Impact of WC/Co/diamond sample with peridynamics

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1. Introduction

Metal Matrix Composites (MMCs) are widely used in several strategic industrial sectors, such as defense, aerospace, nuclear power plants, space exploration, being the main source of technological progress in the others, for example machining. In this communication, we use meshless method that is peridynamics for simulation of impact of a sample. Peridynamics is a non-local, meshless quite recently formulated method of stress analysis. Nonlocal methods were developed for crystal analysis [1], [2]. The nonlocal methods were generalized on the coupled problems in [3]. The peridynamics was formulated for the first time by Silling [4, 5].

2. Problem statement

The elastic-plastic model in the peridynamic format is defined in similar form as in the continuous model [6, 7] but with a dependence on peridynamic states.

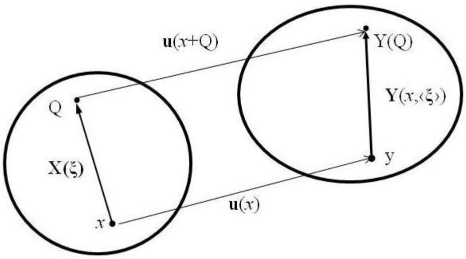


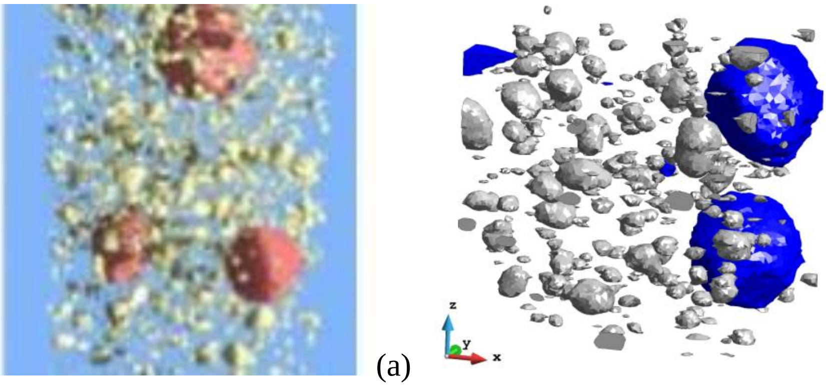
Fig. 1. State of deformation of a body.

The scalar extension state is given: $e(\mathbf{Y}) = |\mathbf{Y}| - |\mathbf{X}|$. We can decompose the scalar extension state into spherical and deviatoric parts: $e = e^i + e^d$. The elastic force state relation is given in analogous form to the standard stress strain relation being the sum of the spherical and deviatoric parts as follows: $t(Y) = \frac{3k\theta}{m}\omega \underline{x} + \alpha\omega e^d$, where k is the bulk modulus, m is the weighted volume, θ is the dilatation, ω is the influence function, $\underline{x}$ is the basic scalar state, α is the coefficient related to shear modulus as follows: $\alpha = (15\mu)/m$, where μ is the shear modulus, e^d is the deviatoric part of the extension state.

Further on, the relations are similar in structure to the continuous theory of plasticity, [12, 13] but they are written in peridynamic theory format. The relations are as follows: Additive decomposition of the deviatoric extension state e^d into elastic state e^{de} and plastic state e^{dp}: $e^d = e^{de} - e^{dp}$; Elastic force state relation with applied the above additive decomposition $t(Y) = \frac{3k\theta}{m}\omega \underline{x} + \alpha\omega\left(e^d - e^{dp}\right)$; Yielding condition: $f(t^d) = \Psi\left(t^d\right) - \psi_o \leq 0$, where $\Psi(t^d) = \frac{\left\|t^d\right\|^2}{2}$; Flow rule: $\dot{e}^{dp} = \lambda \nabla^d \psi$; Kuhn-Tucker conditions (loading and unloading): $\lambda \geq 0,\ \ f\left(t^d\right) \leq 0,\ \ \lambda f\left(t^d\right) = 0$; and finally the consistency condition: $\lambda \dot{f}\left(t^d\right) = 0$.

3 Computational model

The computational model is obtained from CT scans that are converted into peridynamics discretisation. A part of the CT scan showing the WC grains and diamond grains are shown in Fig. 2 (a). The grains are embedded into a Co matrix.



(a) (b)

Fig. 2. CT scan (left); discretized WC and diamond grains (right) that are embedded into a Co matrix.

The discretization is done with 1663535 points. The material properties of the diamond are: Young's modulus 1210E+08 Pa, Poisson's ratio 0.22 and density 3440.0 kg/m^3, the material is ideally elastic. The material properties of WC are Young's modulus 6.86E+11 Pa, Poisson's ratio 0.22, density 15880 kg/m^3 and critical stretch 0.0005. The elastic-plastic Co material properties are Young's modulus 211.0E+09 Pa, Poisson's ratio 0.296, density 9130.0 kg/m^3, yield stress 460.0E+06 Pa and hardening modulus 500.0E+07 Pa.
In this example, the sample hits the rigid obstacle with the velocity of 150 m/s downwards.

4. Demonstrative example

The calculations are done with the highly parallelized program Peridigm [8]. We present results of the simulation over the time interval 5.0E-09 s. The damage distribution in the WC grains is given in Fig. 3. Damage appears in the grains at the very beginning of the loading process and reaches the value 0.756, Fig. 3 (left). The maximum value of damage parameter at the end of the process is not much higher reading 0.798, Fig. 3 (right). However, we note that many more grains are damaged.

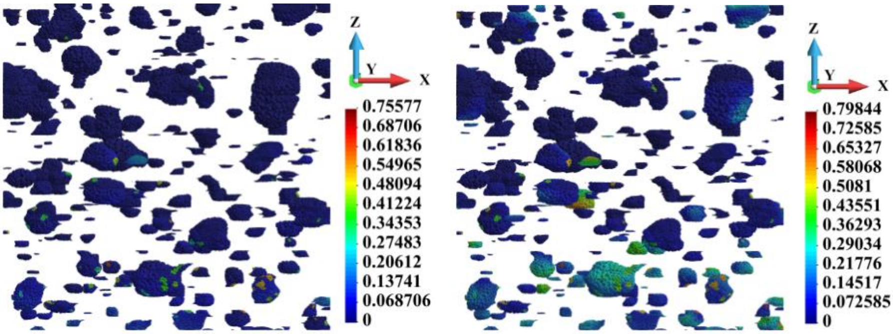


Fig. 3. Damage distribution at time instant 6.0E-10 s (left) and 5.0E-09 s (right).

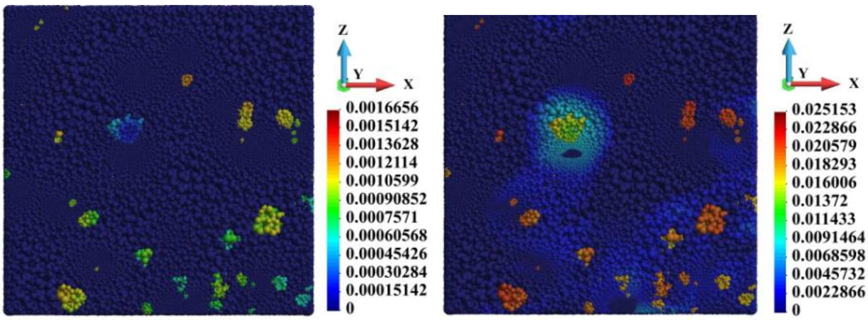


Fig. 4. Equivalent plastic strain distribution at time instant 6.0E-10 s (left) and 5.0E-09 s (right).

Equivalent plastic strains are given in Fig 4. At the beginning of the process, the equivalent plastic strain appears in distinct spots and they are low, Fig.4 (left). They appear in the neighborhood of the WC grains. When the process advances, the plastic strains are higher, and they cover greater regions of the Co matrix.

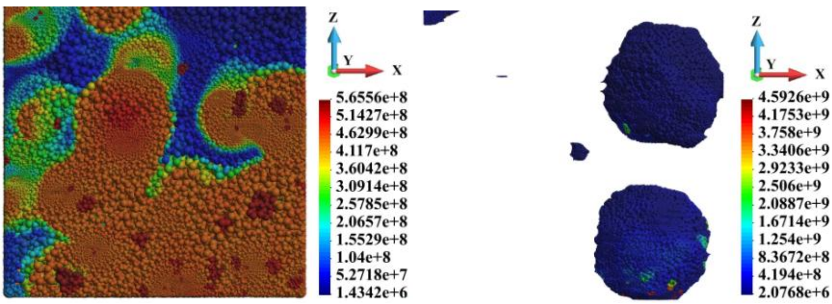


Fig. 5. Mises stress distribution at time instant 5.0E-09 s, in the Co matrix (left) and in diamond grains (right)

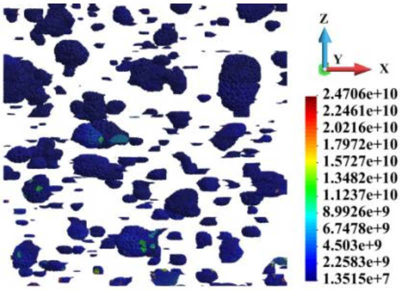


Fig. 6. Mises stress distribution at time instant 5.0E-09 s in the WC grains.

Finally, we observe von Mises stress distribution in three phases of the composite. We find that the lowest Mises stress is in the Co matrix reaching maximum 5.65E+08 Pa, Fig. 5 (left). The highest von Mises stress is achieved in diamond, Fig. 5 (right), reading 4.59E+09 Pa, and the highest von Mises stress in the WC grains, Fig. 6, reaches 2.47E+10 Pa.

The calculations are performed on a CRAY XC-40 with the pool of 960 processes in 960 s.

5. Summary

We present a flow of calculations of a three-phase material WC/Co/diamond along with results of damage, plastic strains and von Mises stresses. Further research will focus on crack initiation in such kinds of composites.

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