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Title: Spatial Distribution of Damage After Shock Loading

Author(s): V. Livescu, J.F. Bingert, D.L. Tonks

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SPATIAL DISTRIBUTION OF DAMAGE AFTER SHOCK LOADING

V. Livescu[1], J. F. Bingert[1], D. L. Tonks[2]

[1]Los Alamos National Laboratory, Materials Science and Technology Division

[2]Los Alamos National Laboratory, Computational Physics Division

The quantification of shock damage in polycrystalline materials is critical for the understanding of mechanisms controlling failure under dynamic conditions. Ductile fracture in metals occurs by the nucleation, growth, and coalescence of voids. Most damage models characterize the distribution of the voids by volume fraction and assume uniform porosity, but voids in a real material are neither uniform in size nor spatial distribution, and vary with experimental parameters. Physically-based damage models must statistically reproduce this heterogeneity of void damage to accurately model ductile failure of materials under shock loading.

This work investigates void damage distributions and clustering of void damage by using a correlation function-based approach to produce quantitative descriptors of microstructural damage. Damage statistics were obtained from three-dimensional reconstructions of experimentally shock-induced damage in plate impact and high-explosive driven specimens.

Discussion will include evolution of damage statistics with experimental parameters, and plastic flow localization due to non-uniform void distribution.

SPATIAL DISTRIBUTION OF DAMAGE AFTER SHOCK LOADING

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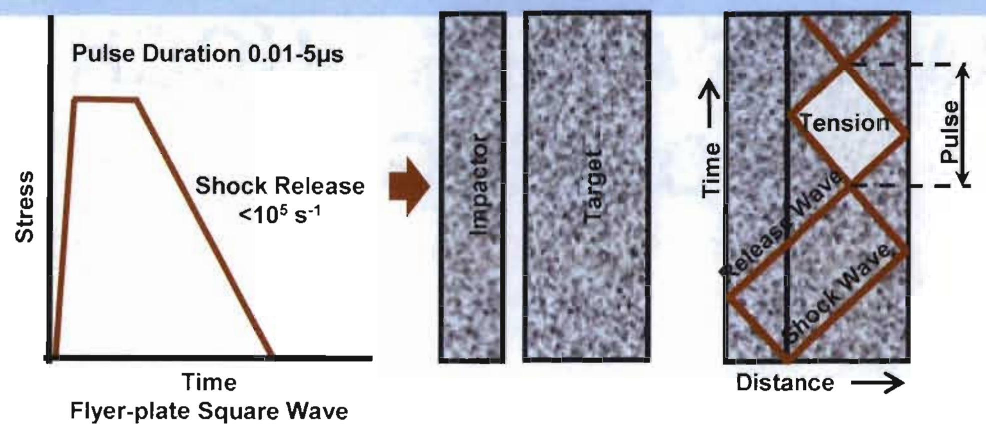
Background



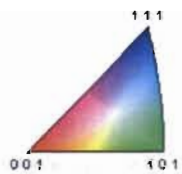
- Spallation is a dynamic fracture and shock-induced damage phenomenon
- Fracture is caused by the interaction of two tensile (release) shock waves
- Spallation experiments are often used to study dynamic ductile fracture in materials
- Ductile fracture is caused by the nucleation, growth and coalescence of voids
- Spall failure occurs by separation at the spall plane if release waves are strong enough

Material

- High-Purity Tantalum - rolled plate (annealed)

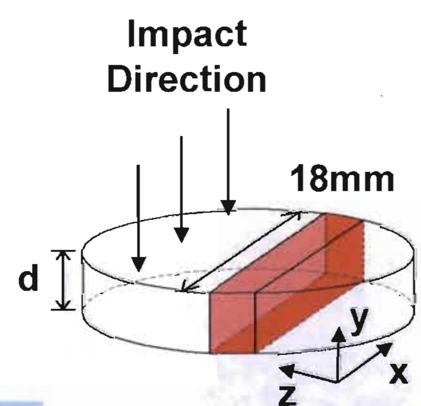
O	N	C	H	Ta
< 50 ppm	< 10 ppm	< 10 ppm	< 5 ppm	Balance

- Average grain size = 35μ
- Moderate microstructural heterogeneities



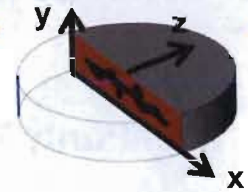
Crystal directions with respect to through-thickness plate direction

- Gas gun experiments:
  - 5.6 GPa, 1.1μs pulse duration, 2mm Ta flyer plate, 4mm Ta target
  - 5.6 GPa, 2.2μs pulse duration, 4mm Ta flyer plate, 8mm Ta target

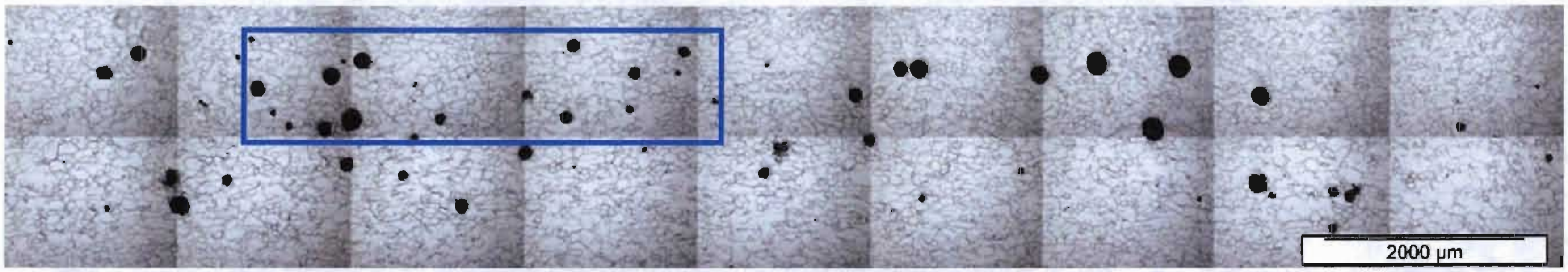


S.R. Chen, G.T. Gray III, *Met. Mat. Trans.* 27A (1996), 2994-3006.

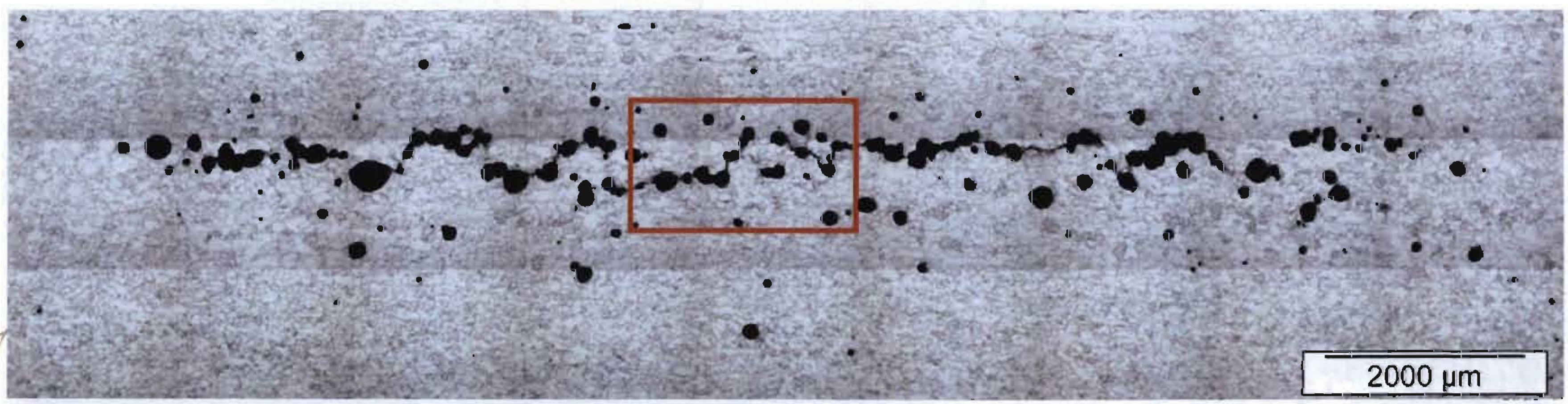
Damage Field in Plate Impact Experiments



- Pulse Duration = 1.1μs, Magnification = 50x
- Apparently Isolated Voids (Cavitation)

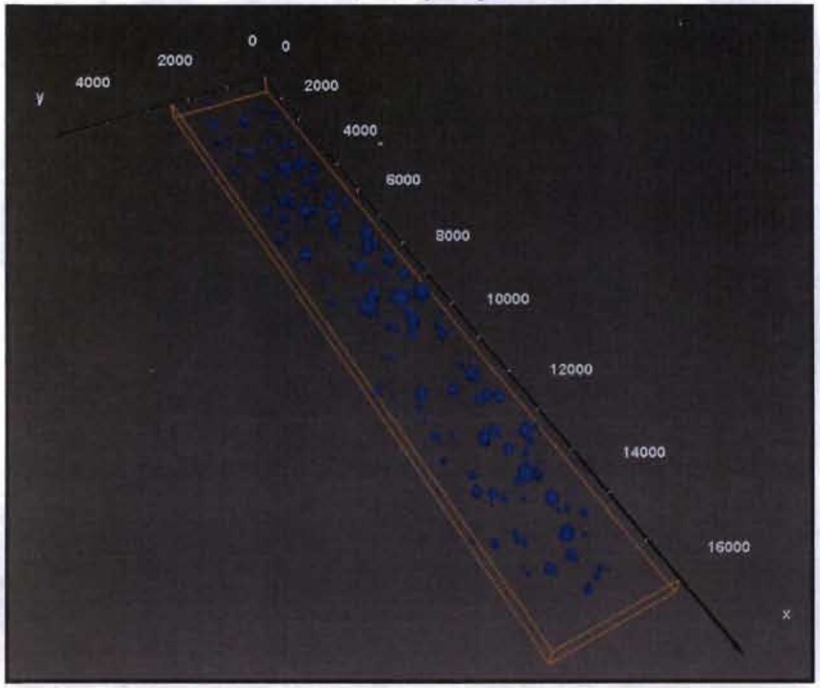


- Pulse Duration = 2.2μs, Magnification = 50x
- Mixed Mode Damage (Cavitation + Shear Localization)

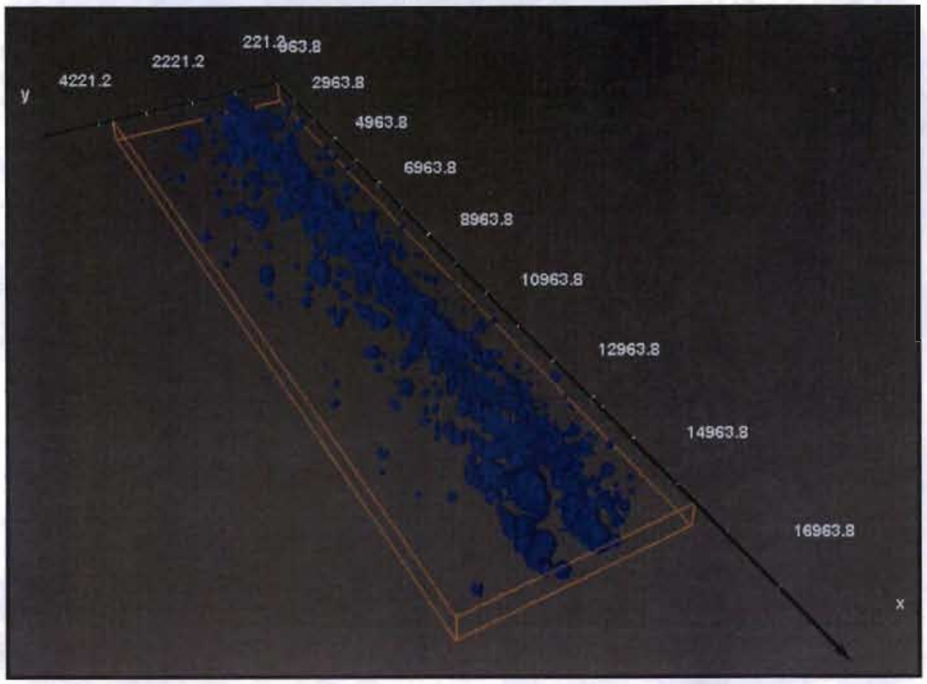


Damage Field in Plate Impact Experiments

5.6 GPa, 1.1μs pulse

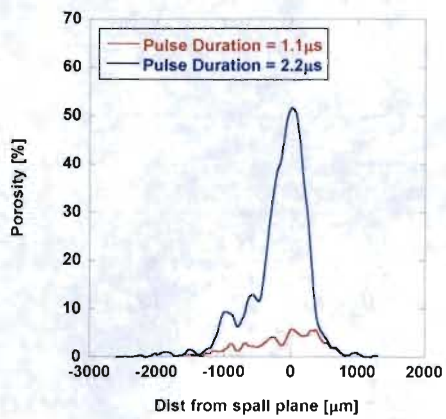


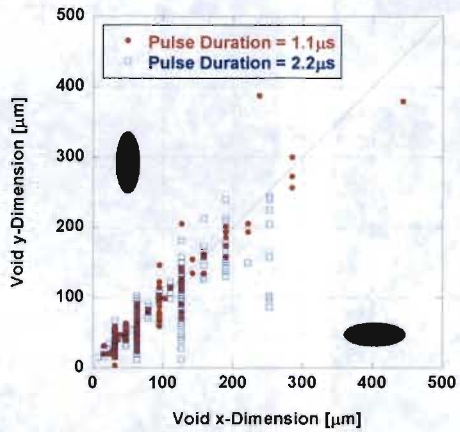
5.6 GPa, 2.2μs pulse

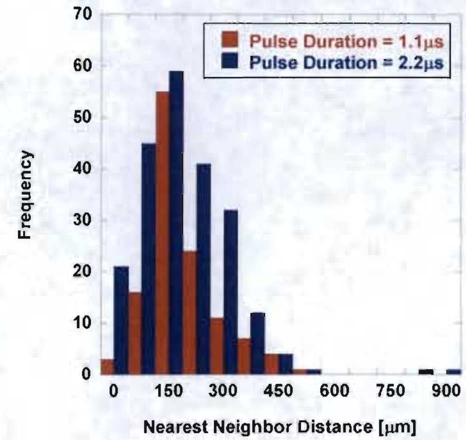


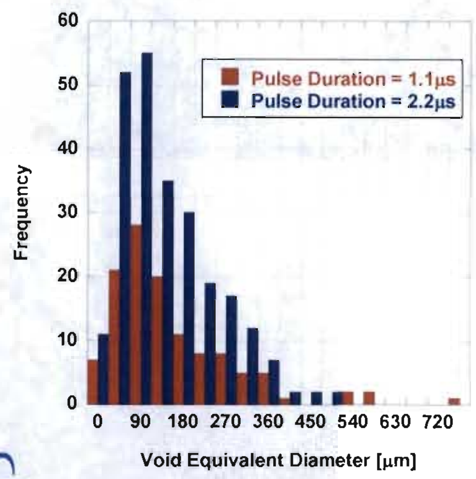
- Nice 3D reconstruction/view of the damage field
- Provides the basis for the the identification of differences in damage

Statistics from 3D data



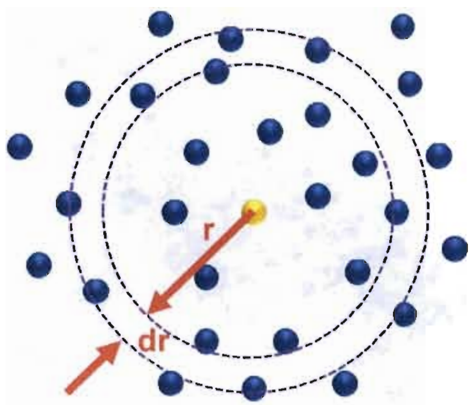




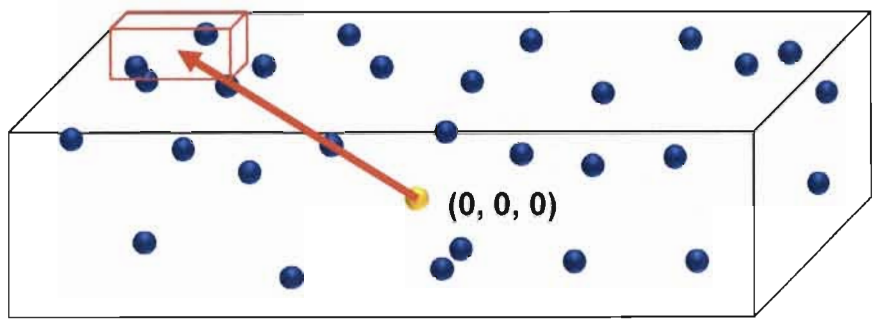


- Porosity increased by an order of magnitude for the longer pulse duration specimen.
- The width of the damage affected region was similar
- No nearest neighbor correlations were obvious
- Void size distribution was similar

Pair Correlation Functions



Radial Distribution Function (RDF)



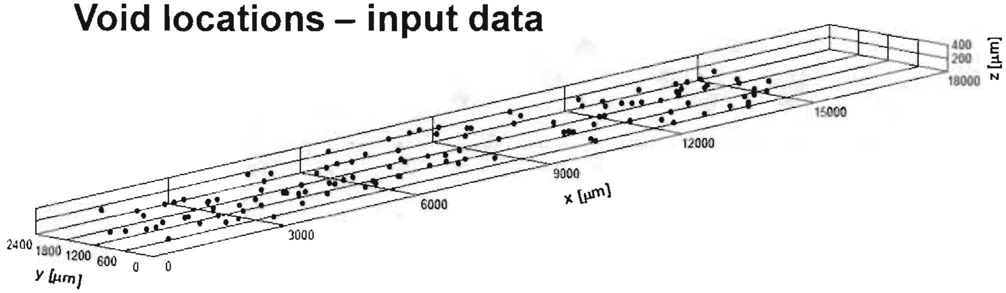
3D Pair Correlation Function (PCF)

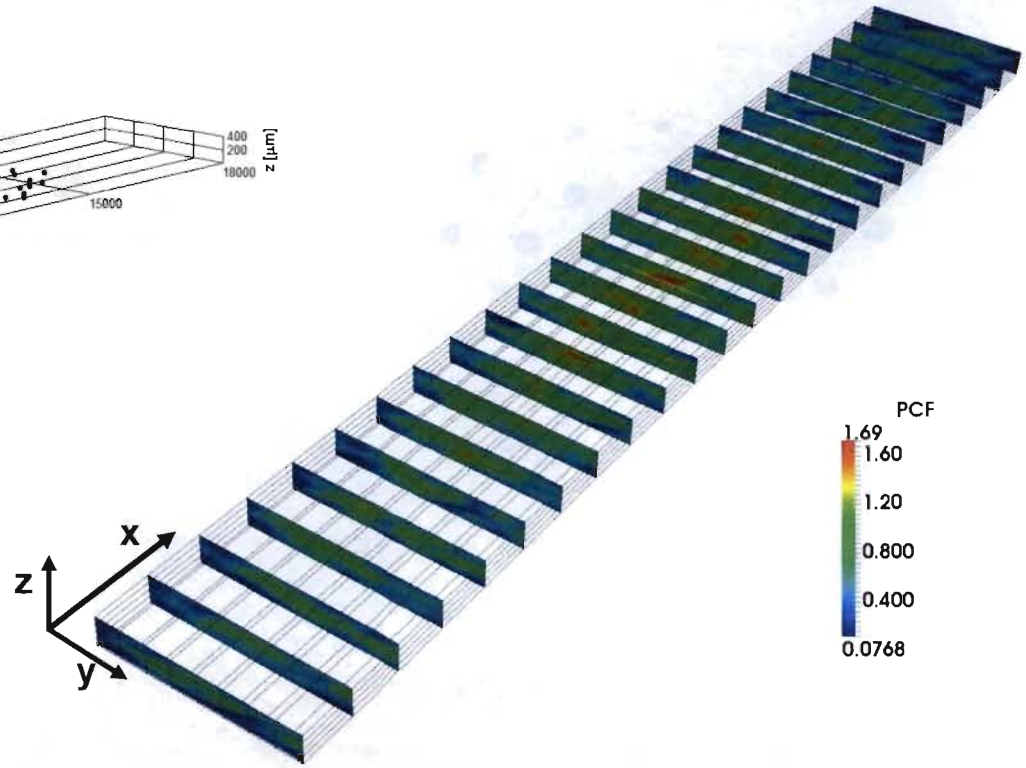
Parameters to consider:

- **Input statistics – satisfactory number of sample points**
- **Binning – small enough for fine graining but large enough for statistical convergence**
- **How to interpret the results**

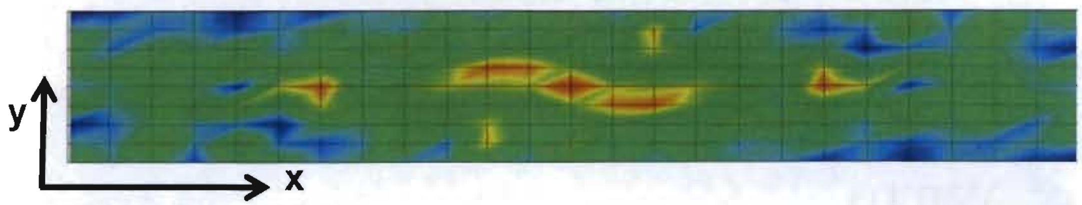
Tantalum 5.6GPa, 1.1μs pulse

Void locations – input data

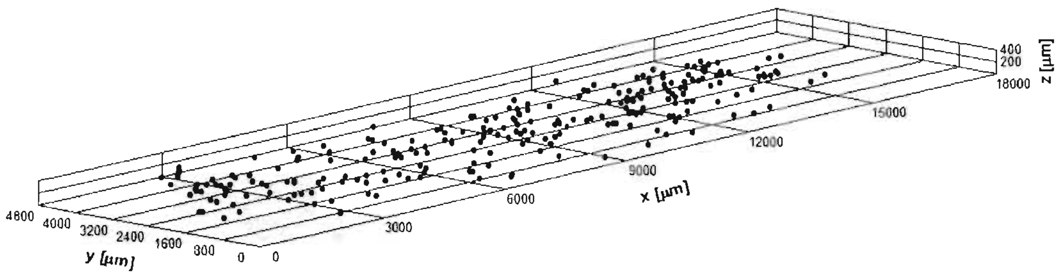




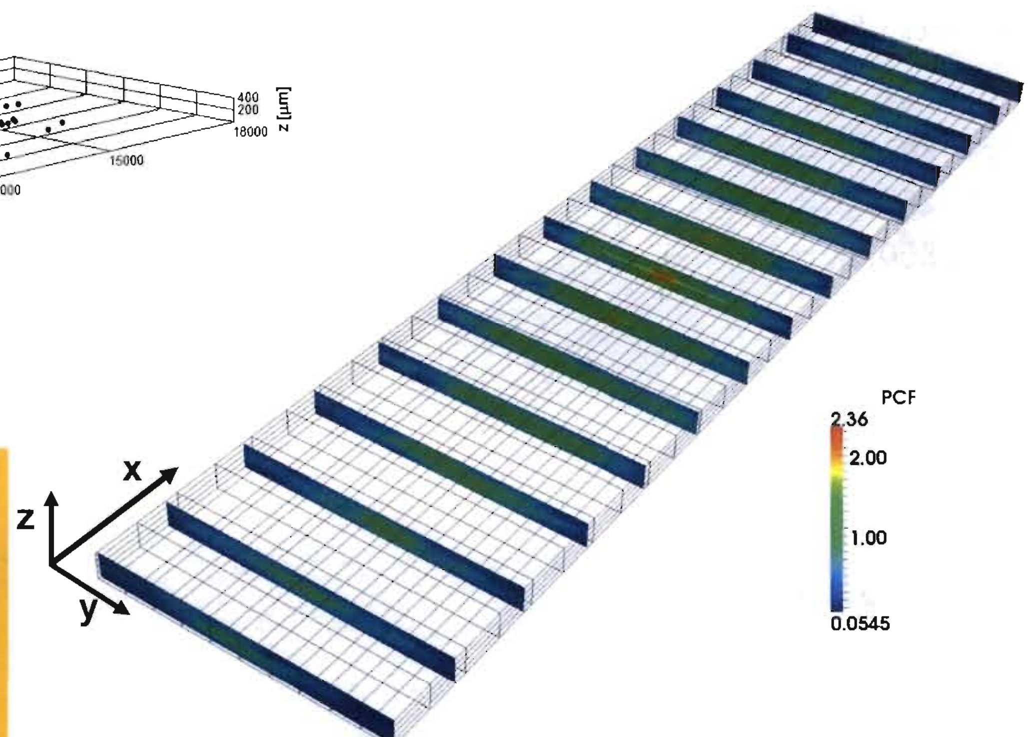
- Hints of alignment along x-direction
- Multiple PCF maxima
- PCF configuration suggests the existence of multiple (weakly defined) clusters.
- Relatively weak correlation – max value only 1.7

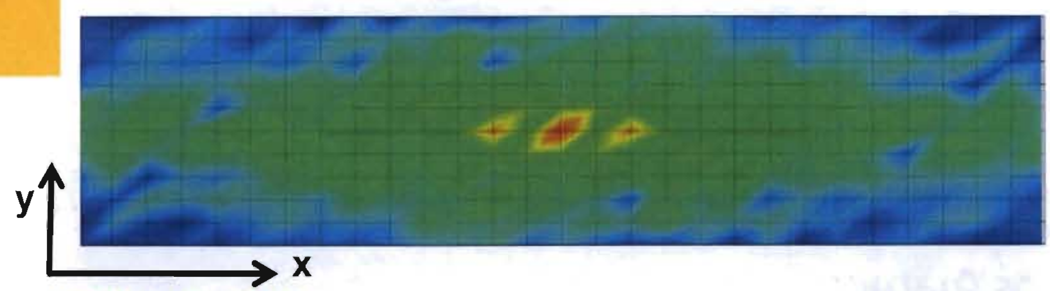


Tantalum 5.6GPa, 2.2μs pulse



- Hints of alignment along x-direction
- Multiple PCF maxima
- PCF configuration suggests the existence of two main clusters
- Slightly stronger correlation – max value only 2.4

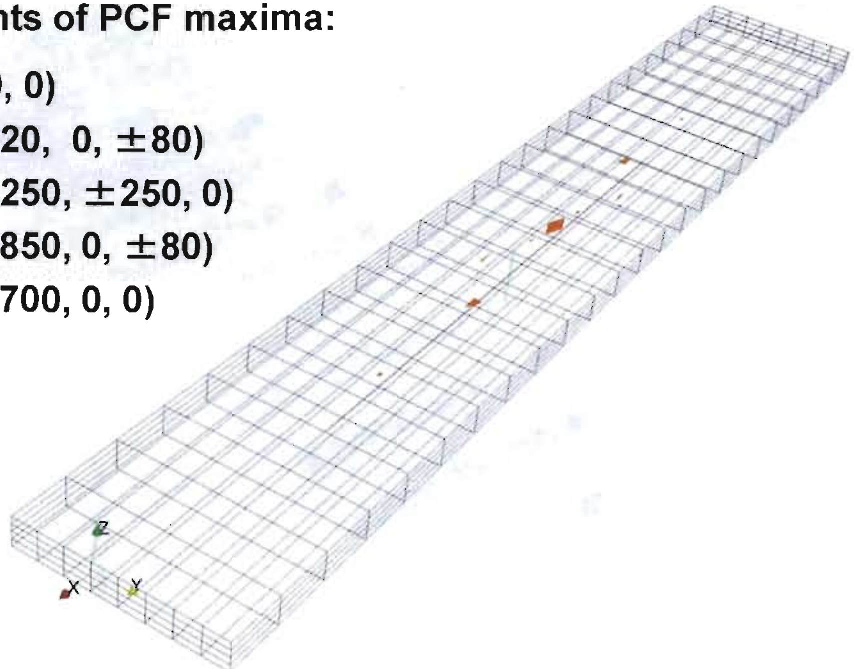


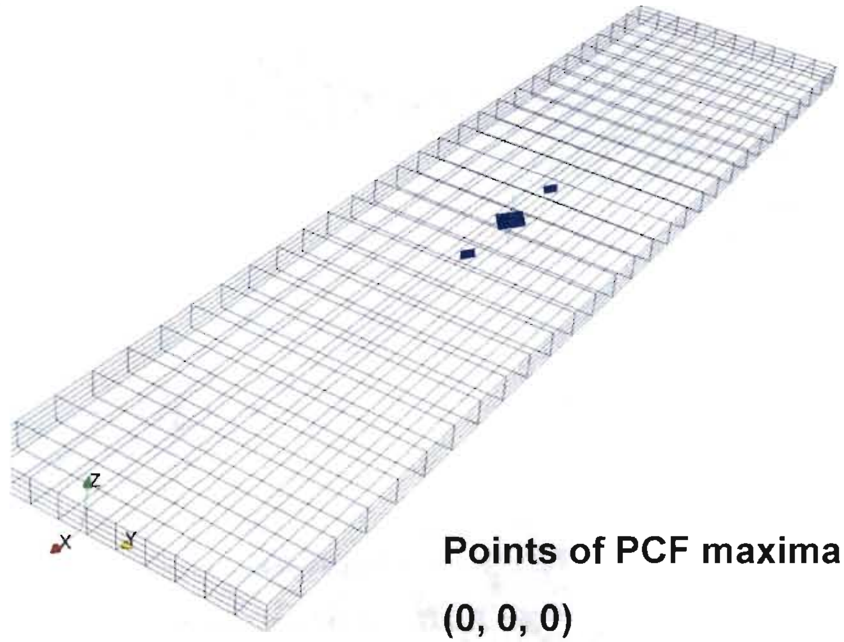


Locations of PCF Maxima

Points of PCF maxima:

(0, 0, 0)
(±620, 0, ±80)
(±1250, ±250, 0)
(±1850, 0, ±80)
(±3700, 0, 0)



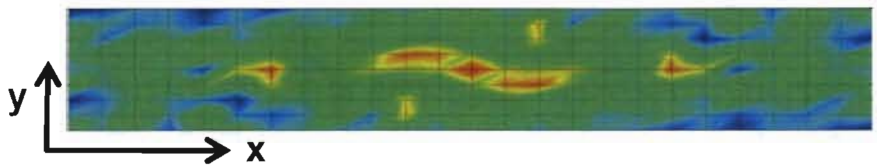


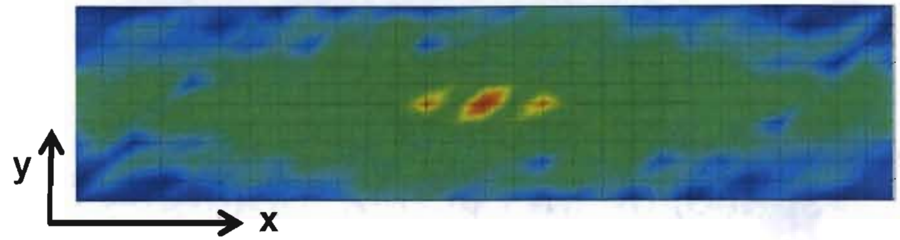
Points of PCF maxima:

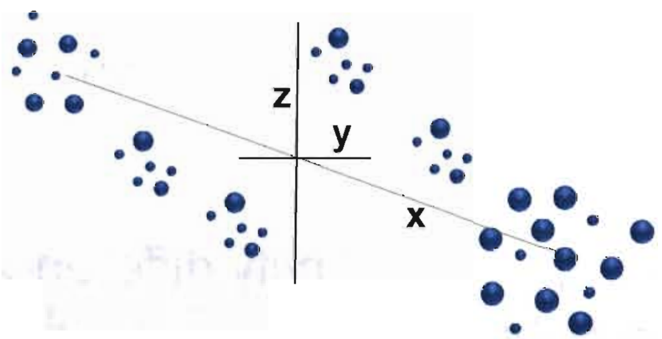
(0, 0, 0)
(±1075, 0, 0)

- **Similar trend visible for both specimens**
- **Weak tendency to form void clusters becomes stronger in the long pulse case**

Potential void cluster configurations







- More complex void clustering
- Locations where voids have nucleated are more uniformly spread throughout the volume.
- Weak correlation indicates some potential for clustering

- Evidence that, as damage evolves at longer pulse duration, voids tend to cluster mainly along the x-axis.
- Difference in PCF peak maximum value due to overlapping correlation of the two clusters
- Difference in extent of maxima vs. secondary maxima:
  - Difference in cluster size and/or
  - Artifact of plotting due to finite bin size

Summary

- Pair correlation functions (PCFs) are an important tool for determining spatial distribution of features of interest in a volume, i.e. void damage in a microstructure.
- Applied to two sets of data from plate impact experiments in Tantalum, PCFs identified potential void clustering configurations.
- Although the correlations are relatively weak, they identify differences in the void damage spatial spread between the short and long pulse cases.
- Stronger clustering tendency is identified at longer pulse duration, potentially due to void nucleation along strain localizations between existing voids that were nucleated earlier in the deformation process.