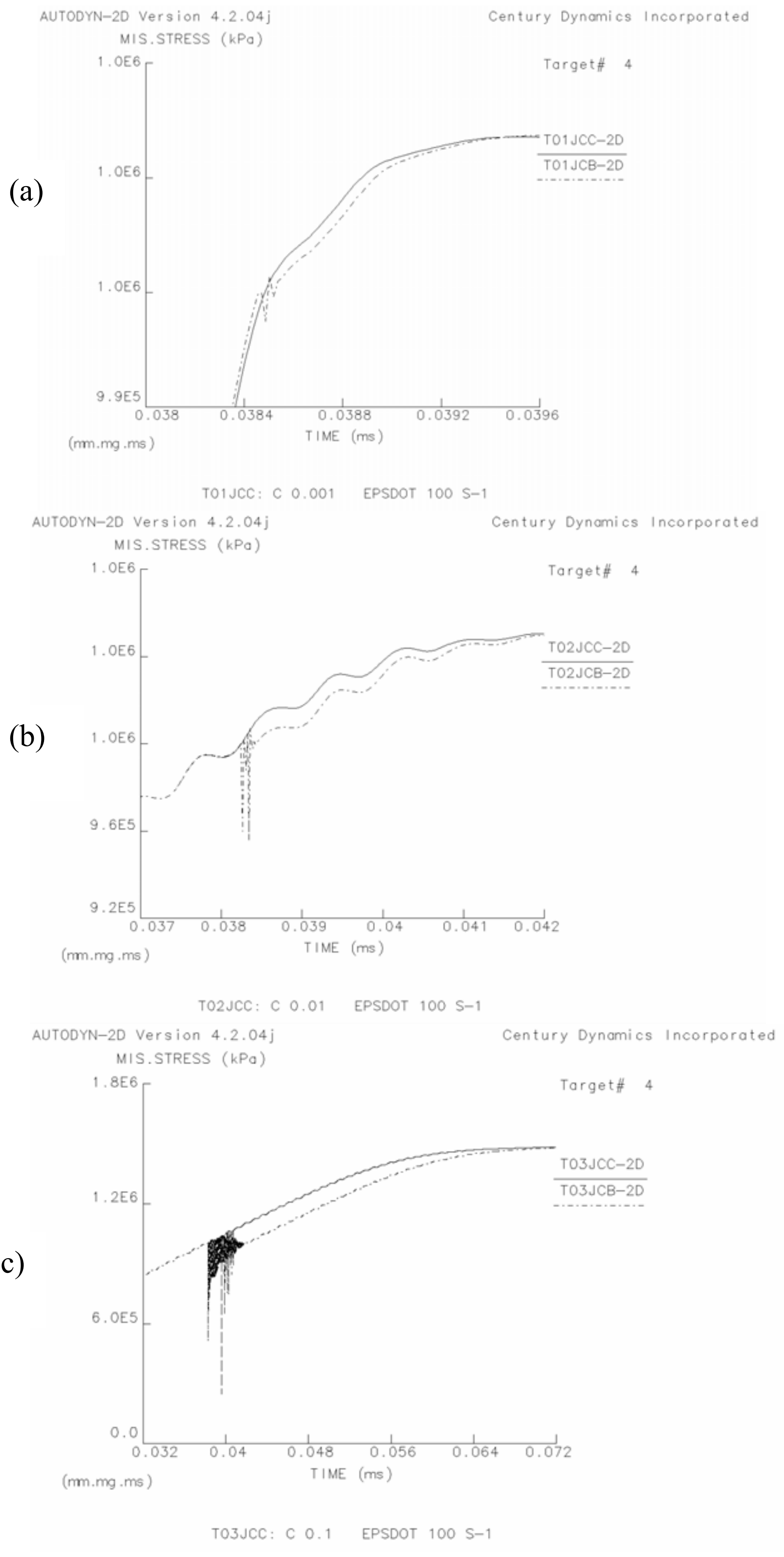

Figure 5. Magnifications of portions of the curves in previous figure. Comparison between the standard model and user model. The smooth curve, often lying above the other one, is from the user model. (a) $C = 0.001$, (b) $C = 0.01$, (c) $C = 0.1$.

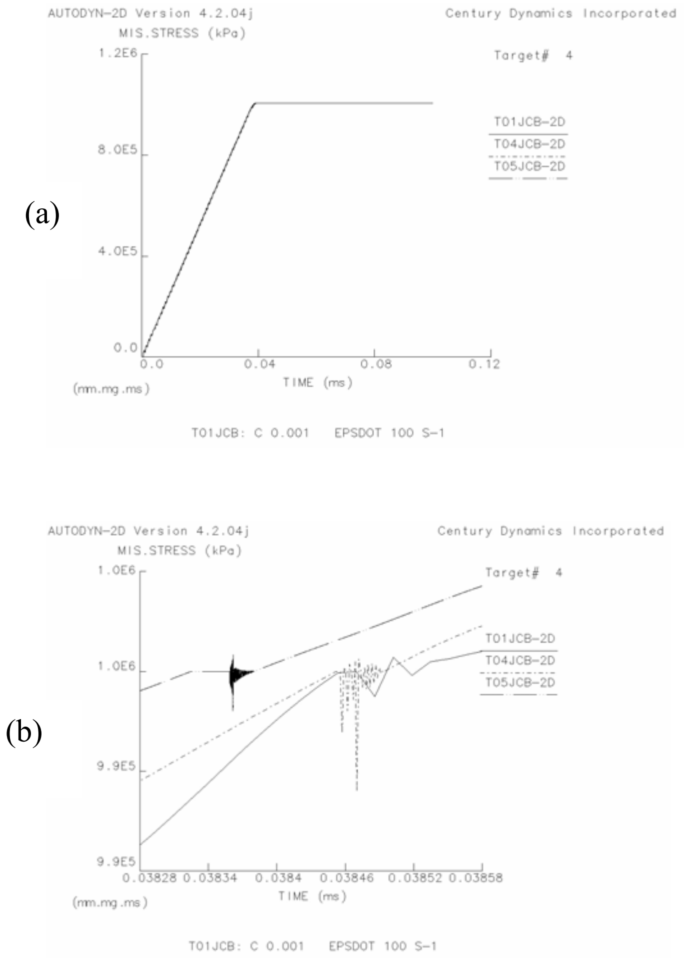

Figure 6. Effective stress vs. time. The influence of time step. T01JCB is run with default time step, 16 ns, whereas T04JCB and T05JCB are run with 1.6 ns and 0.16 ns, respectively. (a) Normal scale, (b) a magnification

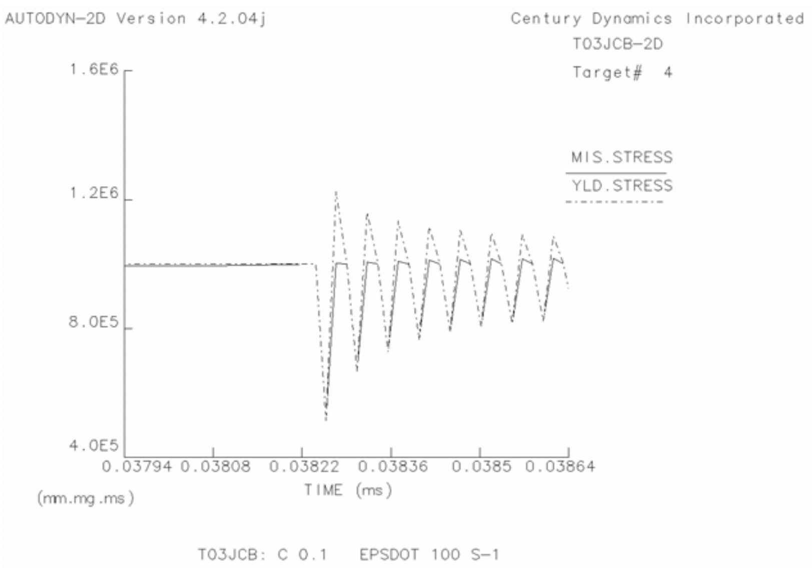

Figure 7. Further magnification of the diagram in Figure 3(c), where $C = 0.1$ and the time step is 16 ns.

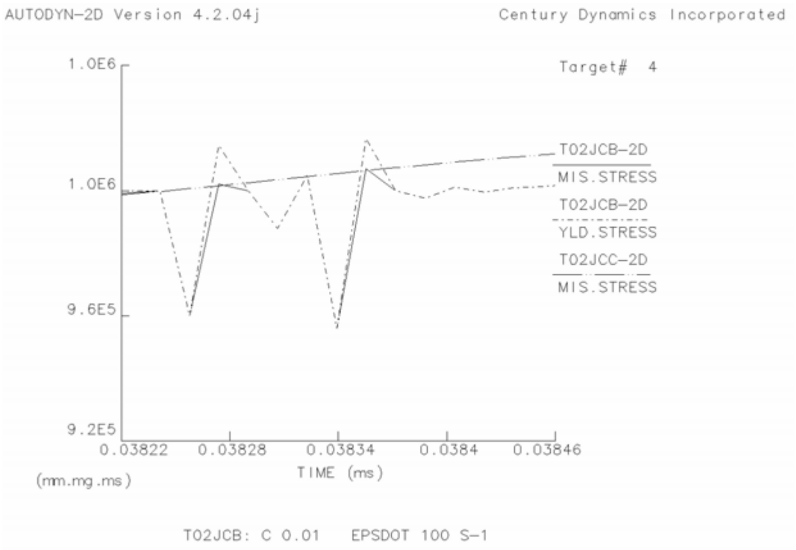

Figure 8. The solid and the dotted line show effective stress and yield stress vs. time, respectively, computed by the standard model (case 2). The dashed line (almost straight) shows the effective stress computed by the user model (case 5).