Applied Mathematical Modelling 36 (2012) 2724–2738

Contents lists available at SciVerse ScienceDirect

Applied Mathematical Modelling

journal homepage: www.elsevier.com/locate/apm

Study of dynamic behavior of ceramic–metal FGM under high velocity impact conditions using CSPM method

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ARTICLE INFO

Article history:
Received 2 February 2011
Received in revised form 19 September 2011
Accepted 21 September 2011
Available online 29 September 2011

Keywords:
Functionally graded material
CSPM
JHB
Impact

ABSTRACT

In Problems with large deformation including fracture and fragmentation, the grid based methods have some limitations which make them unsuitable for simulating these types of problems. An example is extreme mesh distortion in a lagrangian approach like Finite element method. Another situation is the inability of Eulerian based formulations in tracking the history of a desired physical property at the interface of multi materials including impact problems. A promising solution is taking the advantage of meshless and particle based methods which do not use any kind of grid in the physical domain of problem. In this paper, corrective smoothed particle algorithm (CSPM) as a meshless particle method is used to study the mechanical behavior of a ceramic–metal functionally graded material (FGM) under high velocity impact conditions. A mixed strength model with sigmoid formulation has been used to describe both yielding and fracture phenomena in the FGM. The strength model includes the JC dynamic yield relation and Johnson–Holmquist–Beissel (JHB) fracture model with a continuum damage description approach. An efficient renormalization in continuity density approach is used to improve the smoothed particle hydrodynamics (SPH) approximation of boundary physical variables. This study shows that CSPM in combination with the proper strength model describing the FGM dynamic behavior, can predict the mixed plastic and brittle response of a ceramic–metal functionally graded material under high impact velocities.

1. Introduction

FGMs, as new generation of materials, are widely used in heat barrier systems and aerospace industries with promising advantages in energy absorbing applications. Predicting dynamical behavior of FGMs under high velocity impact conditions is especially important in armor systems and body protection in aerospace vehicles. The dynamic propagation of a finite crack in functionally graded materials was studied by Meguid et al. [1]. Dai et al. investigated the natural frequencies and static deformation in a FGM plate using the radial point interpolation method [2]. Stress analysis in anisotropic functionally graded materials using the MLPG method was studied by Sladek et al. [3]. Qian, studied the static and dynamic analysis of 2-D functionally graded elasticity by adopting meshless local Petrov–Galerkin method [4]. Zhang and Batra investigated wave propagation in functionally graded materials using modified smoothed particle hydrodynamics [5].

In Problems with large deformation including fracture and fragmentation, the grid based methods have some limitations which make them unsuitable for simulating these types of problems. An example is extreme mesh distortion in a lagrangian approach like Finite element method. Another situation is the inability of Eulerian based formulations in tracking the history

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doi:10.1016/j.apm.2011.09.056

of a desired physical property at the interface of multi materials including impact problems. A promising solution is taking the advantage of meshless and particle based methods which do not use any kind of grid in the physical domain of problem. A very promising meshless particle numerical technique for simulating dynamic fracture behavior of materials is the SPH particle method and its modified version CSPM.

Smoothed particle hydrodynamics (SPH) is a particle and meshless method with promising advantages in modeling extreme large deformations that include brittle damage and fracture in ceramics. SPH was first proposed to solve cosmological problems in three-dimensional open space such as the simulations of binary stars and stellar collisions [6,7]. The SPH method has also been applied extensively in computational fluid dynamics related areas that include multi-phase flows [8], incompressible flow simulations [9,10] and free surface flow analysis [11,12]. Benz and Asphaug applied SPH to simulate fracture in brittle solids [13–15]. Johnson and Libersky have made outstanding contributions in the application of SPH in impact problems [16–18]. In 1999, Chen et al. in their paper [19], presented an improvement for tensile instability in smoothed particle hydrodynamics using renormalization schemes which could improve the accuracy of results in free surfaces. To the best of authors' knowledge there is no available research on dynamic response of FGMs under high velocity impact conditions including fracture and fragmentation.

In this paper, the corrective smoothed particle method (CSPM) is used to study the dynamic fracture response of a ceramic–metal functionally graded material under high velocity impact conditions. A mixed strength model with sigmoid formulation is adopted to describe both yielding and fracture phenomena in the FGM. Temperature field is evaluated from a heat conduction equation with variable thermal conductivity and the result is used in Johnson–Cook yield model. The present study indicates that CSPM in conjunction with proper strength model describing the FGM dynamic behavior, can predict the mixed plastic and brittle response of a ceramic–metal functionally graded material under high velocity impact conditions.

2. Smoothed particle hydrodynamics

In SPH formulation, an arbitrary function $f(x)$ and its derivative are approximated using Eqs. 1, 2, respectively.

$$f_i(r) = \sum_j \frac{m_j}{\rho_j} f_j W_{ij}(r - r_j, h), \tag{1}$$

$$\nabla f_i(r) = \sum_j \frac{m_j}{\rho_j} f_j \nabla W_{ij}(r - r_j, h). \tag{2}$$

In the above equations, m_j, ρ_j are the mass and density of neighbor particle j, and $W_{ij}(r - r_j, h)$ is the kernel function that is covering the support domain with a radius of $2h$.

The SPH form of continuity, momentum and energy equations with detailed explanation can be found in [20].

3. Artificial viscosity

In order to prevent particles penetration and increasing the solution consistency, Monaghan and Gingold used the following artificial terms in addition to pressure terms in the momentum equation [21]

4. Material equation of state

4.1. Tillotson EOS

The Tillotson EOS was suggested by Tillotson in 1962 [22] for describing the dynamic behavior of metals in high pressures and high rates of plastic strain including phase transition. In this form of EOS, the Hugoniot pressure–volume space is written for four distinct regions with the pressure–density relations in different zones. Constant parameters which have been used for the AL material are presented in Table 1.

Table 1
Values of parameters in Tillotson EOS relation for AL material.

Parameter	Value
e_0 (J/kg)	5 e6
e_s(J/kg)	3 e6
e'_s (J/kg)	15 e6
a	.5
b	1.63
A (kpa)	7.52 e7
B (kpa)	6.5 e7