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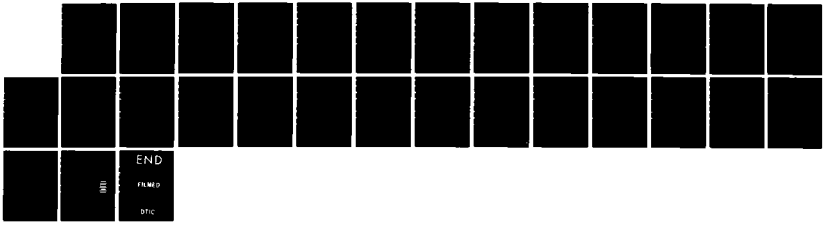

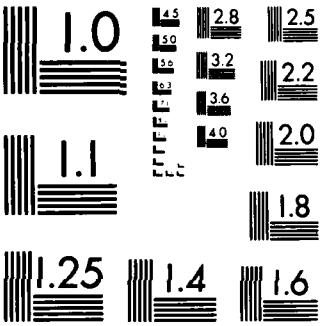

MEMORANDUM REPORT BRL-MR-3448

COMPUTATIONAL METHODS FOR THE EXPLOSIVE AND IMPACT COMPACTION OF POWDERS

Ralph F. Benck

May 1985

US ARMY BALLISTIC RESEARCH LABORATORY
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20. ABSTRACT *(Continue on reverse side if necessary and identify by block number)*

The effects of computational cell size and slide line routines upon TROTT computer code simulations of explosive and impact powder densifications were determined. A 30 by 40 grid of quadrilateral cells was computationally adequate to describe the systems under study and the presence of a slide line did not appreciably affect the final calculated powder density.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

I. INTRODUCTION

The TROTT[1] computer code is being used to simulate explosive and plate impact densifications of various materials.[2] In the present report the effects of two computational parameters, cell size and slide lines, on computed compactions will be discussed.

TROTT is a Lagrangian finite difference computer program for calculating two-dimensional stress wave propagation through solid, porous or composite materials. The stress waves may be caused by detonation of an explosive or through an impact in either planar or axisymmetric flow. The computations involve the standard leapfrog method of Von Neumann and Richtmyer,[3] using artificial viscosity to smooth shock fronts. For the calculations, the material is divided into small, quadrilateral or triangular, cells or continuum elements. The motion and stresses throughout the material are determined as a function of time by solving the mass, momentum and energy conservation relations, together with the constitutive relations of the material.

II. COMPUTATIONAL PROCEDURES

The BRL is studying processes by which powders are dynamically compacted into solids. The experimental portion of these compaction studies is supplemented by the use of computer simulations. Material variables that are taken into account in the computer simulations include type and amount of explosive, sample geometry, container material, initial density of powder, and temperature. It is essential that the computational process itself does not influence the results of the compaction simulation. The purpose of the present report is to assess the effects that computational cell size and slide lines have upon the ability of the TROTT Computer Code to accurately simulate dynamic compaction of various powders.

A. Cell Size Effect.

In choosing the dimensions of computational cells, too large or too small a cell should be avoided. If too small a cell is used the computations become excessively long and expensive whereas too coarse a cell size can lead to misleading and inaccurate results. One way to ascertain whether or not a cell size is adequate is to perform calculations in which

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[1] *L. Seaman and D. R. Curran, Contract Report ARBRL-CR-00428, "TROTT Computer Program for Two-Dimensional Stress Wave Propagation," SRI International, 333 Ravenswood Ave., Menlo Park, CA 94025, April 1980, AD-A085766.*

[2] *G. L. Moss, R. F. Benck, P. H. Netherwood, and J. R. Stratton, "Dynamic Compaction of Ceramic Materials," Ballistic Research Laboratory, Memorandum Report, ARBRL-MR-03327, Aberdeen Proving Ground, MD 21005-5066, December 1983. AD-A137257.*

[3] *J. Von Neumann and R. D. Richtmyer, "A Method for the Numerical Calculation of Hydrodynamic Shocks," J. Appl. Phys., Vol. 21, p. 232 (1950).*

the size of the cells is varied. If the results of the calculations are essentially identical it can be reasonably assumed that the results are not dependent on cell dimensions, at least over the dimension interval involved. Cell size effects will be determined for compactions accomplished with impacts and explosions.

1. Explosive Compaction.

Processes that involve detonations are simulated in TROTT by using the EXPLODE subroutine. EXPLODE is based upon Chapman-Jouguet detonation theory which incorporates the concept that transformation between chemical energy and internal energy occurs within the shock front. (For further discussion see any standard reference such as Taylor.)[4]

Figure 1 shows a compaction configuration used in a test of the cell size dimensions on computed results. The copper powder is 60 percent of theoretical density (60%T) and is contained in a copper holder positioned between two layers of amatol (0.94 g/cm^3 20%TNT-80%NH_4NO_3). The complete simulation involved a sample length of 152.4 mm, but only the first 118.8 mm are shown in Figure 1. Compaction is achieved by detonating the amatol along the edge marked A-A in Figure 1. The simulation has been so posed that it results in plain strain geometry with X and Y in the plane and Z in the third (zero strain) direction. Hugoniots of solid and porous copper as interpreted by Seaman and Linde[5] were used to characterize the copper. A subroutine POREQST,[6] developed as a dynamic response model for constitutive relations for porous materials, was used to simulate consolidation of the copper powder.

In Figure 1 the problem has been divided into a 60 (horizontal) by 58 (vertical) grid. The effect of a coarser cell grid was determined by rerunning the Figure 1 simulation using a 40 (horizontal) by 29 (vertical) grid. A comparison of the two configurations is made in Table 1.

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[4] *J. Taylor, "Detonation in Condensed Explosives," Clarendon Press, Oxford, England, 1952.*

[5] *L. Seaman and R. K. Linde, AFWL-TR-68-143, "Distended Material Model Development, Volume 1," Stanford Research Institute, Menlo Park, CA 94025, May 1969, AD-853418.*

[6] *L. Seaman, R. E. Tokheim, and D. R. Curran, DNA 3412F, "Computational Representation of Constitutive Relations for Porous Material," Stanford Research Institute, 333 Ravenswood Ave., Menlo Park, CA 94025, May 1974, AD-A007921.*

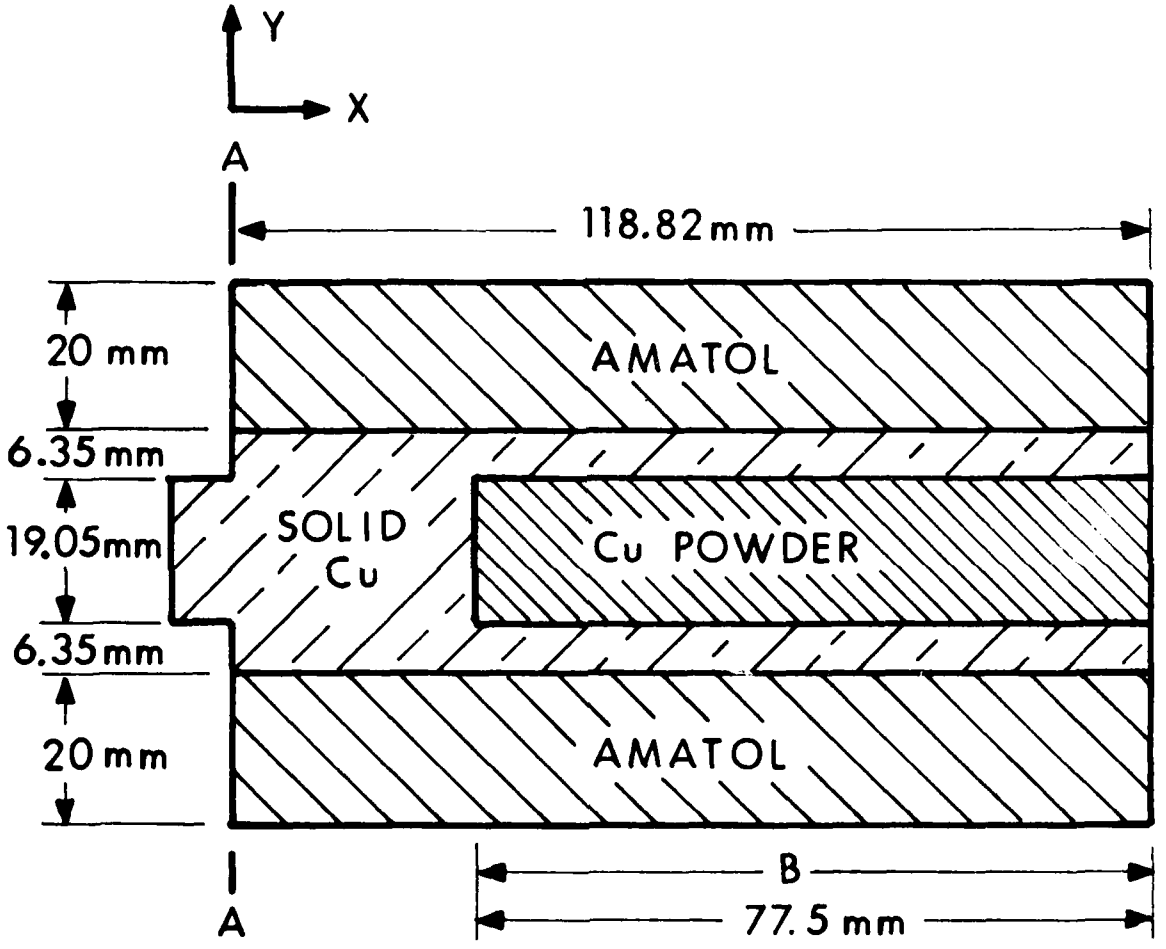

Figure 1. Initial Conditions for Copper Powder Compaction.

TABLE I

Cell Dimensions Used in Copper Compaction Studies

MATERIAL	FINE GRID		COARSE GRID	
	Cell dimensions, mm		Cell dimensions, mm	
	Y vertical	X horizontal	Y vertical	X horizontal
amatol	1.33	2.58	2.86	3.91
copper container	1.27	3.91	3.18	3.91
copper powder	1.27	2.58	1.91	3.91

2. Plate Impact.

TROTT was used to simulate the impact of a mild steel flyer plate onto a mild steel cylinder containing a cavity filled with powdered aluminum oxide, Al_2O_3. The velocity of the flyer plate at impact was 281 m/s. A 60 (horizontal) by 59 (vertical) rectangular cell grid representation of the system at impact is shown in Figure 2. For this calculation an axisymmetric geometry with X axial, Y radial and Z circumferential was used. The axis of symmetry in Figure 2 is the upper edge of the grid. To compute the effect of a coarser cell grid the compaction was rerun using cells approximately three times as large as those used in Figure 2. In both computations the cell sizes in the flyer plate, Al_2O_3 powder and the portion of the sample holder between flyer plate and Al_2O_3 were the same throughout each region. The cells in the remainder of the sample holder were kept at constant width (Y) but the length (X) of each succeeding row of cells beyond the Al_2O_3 was increased by approximately 12 percent. This steady increase in cell size allowed the existing experiment to be modeled, avoided awkward cell discontinuities and limited computing time.

B. Slide Line Effect.

TROTT incorporates a slide line routine that allows pressures to be transmitted through slide line boundaries but minimizes distortion in boundary layer cells. Minimum distortions are usually desirable but slide lines can add an extra element of artificiality to the results. One of the purposes of the current report is to model real phonomena so computations with and without the use of slide lines were investigated. Calculations were made for an explosive compaction of powdered Al_2O_3 in a molybdenum, Mo, container; specifically 20 mm of amatol was placed on a 6.35 mm thick Mo plate placed on a 12.5 mm thick layer of Al_2O_3 powder. The bottom edge

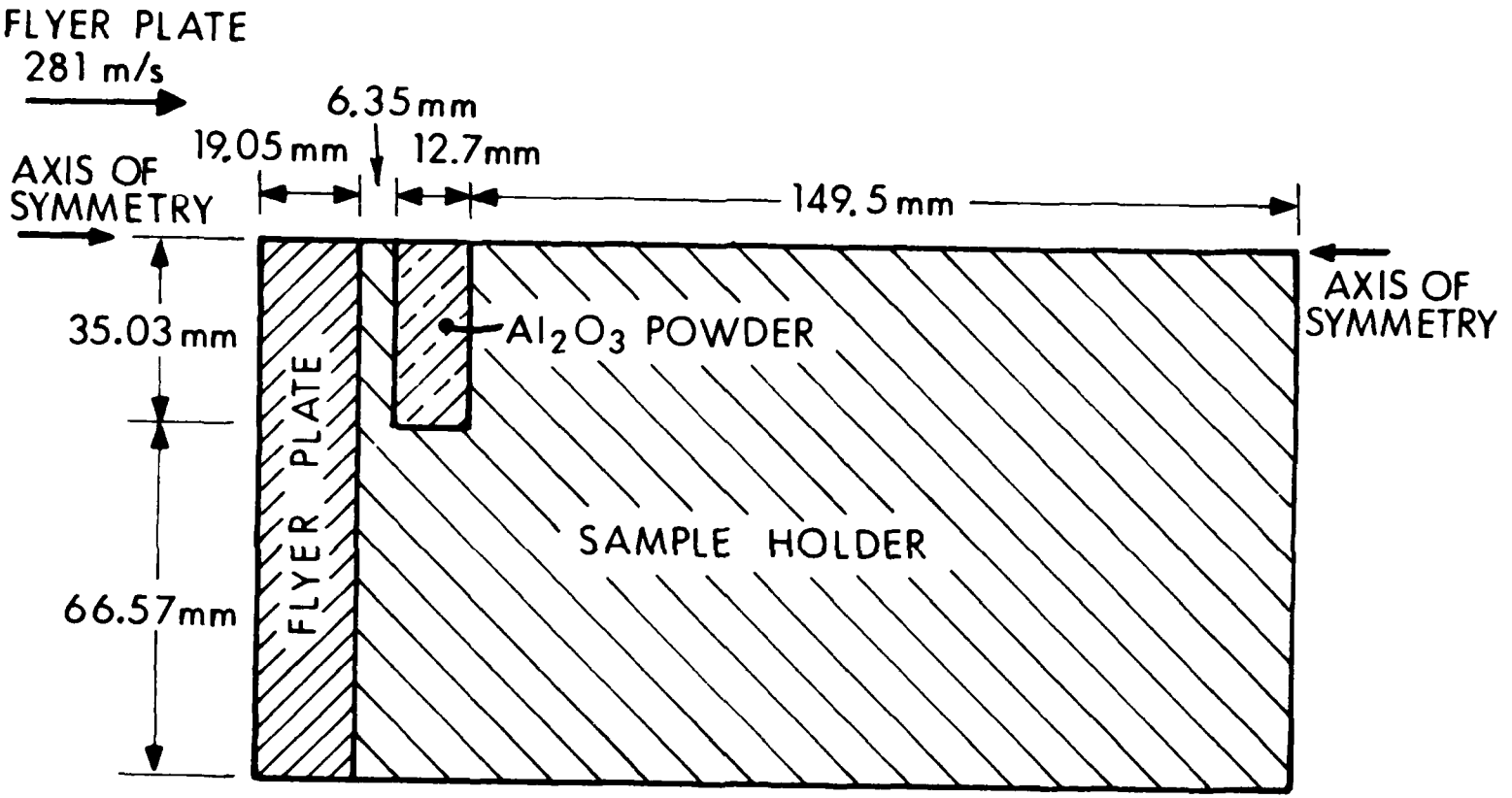

Figure 2. Initial Conditions for Plate Impact Experiment.

of the powder was constrained to act as a rigid boundary. The initial computational cell representation for this test is illustrated in Figure 3 with the slide line imposed between the amatol and Mo wall. Computations were made without the slide line for comparison. A planar detonation was initiated along the left edge of the explosive.

III. RESULTS

The effects of computational cell size and slide lines upon simulations of explosive and impact driven powder compactions were computed.

A. Cell Size Effect.

The effect of increasing computational cell size upon the computed density and/or pressures of powdered copper and Al_2O_3 were investigated for both explosive and impact driven densifications.

1. Explosive Compaction of Copper Powder.

The effects of the detonation of amatol on the copper powder density using initial configurations as given in Figure 1, were computed and are presented in Figure 4. The density presented in Figure 4 is that of a horizontal slice of the copper powder measured along the center of the copper powder. The area sampled is along B-B of Figure 1. Figure 4 represents the computed copper powder density, 28.8 μs after line detonation of the amatol and does not indicate the final density of the copper. Calculations at later times show that the copper eventually attains a density of 100%T. As Figure 4 illustrates the calculated densities from the two grids are essentially equivalent along BB.

2. Plate Impact Compaction of Al_2O_3.

Figure 5 is a plot of calculated Al_2O_3 density as a function of time after impact for a cell located 10 mm from the center line (axis of symmetry) and 4 mm behind the rear side of the cover plate (edge effects at this location should be minimal). Figure 5 includes data generated from both fine and coarse cell grids. Figure 5 indicates that there appears to be little difference between densities generated through the use of the two grid sizes.

B. Slide Line Effect.

Figure 6 shows the computed geometrical representation of a sweeping explosive densification of Al_2O_3, 42.4 μs after detonation using the slide line routine. A similar curve at 41.9 μs for a calculation without using slide lines is presented in Figure 7. Computed copper densities with and without slide lines are presented in Figure 8. These calculations are at 33.10 μs after detonation initiation and are an average of the cell densities at each vertical location. As is illustrated in Figure 8 the powder is fully densified in the first two cm and doesn't appear to be overly sensitive to the use of slide lines even though the expansion of the explosive products is noticeably different.

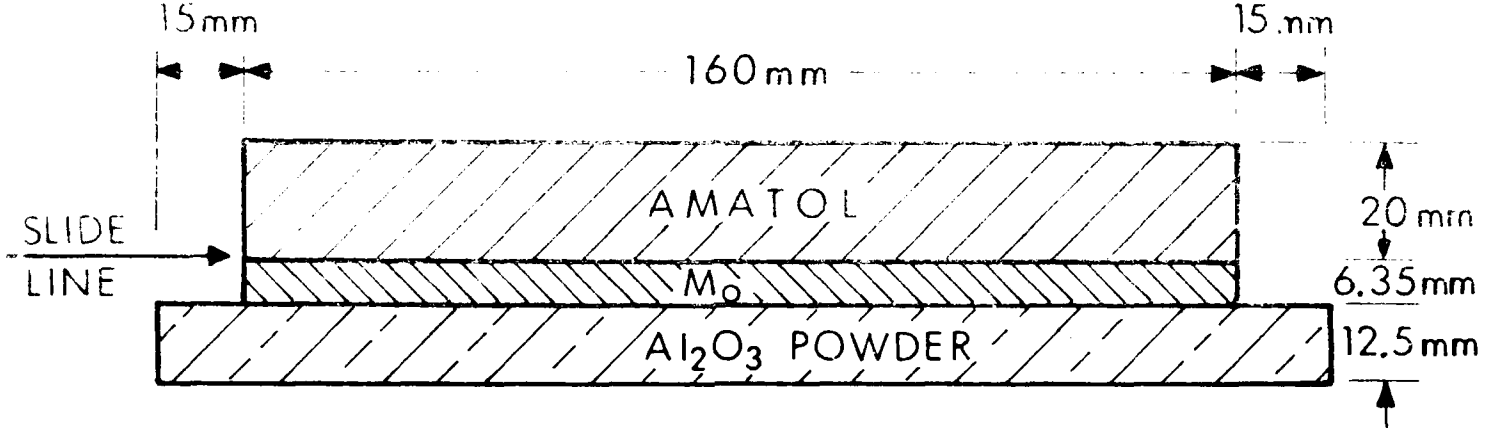

Figure 3: Initial Conditions for Al_2O_3 Compaction - Sweeping Wave.

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IV. CONCLUSIONS

TROTT computer simulations indicate that under the experimental conditions discussed herein for the explosive compaction of powdered copper and plate impact densifications of Al_2O_3, a 30 by 40 grid of quadrilateral cells is adequate.

TROTT calculations also indicate that in the simulation of a sweeping densification of Al_2O_3 the presence or absence of a slide line does not appreciably affect the final calculated Al_2O_3 density.

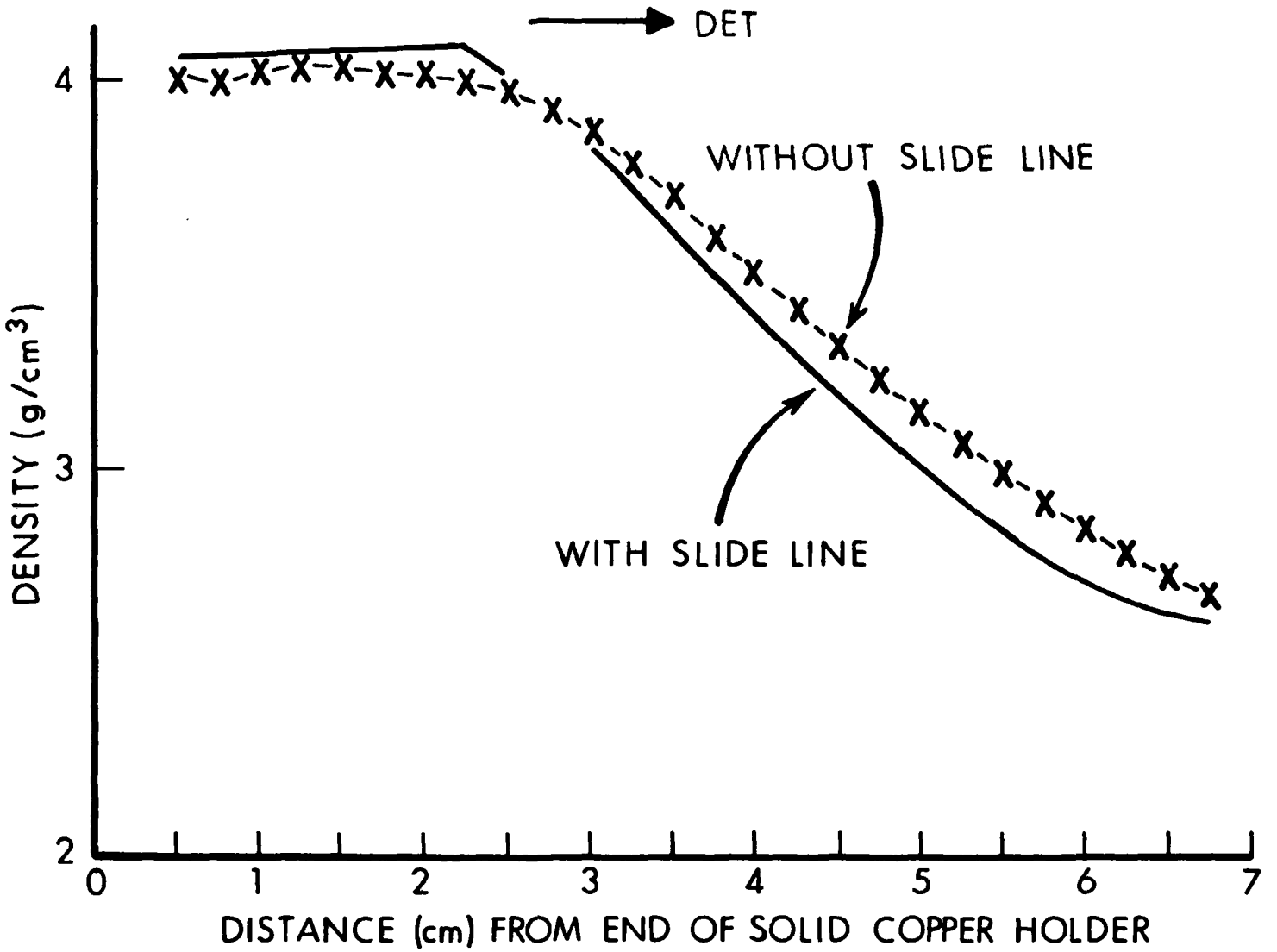

Figure 8. Density of Copper Powder as a Function of Distance from Solid Copper Interface, 33.1 μs after Detonation Initiation.

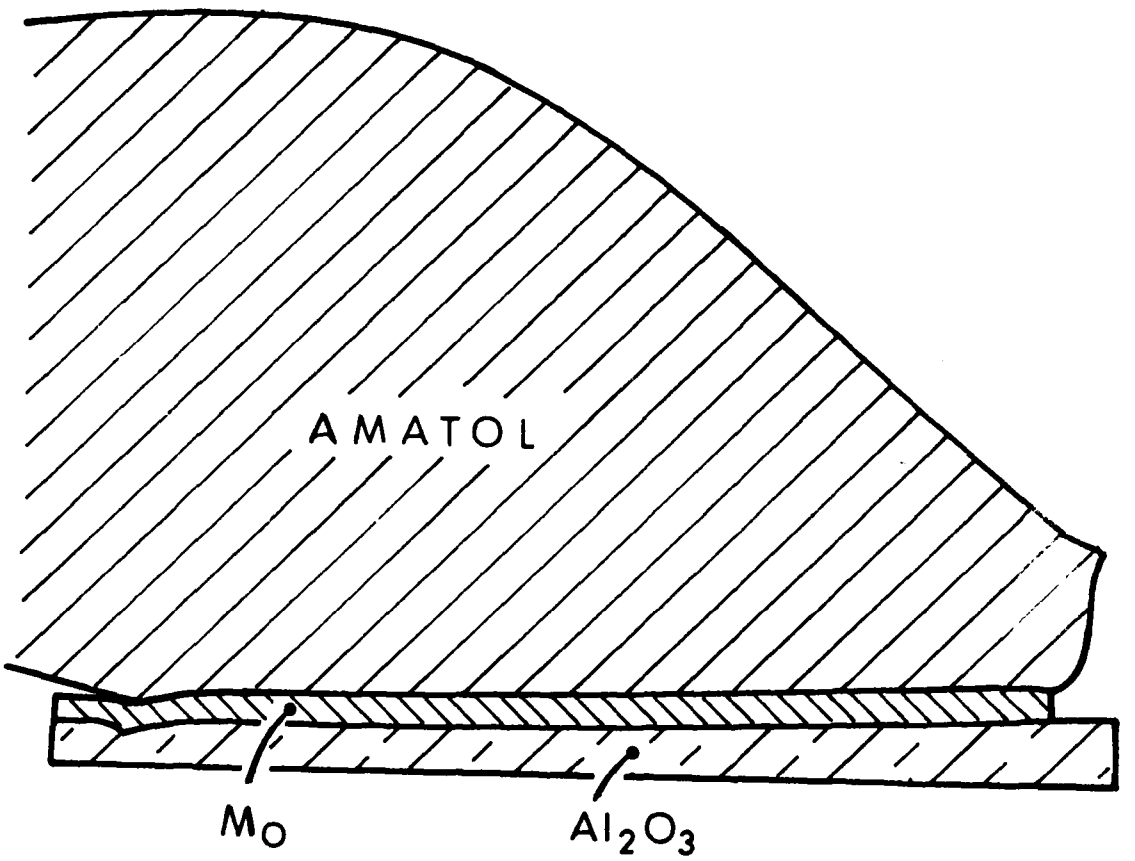

Figure 7. Amatol-Mo-Al_2O_3, 41.9 μs after Detonation Initiation - Without Slide Line.

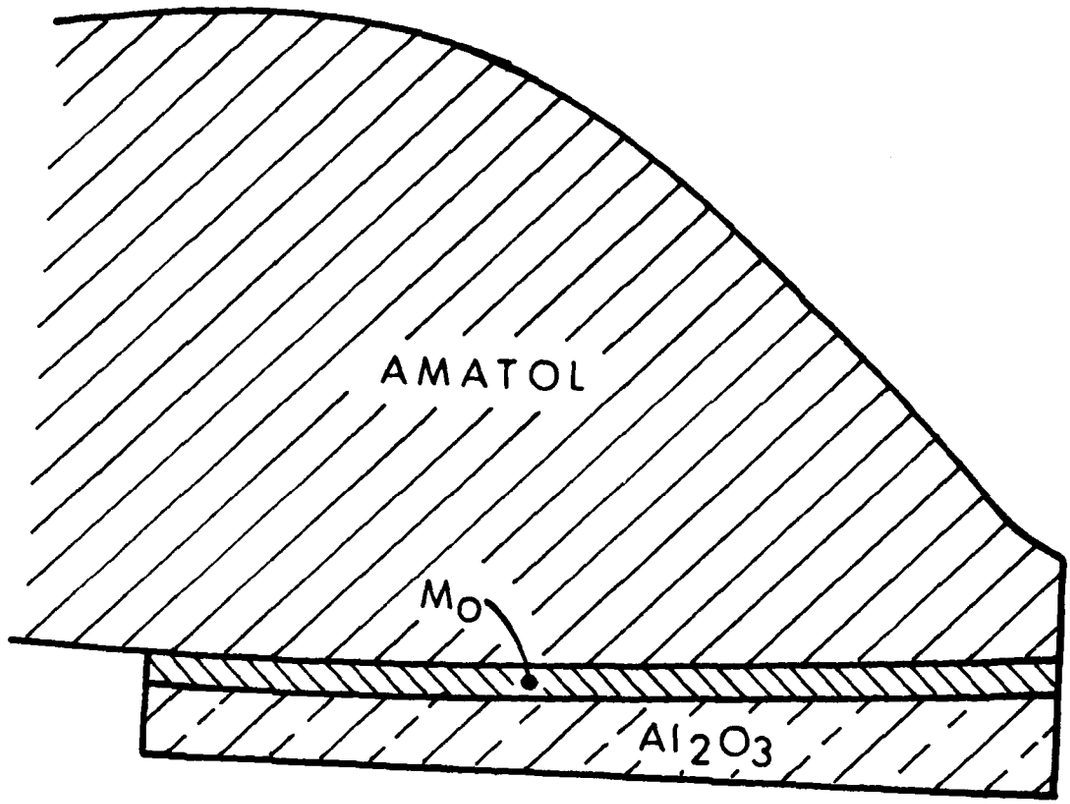

Figure 6. Amatol-Mo-Al_2O_3, 42.2 μs after Detonation Initiation - With Slide Line.

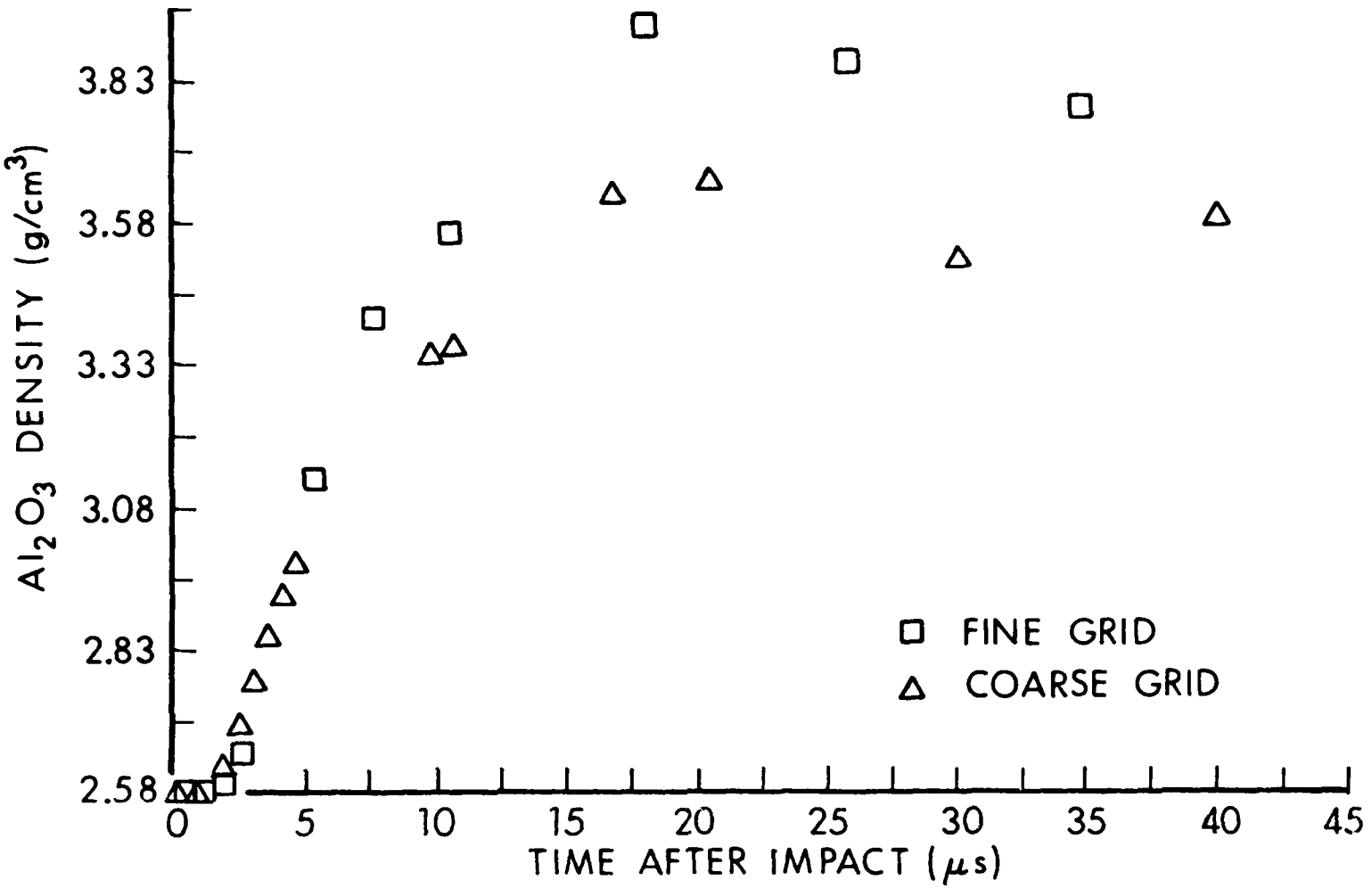

Figure 5. Density of Al_2O_3 Powder as a Function of Time after Plate Impact for Both Fine and Coarse Grids.

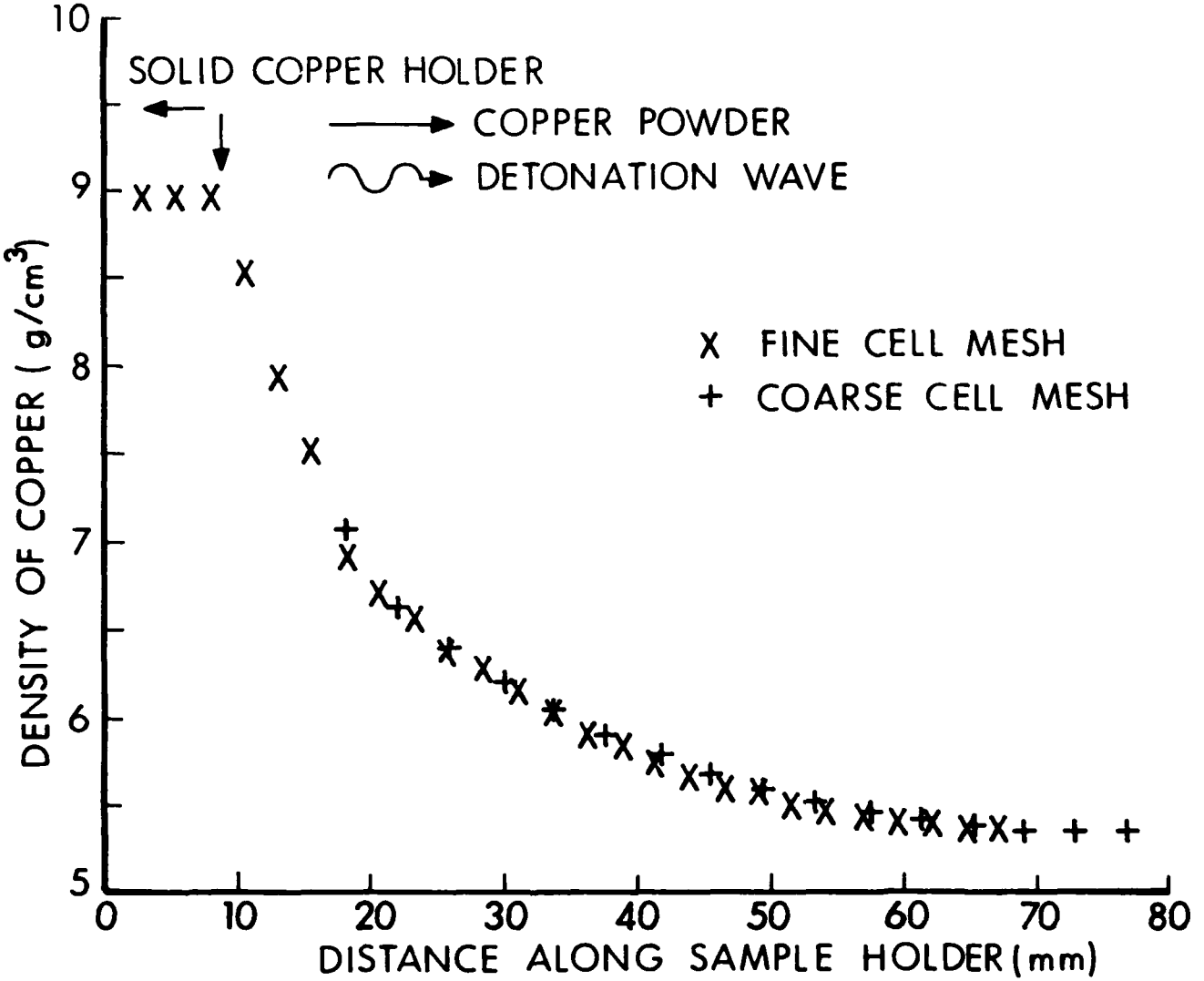

Figure 4. Density of Copper Powder, 28.8 μs after Detonation Initiation.

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