Examples of Failure Analysis of Multiphase Materials

Eligiusz Postek
Institute of Fundamental Technological Research of the Polish Academy of Sciences
Content of presentation

1. Introduction
2. The aim of the work
3. Thermomechanical problem
   a) Taylor bar b) WC/Co plate
5. SiC foam fast compression
6. SiC foam impact
7. Summary
Problem statement

\[ KT + CT\dot{T} = F \]

Thermal equation of equilibrium, fulfills boundary and initial conditions

\( \mathbf{T}, \dot{\mathbf{T}} \) are the temperature vector and temperature rate vector

\( \mathbf{K} \) is the conductivity matrix, \( \mathbf{C} \) is the heat capacity matrix (diagonal), \( \mathbf{F} \) is the vector of thermal source and fluxes

\[ \mathbf{M}\ddot{\mathbf{u}} = \mathbf{f} - \mathbf{p} \]

\( \mathbf{M} \) is the diagonal mass matrix, \( \mathbf{u} \) is the displacement vector, \( \ddot{\mathbf{u}} \) is the nodal acceleration vector, \( \mathbf{f} \) is the internal force vector and \( \mathbf{p} \) is the nodal load vector

\( \ddot{\mathbf{u}}_n = (\mathbf{M})^{-1}(\mathbf{f}_n - \mathbf{p}_n) \) where \( n \) denotes the current time step and \( \Delta t \) is the time interval

\( \dot{\mathbf{u}}_{n+1/2} = \mathbf{u}_{n-1/2} + \ddot{\mathbf{u}}_n \Delta t \)

Velocity; \( \mathbf{u}_{n+1} = \mathbf{u}_n + \dot{\mathbf{u}}_{n+1/2} \Delta t \) displacements

\[ \mathbf{T}_{n+1} = (\mathbf{C})^{-1}(\mathbf{F}_n - \mathbf{K}_n \mathbf{T}_n) \]

Nodal temperature vector
\[
\mathbf{f} = \chi \sigma : \mathbf{e}^{pl}
\]

\(\mathbf{f}\) is the heat flux due to plastic strain; \(\sigma\) is the Cauchy stress tensor, \(\mathbf{e}^{pl}\) is the plastic strain deformation rate.

\[
\sigma^o = \left( A + B \left( \bar{\varepsilon}^{pl} \right)^n \right) \left( 1 + C \ln \dot{\varepsilon}^* \right) \left( 1 - \zeta^m \right)
\]

\(A\) is the yield stress, \(B\) is the hardening coefficient, \(C\) is the strain rate coefficient, \(\bar{\varepsilon}^{pl}\) is the equivalent plastic strain, \(\dot{\varepsilon}^*\) is the rate of the equivalent plastic strain.

\[
\zeta = \begin{cases} 
0 & \text{for } T < T_{\text{trans}} \\
\left( T - T_{\text{trans}} \right) / \left( T_{\text{melt}} - T_{\text{trans}} \right) & \text{for } T_{\text{trans}} \leq T \leq T_{\text{melt}} \\
1 & \text{for } T > T_{\text{melt}}
\end{cases}
\]

where \(T\) is the current temperature, \(T_{\text{trans}}\) is the temperature around which the yield stress becomes temperature-dependent, and \(T_{\text{melt}}\) is the melting temperature.
Taylor bar

Parameters of the Johnson-Cook material model.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values and units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young's modulus</td>
<td>$2.1 \times 10^5$ MPa</td>
</tr>
<tr>
<td>Poisson's coefficient</td>
<td>0.296</td>
</tr>
<tr>
<td>Yield stress (A)</td>
<td>455.0 MPa</td>
</tr>
<tr>
<td>Hardening coefficient (B)</td>
<td>2475.0 MPa</td>
</tr>
<tr>
<td>Hardening exponent (n)</td>
<td>0.9</td>
</tr>
<tr>
<td>Strain rate coefficient C</td>
<td>0.0235</td>
</tr>
<tr>
<td>Thermal softening exponent (m)</td>
<td>1.0</td>
</tr>
<tr>
<td>Melt temperature $T_{melt}$</td>
<td>1728 K</td>
</tr>
<tr>
<td>Transition temperature $T_{trans}$</td>
<td>293 K</td>
</tr>
<tr>
<td>Specific heat $C_h$</td>
<td>440 J/kg K</td>
</tr>
<tr>
<td>Thermal conductivity K</td>
<td>150 W/m K</td>
</tr>
<tr>
<td>Thermal expansion $\alpha_t$</td>
<td>$5.0 \times 10^{-5}$ 1/K</td>
</tr>
<tr>
<td>Mass density</td>
<td>9130 kg/m³</td>
</tr>
</tbody>
</table>

Maximum displacement, equivalent plastic strain, temperature in analyzed meshing cases, and a comparison between the adiabatic and coupled solutions.

<table>
<thead>
<tr>
<th>Case</th>
<th>Number of nodes and elements</th>
<th>Displacement $\times 10^{-2}$ m</th>
<th>Equivalent plastic strain (Element Eo)</th>
<th>Temperature, [K] (Element Eo)</th>
<th>Equivalent plastic strain (Node Po)</th>
<th>Temperature, [K] (Node Po)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>Adiabatic Nds 21,917</td>
<td>1.068</td>
<td>1.206</td>
<td>759.4</td>
<td>1.156</td>
<td>759.3</td>
</tr>
<tr>
<td></td>
<td>Coupled Els 19,200</td>
<td>1.072</td>
<td>1.203</td>
<td>707.6</td>
<td>1.154</td>
<td>707.6</td>
</tr>
<tr>
<td>B2</td>
<td>Adiabatic Nds 32,767</td>
<td>1.068</td>
<td>1.195</td>
<td>780.4</td>
<td>1.195</td>
<td>780.3</td>
</tr>
<tr>
<td></td>
<td>Coupled Els 28,800</td>
<td>1.070</td>
<td>1.193</td>
<td>720.3</td>
<td>1.193</td>
<td>720.3</td>
</tr>
<tr>
<td>B3</td>
<td>Adiabatic Nds 43,617</td>
<td>1.067</td>
<td>1.206</td>
<td>786.2</td>
<td>1.206</td>
<td>786.2</td>
</tr>
<tr>
<td></td>
<td>Coupled Els 38,400</td>
<td>1.071</td>
<td>1.203</td>
<td>724.3</td>
<td>1.203</td>
<td>724.3</td>
</tr>
<tr>
<td>B4</td>
<td>Adiabatic Nds 54,467</td>
<td>1.069</td>
<td>1.210</td>
<td>788.0</td>
<td>1.210</td>
<td>788.0</td>
</tr>
<tr>
<td></td>
<td>Coupled Els 48,000</td>
<td>1.071</td>
<td>1.206</td>
<td>725.7</td>
<td>1.206</td>
<td>725.6</td>
</tr>
</tbody>
</table>
Temperature

Impact velocity 350 m/s
Eq plastic strain

Impact velocity 550 m/s
Eq plastic strain

<table>
<thead>
<tr>
<th>Displacement $\times 10^{-2}$ m</th>
<th>Equivalent plastic strain (element Eo)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adiabatic</td>
<td>1.742</td>
</tr>
<tr>
<td>Coupled</td>
<td>4.124</td>
</tr>
<tr>
<td></td>
<td>3.090</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Temperature [K] (Element Eo)</th>
<th>Equivalent plastic strain (Node Po)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1666.3</td>
<td>4.134</td>
</tr>
<tr>
<td>1178.3</td>
<td>3.092</td>
</tr>
</tbody>
</table>
Relationship between the maximum equivalent plastic strain (a) and the maximum temperature (b) and the impact velocity in the adiabatic and coupled solutions.
Time variation of the maximum equivalent plastic strain for different impact velocities; (a) adiabatic solution, (b) coupled solution.

Time variation of the maximum temperature for different impact velocities; (a) adiabatic solution, (b) coupled solution.
Junctions A, B, C and D

WC/Co composite model

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values and units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young’s modulus</td>
<td>$6.2 \times 10^5$ MPa</td>
</tr>
<tr>
<td>Poisson’s coefficient</td>
<td>0.215</td>
</tr>
<tr>
<td>Specific heat $c_\text{f}$</td>
<td>250 J/kg K</td>
</tr>
<tr>
<td>Thermal conductivity $K$</td>
<td>95 W/m K</td>
</tr>
<tr>
<td>Thermal expansion $\alpha_\text{f}$</td>
<td>$1.5 \times 10^{-5}$ 1/K</td>
</tr>
<tr>
<td>Mass density</td>
<td>14,770 kg/m$^3$</td>
</tr>
</tbody>
</table>
Mesh dependency check. Maximum displacement, equivalent plastic strain, temperature for different meshes, and a comparison between the adiabatic and coupled solutions.

<table>
<thead>
<tr>
<th>Case</th>
<th>Number of nodes and elements</th>
<th>Displacement $x 10^{-6}$ m</th>
<th>Equivalent plastic strain</th>
<th>Temperature [K]</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Adiabatic: Nds 40,726/Els 15,516/Coupled: Nds 18,666</td>
<td>1.7353</td>
<td>3.6238</td>
<td>1646.7</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3320</td>
<td>2.0727</td>
<td>386.7</td>
</tr>
<tr>
<td>P2</td>
<td>Adiabatic: Nds 75,634/Els 31,032/Coupled: Nds 37,332</td>
<td>1.6199</td>
<td>3.5469</td>
<td>1637.9</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2579</td>
<td>2.0431</td>
<td>385.7</td>
</tr>
<tr>
<td>P3</td>
<td>Adiabatic: Nds 101,486/Els 24,252/Coupled: Nds 61,554</td>
<td>1.7254</td>
<td>3.5429</td>
<td>1637.3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.3419</td>
<td>2.1045</td>
<td>389.6</td>
</tr>
<tr>
<td>P4</td>
<td>Adiabatic: Nds 130,482/Els 32,336/Coupled: Nds 82,072</td>
<td>1.6259</td>
<td>3.5189</td>
<td>1634.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.2776</td>
<td>2.0772</td>
<td>389.0</td>
</tr>
</tbody>
</table>
(a) region of the maximum equivalent plastic strain and temperature, (b) detail of the mesh with Element Mo

Comparison of the adiabatic and coupled solutions depending on the impact velocity at Element Mo; (a) equivalent plastic strain, (b) temperature
Equivalent plastic strain in the adiabatic and coupled solutions; (a) Junction A, (b) Junction B, (c) Junction C, (d) Junction D.

Impact velocity versus equivalent plastic strain at Junctions A, B, C and D towards the end of the process.
Temperature in the adiabatic and coupled solutions; (a) Junction A, (b) Junction B, (c) Junction C, (d) Junction D.
Temperature in the adiabatic and coupled solutions; (a) Junction A, (b) Junction B, (c) Junction C, (d) Junction D.

Temperature at the end of the process

<table>
<thead>
<tr>
<th>Junction</th>
<th>Velocity</th>
<th>Adiabatic</th>
<th>Coupled</th>
<th>%</th>
<th>75 m/s</th>
<th>Adiabatic</th>
<th>Coupled</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 m/s</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>382</td>
<td>300</td>
<td>21.5</td>
<td></td>
<td>1116</td>
<td>338</td>
<td>230.2</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>367</td>
<td>302</td>
<td>17.2</td>
<td></td>
<td>770</td>
<td>245</td>
<td>214.3</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>364</td>
<td>301</td>
<td>17.3</td>
<td></td>
<td>868</td>
<td>354</td>
<td>145.2</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>294</td>
<td>294</td>
<td>0.0</td>
<td></td>
<td>305</td>
<td>302</td>
<td>1.0</td>
<td></td>
</tr>
</tbody>
</table>
HMH stress in the adiabatic and coupled solutions; (a) Junction A, (b) Junction B, (c) Junction C, (d) Junction D.

<table>
<thead>
<tr>
<th>Velocity</th>
<th>30 m/s</th>
<th>60 m/s</th>
<th>75 m/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adiabatic $\times 10^{19}$</td>
<td>Coupled $\times 10^{19}$</td>
<td>$%$</td>
</tr>
<tr>
<td>Junction A</td>
<td>1.465</td>
<td>1.537</td>
<td>4.9</td>
</tr>
<tr>
<td>Junction B</td>
<td>1.333</td>
<td>1.291</td>
<td>3.2</td>
</tr>
<tr>
<td>Junction C</td>
<td>1.271</td>
<td>1.264</td>
<td>0.6</td>
</tr>
<tr>
<td>Junction D</td>
<td>0.102</td>
<td>0.116</td>
<td>13.7</td>
</tr>
</tbody>
</table>
Temperature at Elements Aa, Ba, Ca and Da in the grains adjacent to the binders, coupled solution; (a) Junction A, (b) Junction B, (c) Junction C, (d) Junction D.

Impact velocity versus temperature in the grains at Elements Aa, Ba, Ca and Da adjacent to Junctions A, B, C and D, time instant: $6.0 \times 10^{-8}$ s.

<table>
<thead>
<tr>
<th>Velocity</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>30 m/s</td>
</tr>
<tr>
<td>Element adjacent to Junction</td>
<td>[K]</td>
</tr>
<tr>
<td>A</td>
<td>301</td>
</tr>
<tr>
<td>B</td>
<td>301</td>
</tr>
<tr>
<td>C</td>
<td>299</td>
</tr>
<tr>
<td>D</td>
<td>294</td>
</tr>
</tbody>
</table>
HMH stress at Elements Aa, Ba, Ca and Da in the grains adjacent to the binders in the adiabatic and coupled solutions; (a) Junction A, (b) Junction B, (c) Junction C, (d) Junction D.
Displacement (m) fields (magnified 5 times); (a) adiabatic solution; (b) coupled solution.

HMH stress (Pa), time instant: $2.5 \times 10^{-9}$ s; (a) adiabatic solution, (b) coupled solution.
HMH stress (Pa) in the binders, time instant: $10.0 \times 10^{-9}$ s;
(a) adiabatic solution, (b) coupled solution.
HMH stress (Pa), time instant: 75.0 × 10⁻⁹ s; (a) adiabatic solution, (b) coupled solution.

HMH stress (Pa), time instant: 100 × 10⁻⁹ s; (a) adiabatic solution; (b) coupled solution.
Equivalent plastic strain variations at the junctions; (a) adiabatic solution; (b) coupled solution; impact velocity 75 m/s.
Temperature distribution (K); (a) adiabatic solution; (b) coupled solution.
End of the process,
Impact velocity 75 m/s
• The displacement fields obtained for the two solutions are qualitatively similar;
• Although the HMH stress fields in both cases are similar with respect to quality, the maximum stress in the binders is lower than that in the grains;
• The equivalent plastic strains in the binders are lower in the coupled solution;
• The maximum temperature is significantly lower in the coupled solution;
• The polycrystalline material grains are affected by temperature increase;
• Given the significant differences in the solutions, the adiabatic solution should not be used for the analysis of polycrystalline materials.
**Peridynamics method**

Q and x are the points inside an undeformed body. The bond definition

\[ \xi = Q - x \]

The reference state X is a function that is valid on the bond X(ξ). The deformation state is dependent on the new position of the coordinate x in the deformed body y(x) in the following way

\[ Y(x, \xi) = y(x + \xi) - y(x), \]

\[ Y(x, \xi) = y(Q) - y(x). \]

The state of displacements is:

\[ U(x, \xi) = u(x + \xi) - u(\xi), \]

\[ U(x, \xi) = u(Q) - u(x). \]

The scalar extension state e(Y) is of the form:

\[ e(Y) = |Y| - |X|. \]

The decompositions of the scalar extension state into spherical and deviatoric components

\[ e = e^i + e^d. \]

The force state t(Y) is shown in a form similar to the standard stress-strain relation that is the sum of its spherical and deviatoric parts

\[ t(Y) = \left( \frac{3k\theta}{m} \right) \omega x + \alpha \omega e^d. \]

k is the bulk modulus, \( \theta \) is the dilatation, m is the weighted volume, \( \omega \) is the influence function, \( x = |\xi| \) is the basic scalar state, \( \alpha = (15\mu)/m \) is the coefficient being in relation to the shear modulus \( \mu \).
Integration scheme

A special case of the state-based model is the bond-based model

\[ f = c e \zeta(x, t, \xi), \quad c = (18k)/(\pi h^4) \]

\( c \) depends on the bulk modulus \( k \) and the horizon \( h \)

The failure is predominantly assumed on cracks appearance, the \( e_{cr} \) evaluation is based on fracture energy evaluation,

\[ e_{cr} = \sqrt{\frac{5G_{ci}}{9kh}} \]

where \( G_{ci} \) is the fracture energy depending on the mode of failure

**Peridynamics method**

The material failure model is based on the following assumptions: the bonds fail when their elongation overcomes the critical elongation; the total damage is due to the accumulation of broken bonds; and the bond breaking is an irreversible process.

The damage definition \( d \) reads:

\[ d(x, t) = 1 - \frac{\int_{\Omega} \zeta(x, t, \xi) d\Omega}{\Omega} \int d\Omega. \]

The damage variable varies between 0 and 1. The value 0 means that the material is pristine while 1 means that the material is completely damaged.

\[ G_I = \frac{(1 - \nu^2) K_I}{2E} \]
The contact is checked between the triangular facets of the bodies that are contact candidates. The sphere is transformed into an icosahedron.

Transformation of a sphere into an inscribed icosahedron: (a) sphere; (b) icosahedron.

$$f_{ct} = \begin{cases} C_t (r_r - d)V_1V_2 & \text{for } d \leq r_r \\ 0 & \text{for } d > r_r \end{cases}$$

where $d$ is the distance between the bodies, $V_1$ and $V_2$ are the volumes associated with the corresponding calculation points and $C_t = 18K_s/\pi h^5$. The constant $K_s$ is the artificial spring stiffness assumed as a high penalty number of the range $1.0E+12 \div 1.0E+20$. 
Al₂O₃/ZrO₂

Schemes of the analyzed samples (dimension x1.0E-07 m), Al₂O₃ – grey, ZrO₂ - blue: (a) Low content of Al₂O₃, Case A (41%); (b) High content of Al₂O₃, Case B (75%).
Damage advancement (dimension x 1.0E-5 m), Case A, impact velocity 60 m/s: (a) time 1.125E-08 s; (b) time 2.375E-08 s; (c) time 3.000E-07 s; (d) time 4.000E-08 s.

Damage advancement (dimension x 1.0E-5 m), Case B, impact velocity 60 m/s: (a) time 1.125E-08 s; (b) time 2.375E-08 s; (c) time 3.000E-07 s; (d) time 4.000E-08 s.
Damage advancement, the highest distance of a point of \( d > 0.8 \) from the hitting edge: (a) Case A; (b) Case B.

Damage advancement, the highest distance of a point of \( d > 0.8 \) from the hitting edge, microstructure comparison: (a) impact velocity 10 m/s; (b) impact velocity 60 m/s.
Damage advancement (dimension x 1.0E-5 m), the highest distance of a point of d>0.8 from the hitting edge at the impact velocity 10 m/s: (a) time 2.375e-8 s ; (b) time 3.000e-8 s.

Comparison of damage variable distributions in the cross-section of the plate along x-axis at the mid-span of the plate, from the top: Case A, impact velocity 30 m/s, Case A, impact velocity 60 m/s, Case B, impact velocity 30 m/s and Case B, impact velocity 60 m/s.
Comparison of variations of damage variable in time for Case A and B at different points: (a) Point A; (b) Point B; (c) Point C; (d) Point D.

Damage in Case B starts later
Variation of damage variable in time for different impact velocities, Case A: (a) Point A; (b) Point B; (c) Point C; (d) Point D.
Variation of percentage of total damage in time for different impact velocities: (a) Case A; (b), Case B.

Dependence of percentage of total damage at particular time instants on impact velocity: (a) Case A; (b), Case B.
Following the considerations, we summarize and arrive at the conclusions as follows:

• Damage analysis of the impacting plates should be performed in three-dimensions,

• Damage is concentrated close to the mid-span of the depth of the cross-section and is the lowest close to the surfaces of the plates,

• Damage growth during impact that is characterized by percentage of total damage of the plate is strongly nonlinear,

• Damage appears early at sparse distributed points well before damage front where the damage becomes massive,

• At least in the investigated impact velocity range, the traces of damage appears practically in the entire plate independently of the impact velocity what means that almost the entire plate appears to be damaged to the different extent,

• When taking into account total damage variation dependence on impact velocity, the damage variation is almost linear at particular time instants. The latter allows for the damage prediction for different impact velocities using linear interpolation.

• At the beginning of the process, damage forms lines that are parallel to the hitting edge. We concern the phenomenon as a characteristic feature of the damage process of thin ceramic platelets.
# Material parameters:

**Skeleton:**  
Young’s modulus  430.0 GPa  
(SiC)  
Poison’s ratio  0.75  
Mass density  3200 kg/m³  
Fracture toughness  4.1 MPa.(m)^{1/2}  

**Base and piston:**  
Young’s modulus  210.0E+09 Pa  
(steel)  
Poison’s ratio  0.3  
Mass density  7800.0 kg/m³  

**internal structure of the SiC foam**
**Discretization:**
- total 461,496 calculation points
- Skeleton - 261,496
- Base - 100,000
- Piston - 100,000

**Impact velocities:**
- 40 m/s and 365 m/s

**Critical stretch:**
- SiC – 9.5716E-05

**Horizon:**
- skeleton: 30.0E-04 m, base and piston 6.0E-04 m

**Process time:**
- 3.06E-05, time increment 2.0e-08 s
  (below critical time), 1500 increments, solution time 3800 s, 1920 CPUs

**Contact model** – general contact, penalty formulation, friction coefficient 0.3
Positions of the points in the details: region P, region Q, region R

Local damage (at points) variation

Total damage variation
Numerical example

Points where $d>0.95$

$V=385$ m/s

Points where $d>0.95$

$V=385$ m/s, end of the process

$V=40$ m/s, end of the process

$V=385$ m/s, end of the process
• When the sample is subjected to the high-velocity impact, the structure undergoes self-contact in the pores.

• The destruction of the SCF into fragments of the structure appears in the course of a high-velocity impact.

• During high velocity process the self-contact appears.

• In the low-velocities impact, the damage of the structure is mainly due to local microcracks in the material.

• During high velocity impact appears out of plane failure mode.
The **SCF sample** is discretized with 261,496 volumes, while the **steel base** counts 100,000 volumes.

In the calculations, the **horizon** $h$ value for the:
- foam is assumed of 30.0E-04 m,
- base is 6.5E-04 m.
Percent of damage of the sample for low velocities, and for high velocities.
Damage at the observed points: low velocities, high velocities.
Impact velocity 15 m/s, damage at time 2.4E-06 s, 11.4E-06 s, 19.8E-06 s

Impact velocity 15 m/s, points of damage d < 0.8 at time 2.4E-06 s, 11.4E-06 s, 19.8E-06 s
Impact velocity **800 m/s**, damage distribution at time 2.4E-06 s, 11.4E-06 s, 19.8E-06 s.

Impact velocity **800 m/s**, points of damage \( d < 0.8 \) at time 2.4E-06 s, 11.4E-06 s, 19.8E-06 s.
A qualitative comparison of the high and low-velocity impact of a SiC foam has been presented in the paper. The analysis is performed using the peridynamics method. It has been found that the behaviour of the foam is different when the impact velocity is low in comparison to the high velocity response. The distinction of the low- and high-velocity process is based on evaluating total damage accumulation in the structure.

- In the high-velocities impact range, the total damage of the foam sample grows almost linearly with slight deviations from the linearity.
- When the foam sample is subjected to the high-velocity impact, the structure undergoes self-contact in the pores.
- The destruction of the SCF into fragments of the foam structure appears in the course of a high-velocity impact.
- While the impact is performer with the low-velocity, the fragmentation and self-contact does not appear.
- In the low-velocities impact, the damage of the foam structure is mainly due to local microcracks in the material.
We used 960, 1920 and 3840 processes with the wall-clock times 930 s, 530 s and 290 s, respectively.
The calculations were done using PL-GRID national computational resources at the Interdisciplinary Centre for Mathematical and Computational Modeling, University of Warsaw, the CYFRONET, Krakow, and Academic Computer Centre in Gdańsk, Poland.
<table>
<thead>
<tr>
<th>#</th>
<th>Author(s)</th>
<th>Title</th>
<th>Journal</th>
<th>ISSN</th>
<th>DOI</th>
<th>Volume</th>
<th>Pages</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Postek E., Sadowski T.<em>, Bieniaś J.</em></td>
<td><em>Simulation of impact and fragmentation of SiC skeleton</em></td>
<td>Physical Mesomechanics</td>
<td>1029-9599</td>
<td>10.1134/S102995992105009X</td>
<td>24</td>
<td>5, pp.578-587</td>
<td>2021</td>
</tr>
<tr>
<td>5</td>
<td>Postek E., Sadowski T.*</td>
<td><em>Thermomechanical effects during impact testing of WC/Co composite material</em></td>
<td>COMPOSITE STRUCTURES</td>
<td>0263-8223</td>
<td>10.1016/j.compstruct.2020.112054</td>
<td>241</td>
<td>pp.112054-1-25</td>
<td>2020</td>
</tr>
<tr>
<td>8</td>
<td>Postek E., Sadowski T.*</td>
<td><em>Impact model of WC/Co composite</em></td>
<td>COMPOSITE STRUCTURES</td>
<td>0263-8223</td>
<td>10.1016/j.compstruct.2019.01.084</td>
<td>213</td>
<td>pp.231-242</td>
<td>2019</td>
</tr>
<tr>
<td>9</td>
<td>Postek E., Pęcherski R.B., Nowak Z.</td>
<td><em>Peridynamic simulation of crushing processes in copper open-cell foam</em></td>
<td>ARCHIVES OF METALLURGY AND MATERIALS</td>
<td>1733-3490</td>
<td>10.24425/amm.2019.130133</td>
<td>64</td>
<td>No.4, pp.1603-1610</td>
<td>2019</td>
</tr>
</tbody>
</table>
Prerequisites for modelling

• grain size distribution,
• interface thickness distribution
• pore size distribution
• pore placement inside the material
• mechanical properties: Young modulus, Poisson coefficient, yield stress, material hardening, material viscosity