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Composite Layering Technique for use in a Eulerian Shock Physics Code

Shane C. Schumacher
[1]Sandia National Laboratories
PO Box 5800 MS-0836
Albuquerque, NM 87185-0836

Abstract. The high strength and low density characteristics of fiber reinforced composite materials have made them applicable to a large variety of applications. As these applications grow, their performance in high strain rate shock environments has increased. The modeling and simulation of such materials is difficult due to their anisotropic behavior and complex internal geometries. Fiber reinforced composite materials consist of a collection of layers that create a laminate. Each layer is typically transverse isotropic or orthotropic consisting of a fiber and matrix material. One approach is to explicitly model each layer, while accurate, this is often not feasible for full system calculations as the laminate layer count increases in size. Additionally, modeling each layer given the finite thickness proves to be a challenging process and typically a smearing approach is used to represent the laminate response removing the identity and material response of each layer. The creation of a layering capability is a good compromise between the inaccuracy of smearing and the computational cost of explicitly modeling each layer. The layering is done using a sub-grid technique in an individual grid cell. The grid cell is partitioned based on layer location in the laminate and the material deformation. The volume occupied by the given layer is computed and the layer calculates a material response based on the cell strain field. The resulting material stress and state variables are volume weighted with the remaining layers in the given grid cell yielding a cell response. The result is a technique that requires less computation time than modeling each layer while increasing the accuracy over smeared approximations.

Keywords: Composite, shock physics.

INTRODUCTION

Given the complex nature of directional composite materials a technique is desired to model these complex objects within a Eulerian shock physics code. The two extremes in modeling these complex geometries of directional composites are smearing of the material properties and explicitly modeling each individual layer. Smearing of the material properties is computationally efficient, but loses accuracy in the solution. Explicitly modeling each layer is highly accurate, but is not feasible for system analysis. The technique described in this paper is a sub-grid method that tracks the orientation of each layer and provides a mapping between the global and material (local) coordinate system. This is an improvement in accuracy over smeared approximations, without the computational expense of explicit layer modeling.

PROCEDURE

To utilize this layering technique, the user must describe the material geometry, which then gets mapped to the Global Coordinate System. This initial orientation and mapping is used throughout the problem to track the material rigid body motion and deformation.

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Data gathering from the user is the first step in the process. The necessary input from is the user-defined coordinate system, number of material layers, layer orientation and layer thickness. The user-defined coordinate system within the computational grid is defined using three points in space: the origin, a point defining the 3-axis and a point defining the 1-3 plane, see Figure 1. The origin is placed at the base of the object to be inserted into the grid.

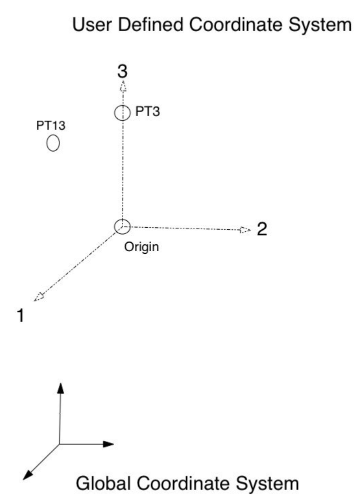

Figure 1. The user defined coordinate system described inside the global coordinate system.

The layer orientation is used to locate a material direction for each material layer. The layer orientation initializes each object layer by setting a material unit vector that is stored as a history variable. The user inputs the layer's orientation by a combination of two rotations relative to the user-defined coordinate system. The user specifies the axes and the rotation desired about the axes. Given the user-defined coordinate system and two rotations, most if not all objects may be properly described. Using Figure 2 as a reference, the first rotation is from unprimed to the primed axes; and the second rotation rotates the primed to the double primed axes.

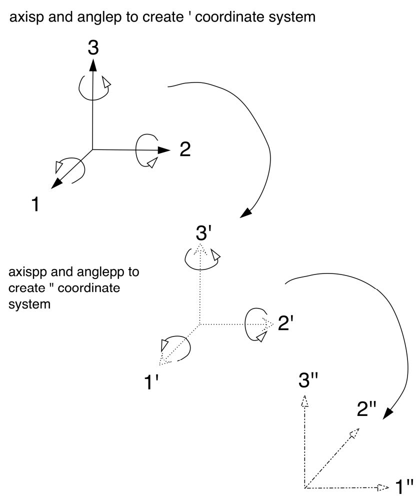

Figure 2. Description of the layer orientation using the user defined coordinate rotations relative to the user defined coordinate system.

The object is inserted into the Eulerian grid as a solid continuous object. The material unit vectors are initialized based on cell location and layer thickness. Visual inspection of the inserted object shows proper orientation and alignment within the grid, shown in Figure 3.

In addition to the initialization of the material unit vectors in each cell, global coordinates of the cell center are stored as history variables, Figure 4. The stored global coordinate locations are allowed to advect through the grid as the material undergoes translation, rotation and/or deformation. Using the stored cell center, the origin definition the user-defined coordinate system and the layer thickness the location of each layer within the object is determined. Currently, this process does not account for the through thickness strain resulting in layer thickness changes, but future efforts can easily accommodate this based on the strain field.

Once the layers within a cell are located, the cell is sectioned based on the material direction and rigid body rotation using a normal vector to the surface (along the through thickness direction). A volume

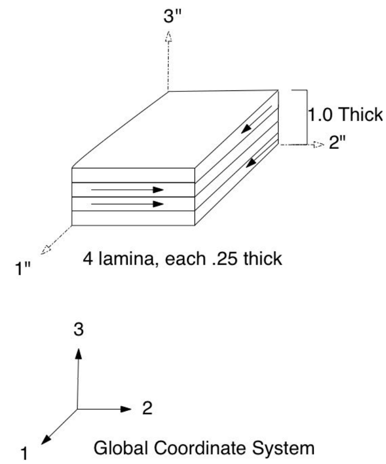

Figure 3. Object insertion using the user defined coordinate system relative to the global coordinate system.

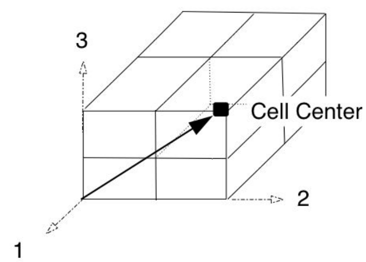

Figure 4. The vector location of the cell center relative to the user defined coordinate system.

fraction is computed for each layer occupying the cell, [1,2]. The constraint on the system is shown in Eq. 1,

$$\sum \phi_i = 1, \tag{1}$$

where ϕ_i is the volume fraction of each layer.

The volume fraction is used to compute the overall cell state response by volume fraction weighting the individual layer state variables.

EXAMPLE PROBLEMS

Two example problems are shown below to demonstrate the layering technique. The first example is an oblique composite plate moving through a Eulerian grid. The composite plate is orientated at 45° and is 1 cm thick. The plate consists of 4 layers orientated at $[0,90]_s$. The problem is shown at startup, Figure 5, and after the plate has moved 0.5 meter through the grid, Figure 6. There are approximately 20 grid cells through the 1 cm thick plate. This problem tests the advection of the material unit vector using this technique. The x-component of the material unit vector, orientated at 45°, in the first layer is plotted in Figure 7. This shows the consistency in the method through the advection process. The results show little or no error in the material unit vector advection.

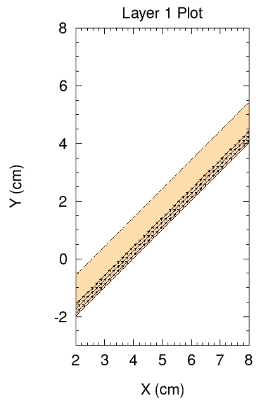

Figure 5. The 1st layer material unit vectors are shown at the start of the advection test.

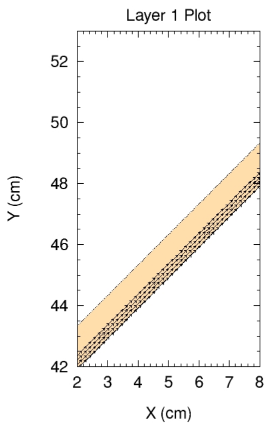

Figure 6. The 1st layer material unit vectors are shown after traveling 0.5 m through the grid.

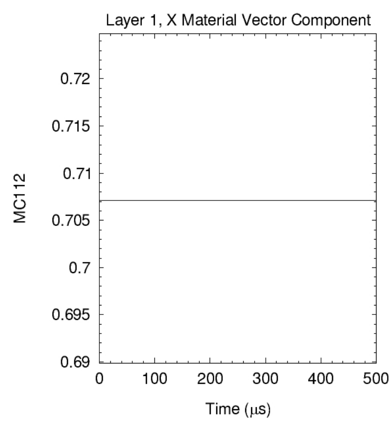

Figure 7. Advection test result in the material unit vector x-coordinate; cosine(45°)= .7071.

The second example problem is a projectile impacting an oblique composite plate. The projectile is a flat disk traveling at 1 km/s. The composite plate has the same orientation, thickness and layup as the previous example. The second layer material orientation vectors are shown at the start up in Figure 8. After 31 μs, the plate undergoes deformation and the change in the orientation of the material vectors are shown in Figure 9. The material unit vectors provide reference to the material coordinate frame relative to the global coordinate system.

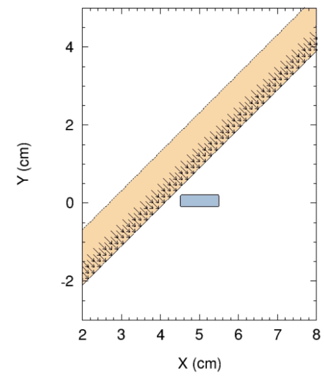

Figure 8. The 2nd layer material unit vectors are shown at the start of the impact simulation.

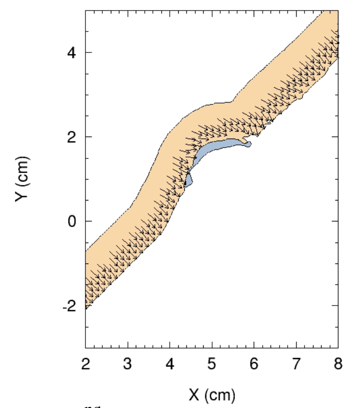

Figure 9. The 2nd layer material unit vectors are shown at 31 μs.

CONCLUSION

A method has been developed for tracking material orientations of a layered material in a Eulerian grid for anisotropic material models. This method has proven to be an effective way of tracking material orientations through Eulerian grids that have been previously plagued by advection and numerical errors. Two examples have been provided to demonstrate the accuracy of the layering technique and application of the technique. The first example provided qualitative accuracy results of the technique and the second example problem describing a typical application of the method to a viable problem impact problem.

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