Review Article



# Mechanical response of a metal plate impacted by a rigid projectile


## Abstract

The results of a quasi-static analysis of the finite elements and the modeling of the mechanical (thermo-viscoplastic) behavior of the material are presented using the constitutive law of Johnson-Cook. This law of behavior being pre-integrated into the ABAQUS code. We were particularly interested in the influence of the mechanical behavior and the nature of the target material on its response to the impacter which is supposed to be rigid.


**Keywords:** empirical model, impact, impactor, johnson-cook, metal plate, rigid, target, thermo-viscoplastic, viscoplastic

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## Introduction

The mechanical behavior of a metal plate impacted by a projectile remains a complex process often including: elastic and plastic deformation, the effect of strain hardening and deformation rate, thermal softening, crack formation, Adiabatic shear (the heat does not have time to evacuate and causes a noticeable rise in the temperature of the room), the ejection of the plug, the formation of petals etc. The model used here is applicable Very useful for numerical simulation in fields as varied as aeronautics, automobile, oil and naval industry, machining processes, military applications or civil engineering. The modeling pathway in this study is the simplest and most widely used empirical model of Johnson-Cook.[1] This model is based on experimental observations. Rusinek et al.[2,3] used it for numerical simulations of impact behavior of thin steel plates using non-deformable conical and hemispherical projectiles using the ABAQUS Explicit code. The behavior of the plate was modeled by a Johnson Cook type law. [4] This model Johnson and Cook proposes an empirical law[4,5] conceived from experimental results, and intended for the fast implementation in the codes of calculation. This model is based on that of Ludwik+ and includes the influences of strain rate, strain hardening and temperature:

$$\sigma = \left[A + B\varepsilon^{n}\right]\left[1 + C\ln\left(\frac{\dot{\varepsilon}}{\dot{\varepsilon}_0}\right)\right]\left[1 - \left(\frac{T - T_0}{T_m - T_0}\right)^{m}\right]$$

The first term represents the hardening function, for $\varepsilon^{\cdot} = \varepsilon^{\cdot}_0$ and $T = T_0$. A denotes the yield strength of the material, B and n being the strain-hardening parameters. The second term writes the effect of the strain rate, C being the sensitivity parameter at this velocity. Finally, the third term represents the effect of temperature (or thermal softening). The coefficient m determines the sensitivity of the stress to the change in temperature; $T_0$ is the ambient temperature and $T_f$ the melting temperature. It is the law of behavior most used in calculation codes.

## Finite element model description

We have treated the example of a linear impact on a standard rectangular steel plate of dimensions 200* 100 mm. Its thickness is 6mm. It rests on two simple supports located each 30mm from the ends. An impactor semi-cylindrical end (d = 20mm) and 60kg of mass comes into contact with the plate at an initial speed of 4m/s.[7]The model is intended for 3D analysis. The projectile is modeled as a non-deformable rigid body. The plate is considered a deformable body. The contact between the projectile and the plate was modeled (Figure 1). with Since the global deformation of the plate is symmetrical, we have chosen to model the quarter of the problem (Symmetry plane (XY) and (YZ). The analytical conditions used in this study are restricted to a non-damaging character. (U2) and blocking of the plate along the axes (OY and OZ) with three-point bending allow the maximum freedom (three degrees of freedom) to be left to the structure and thus to limit the harmfulness of the impact The total number of quadrilateral linear elements with 4 nodes of type S4R is 338 (Table 1) (Table 2).

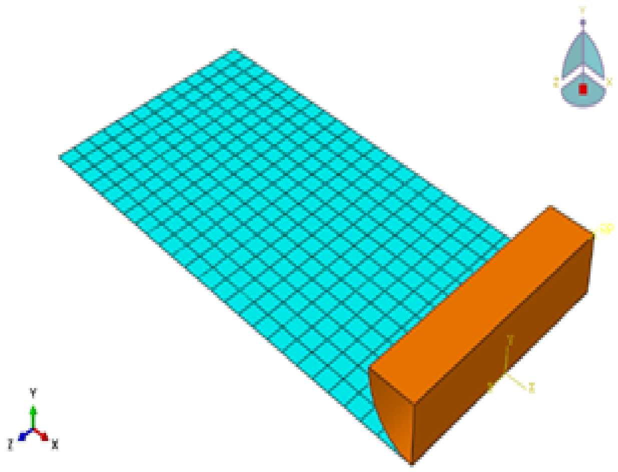

**Figure 1** Analyzed Model.

**Table 1** Input parameters for the model with elastic behavior

| Materials | Density ρ [g/cm³] | Young modulus [GPa] | Poisson's ratio |
|---|---|---|---|
| Steel 4340, C30 | 7.83 | 262 | 0.3 |
| Al6061-T651 | 2.703 | 69 | 0.3 |

**Table 2** Input Parameters for the Johnson-Cook Plasticity Model

| Materials | A [MPa] | B [MPa] | n | Tf[K] | Ttransition[K] | m | C | [1/s] | Specific Heat[J/(kgK)] |
|---|---|---|---|---|---|---|---|---|---|
| Steel 4340,C30 | 792 | 510 | 0.26 | 1793 | 293.2 | 1.03 | 0.014 | 1 | 477 |
| Al 6061-T6 | 324.1 | 113.8 | 0.42 | 925 | 293.2 | 1.34 | 0.002 | 1 | 88.5 |

# Results

## Mechanical behavior of target material

In this part, we analyzed the mechanical behavior of the material (elastic, viscoplastic, thermo-viscoplastic). The evolution of the strain energy as a function of time is illustrated in Figure 2. It reaches a peak and then decreases considerably until it reaches a value which remains constant. The value of this energy is higher the more the behavior varies from elasticity to thermo-viscoplasticity. Plasticity consumes a lot of energy: it is the mechanism that allows metals to withstand shocks as well. In all cases, plastic deformation results from movements within the material which are accompanied by friction (Peierls-Nabarro force in the case of dislocations) and therefore produce heat. It can be noted that most of the energy absorbed by the impacted structure is dissipated by its overall deflection. The variation of the kinetic energy transmitted to the material by the impactor for different behaviors of the target is represented in Figure 3. That of the material with thermo-viscoplastic behavior is more significant. The return of the curve is 75% less than the initial energy. Figure 4 represents a comparison of the evolution of the force as a function of the displacement. Curves have closed loops. The response to the impact of the target with viscoplastic behavior results in an increase up to 1400N followed by a progressive decrease in the force.

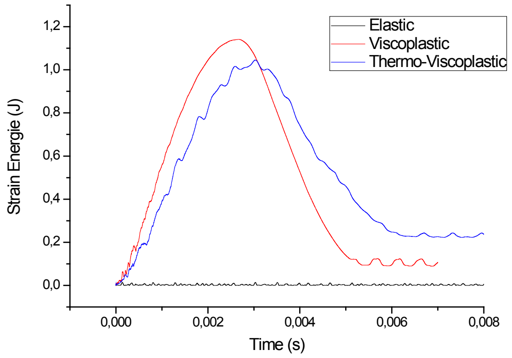


**Figure 2** Variation of the strain energy according to the times.

Concerning the overall response of the plate with thermo-viscoplasticbehavior, it can be noted that a strong evolution of the force took place up to a maximum of 4000N, which remains almost constant during a displacement of 3.5mm. This force drops sharply and reaches its minimum value of between -5000 and -2000N. With respect to this fall, the direction of displacement is reversed. The force of the impact is the deceleration force that an impactor undergoes at the end of a fall. Indeed, the area contained in the curve represents the energy absorbed by the target. Consequently, the energy absorbed by the material with thermo-viscoplasticbehavior is higher. Figure 5 shows the evolution of the speed of impact (we chose the node of the middle of the plate) as a function of time. The curve indicates oscillations at the beginning and then increases from -4 to 3.5m/s for both behaviors. The return is noted from 1m/s to 0.0055s and 0.006s for the respective viscoplastic and thermo-viscoplasticbehaviors. This delay can be explained by the increase of the viscoplasticity with the temperature and consequently the increase of the absorbed energy.

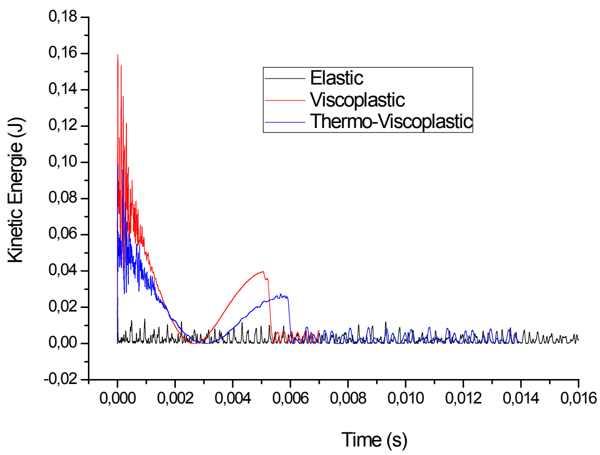


**Figure 3** Variation of the kinetic energy according to the times.

## Effect of the nature of the target

In this section, we analyzed the thermo-viscoplastic behavior of the target while varying its nature. A comparison of the variation of the force as a function of the displacement between two materials of different natures is represented in Figure 6. The overall response of the target assumes the same shape as FIG. 4. It is interpreted by a decrease of the force Amplitude of the impact force of the Aluminum relative to that of the steel. This decrease is accompanied by an elongation of the curve along the axis of displacement. The energy absorbed is higher for steel than for aluminum. The variation of the deformation energy as a function of time is illustrated in Figure 7. This energy reaches its maximum after a rapid evolution; the level of this peak is 1.15J to 0.0025s for the steel and 1.3J to 0.004 S for aluminum. This value decreases considerably to a non-zero constant value. Figure 8 shows the variation in the speed of impact as a function of time and of the nature of the material. The curve marks an increase of -4 to 3.5m /s for both materials with a time lag. The return is noted from 1m / s to

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0.006s and 0.008s for the respective steel and aluminum. The kinetic energy of steel is more significant than that of aluminum (Figure 9).

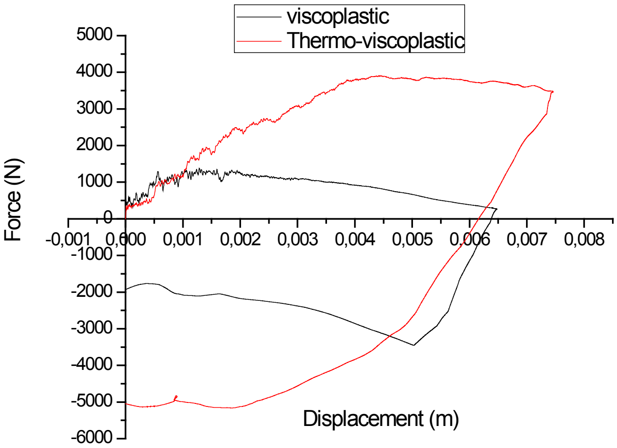


**Figure 4** Variation of the impact force according to the displacement and the material behavior.

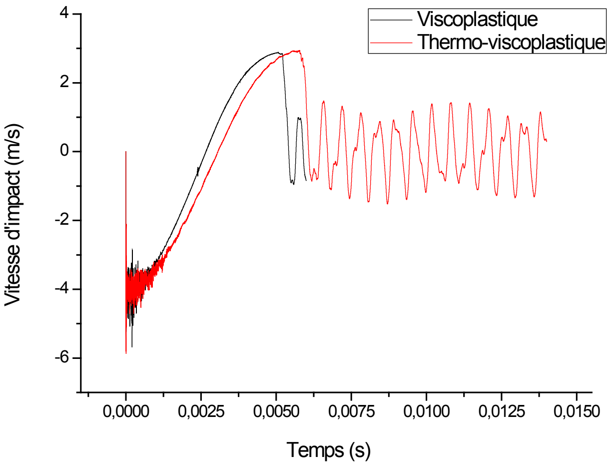


**Figure 5** Variation of the impact speed according to the times and the material behaviour.

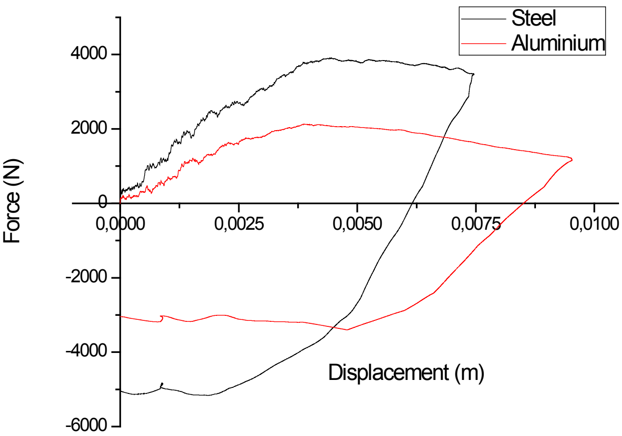


**Figure 6** Variation of the impact force according to the time for different materials.

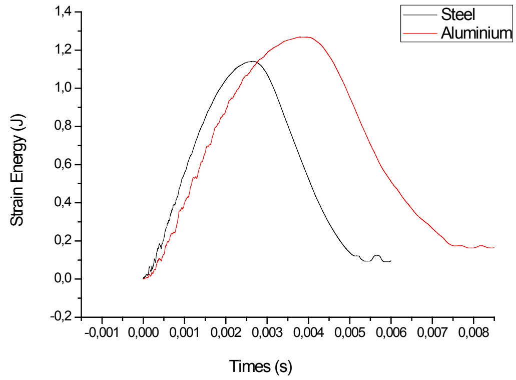


**Figure 7** Variation de strain energy according to the times for different materials.

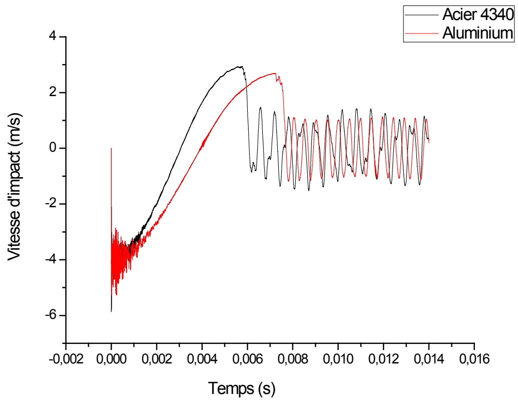


**Figure 8** Variation of the impact speed according to the times for different materials.

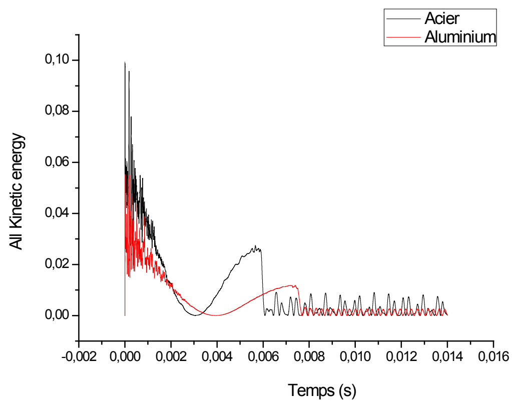


**Figure 9** Variation of the kinetic energy according to the times for different materials.

## Conclusion

The results obtained make it possible to draw the following conclusions:

a. The strain energy is higher for the thermo-viscoplasticity behavior.

b. The kinetic energy of which a part has been transmitted to the target by the impactor with thermo-viscoplastic behavior is more significant.

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c. The curves of the impact force have closed loops.

d. The response to the impact of the target with viscoplastic behavior is translated by a strong evolution of the force up to a maximum, which remains almost constant and marks a plateau. This effort drops sharply and reaches its minimum value. With respect to this fall, the direction of displacement is reversed. The force of the impact is the deceleration force that an impactor undergoes at the end of a fall. Indeed, the area contained in the curve represents the energy absorbed by the target. Consequently, the energy absorbed by the material with thermo-viscoplastic behavior is higher.

e. The curve of the speed of impact marks oscillations at the beginning and then increases from -4 to 3.5m /s for the respective viscoplastic and thermo-viscoplastic behaviors.

f. The force as a function of the displacement takes the same pace as the previous study (Figure 9) but for both natures is interpreted by a decrease in the amplitude of the impact force of the Aluminum compared to that steel. This decrease is accompanied by an elongation of the curve following the displacement. The energy absorbed is higher for steel than for aluminum.

g. The strain energy as a function of time reaches its maximum; the level of this peak is 1.15J to 0.0025s for the steel and 1.3J to 0.004s for the aluminum.

h. The curve of speed impact marks an increase of -4m/s to 3.5m/s for both materials with a time lag. The return is noted at 1m/s at 0.006s and 0.008s for the respective steel and aluminum.

## Acknowledgments

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## Conflicts of interest

Author declares that there is no conflict of interest.

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