

Introduction

- During high strain rate events such as high velocity impact, a stress wave will propagate through the sample. At a free surface this will reflect leading to a rarefaction wave. When rarefaction waves from an impactor and sample interact, tension will develop. If the tensile stress is sufficiently high, a form of material failure known as spall can occur (Fig 1.)

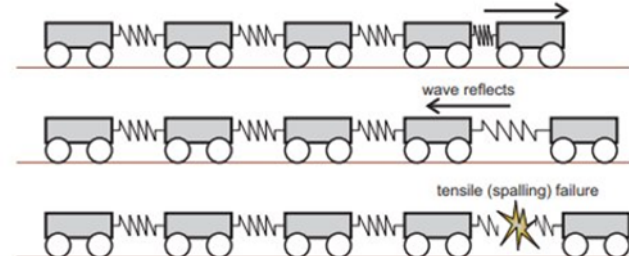


Fig 1. Train carriage analogy for the development of spall

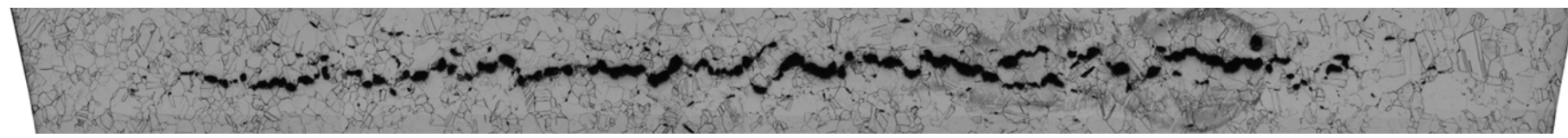
- The aim of this work is to investigate the effect of a second compressive shock on the spalled material. Previous work^{1,2} has shown that at a sufficiently high stress, the material can be recompacted, stitching the failed material back together
- To do this, a modified form of gas gun driven plate impact recovery system³ has been employed using a first shot to generate incipient levels of spall before using a second shot to recompact these voids see Fig 2 (a) & (b)
- This work looks to investigate deformation mechanisms around the recompacted plane through optical and electron microscopy to predict the material response to subsequent loading

Objectives

- Investigate recompaction² using 2-shot system
- Analyse deformation around spall plane to assess deformation mechanisms
- Repeat testing at higher velocities to assess if velocity affects deformation density

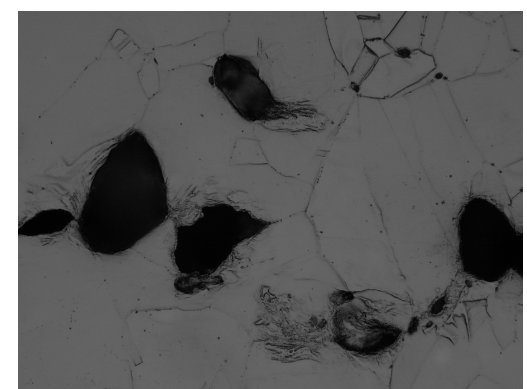
Results – Optical Microscopy

Spall Testing at 160m/s (1.74GPa)

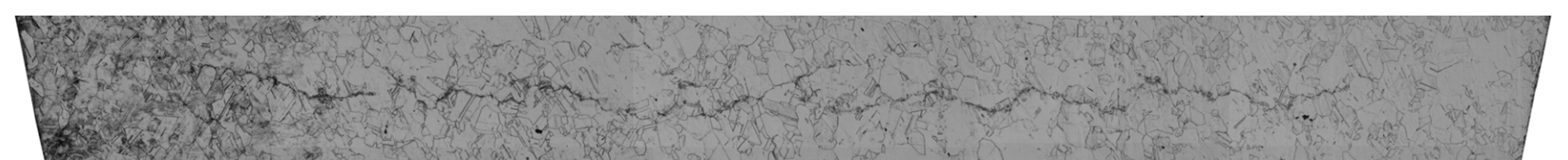


- Clear formation of spall plane
- Void area 0.78mm²
- Limited deformation around voids

Fig. 3. Above; Optical micrograph of voids within spall plane
Right; Optical micrograph of spall plane

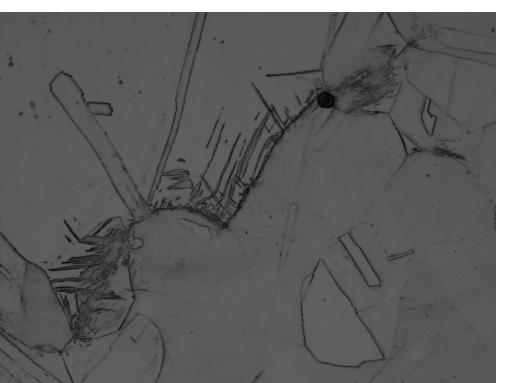


Recompaction testing at 178 m/s (1.84 GPa)



- Scar left in spall plane location
- Significant reduction in void area
- 0.024 mm² remaining void area
- Heavy deformation around scar
- Deformation on both sides of scar

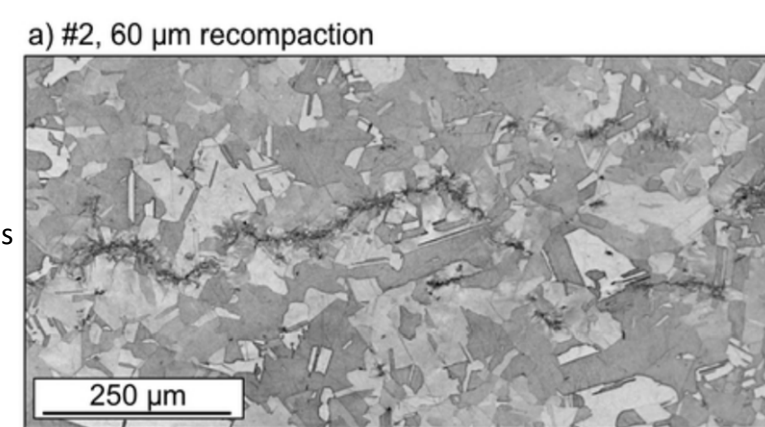
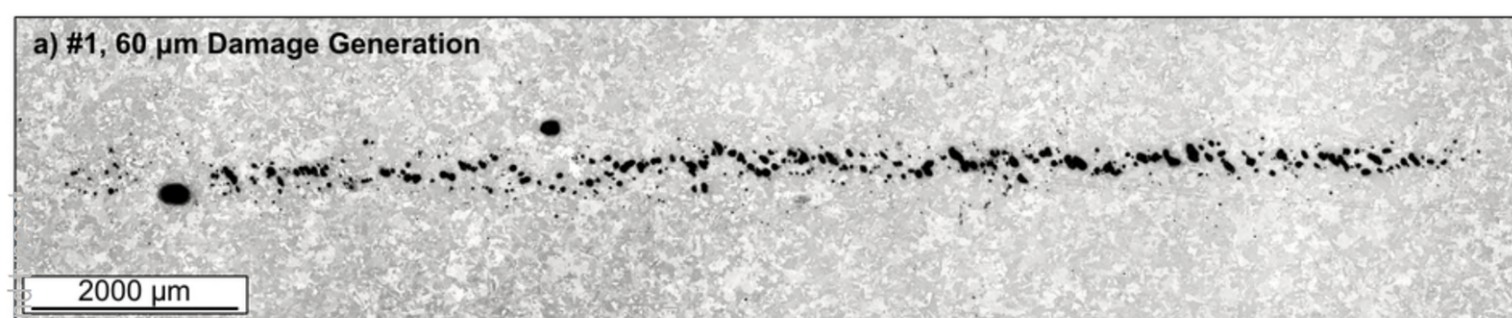
Fig 4. Above; Optical micrographs of recompacted voids in spall plane
Right; Optical micrographs of recompaction scar



Recompaction results from literature^{2,3} (Jones et al)

- Results of current work show similar behaviour to literature results without need for heat bed³ or short interval second shock²
- This shows short term energy from the second shock should be enough for recompaction of voids

Fig 5. Above; Optical micrographs of recompaction scar
Right; Optical micrographs of spall plane
Taken from Jones et al. (2020)



Methodology

2 Stage Recompaction shots

- First Shot - Sample detaches from momentum ring
- Spalled sample from tension produced in first impact
- Second Shot - Spalled samples fitted back into momentum ring, spall plates attached to rear to prevent tension under second impact
- Spall voids closed by compressive wave in the second impact

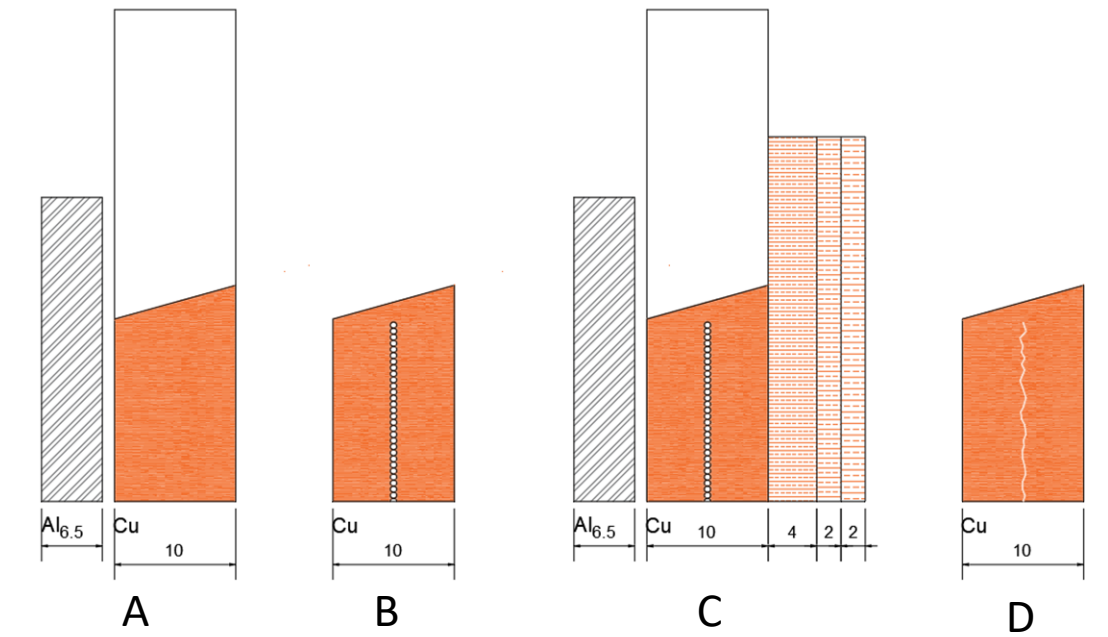


Fig 2. A. Assembly before shock, B. Spalled sample after detaching from momentum ring, C. Spalled sample refitted into momentum ring with spall plates, D. Recompacted sample

Microstructure of deformed sample can then be analysed

4 Shots performed at increasing second shock velocities

Spall shots also performed for comparison

Shot Number	1	2	3	4
First (spall) Shot (m/s)	166	166	166	166
Second (recompaction) Shot (m/s)	166	178	200	215

Results – Scanning Electron Microscopy

Deformation heat maps from recompaction testing at 166-215 m/s (1.74 -2.28GPa)

Secondary Electron SEM

- 10 Images taken of etched samples (4 samples) across recompaction plane
- Images converted to binary (black for deformation and white for no deformation)
- 10µm x 5µm region created in image and % damage calculated
- % Damage is the percentage of black (deformed) pixels in the region of interest
- % Damage plotted for each region of interest and colour coded to create heat map

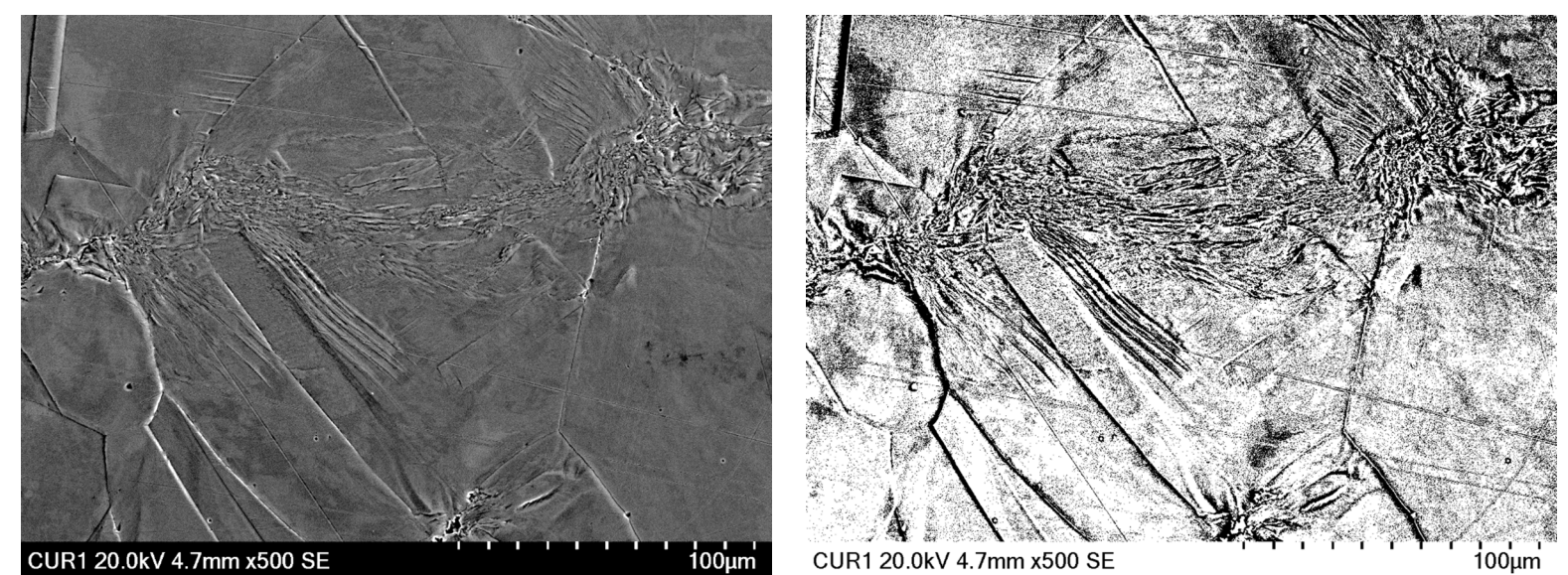


Fig 6a. Left, Greyscale image of sample. Fig 6b. Right Binary image of the same area

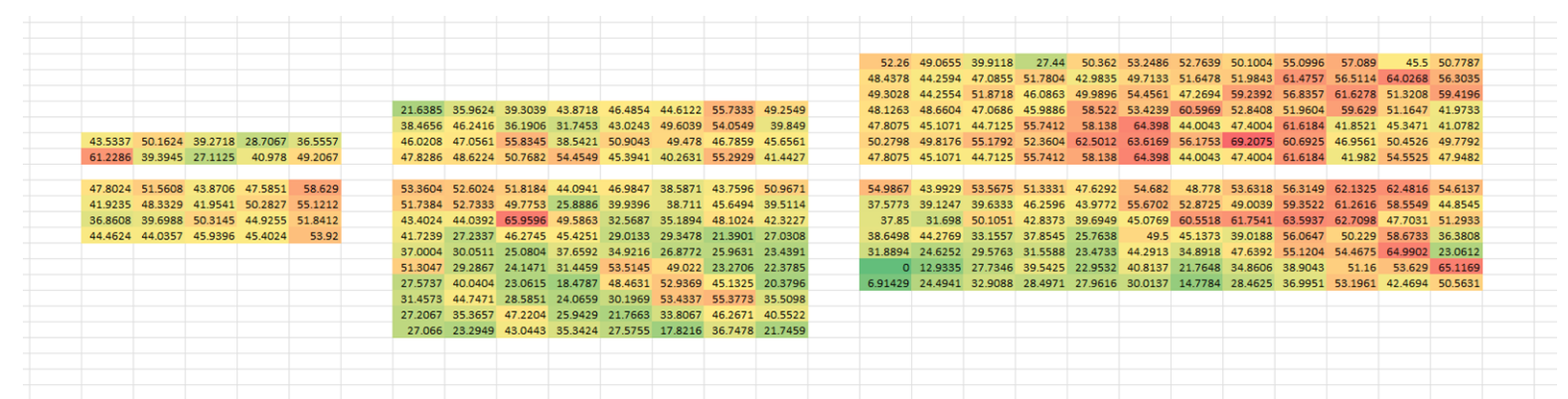


Fig 7. Deformation heat map for the image shown in Fig 6

- Heat maps produced for each of the 10 images and 4 sample (40 total)
- Average deformation for each strip calculated
- Results show increase in deformation on both sides of the spall plane as velocity increases
- Results show slight trend toward deformation on the impact side of the spall plane

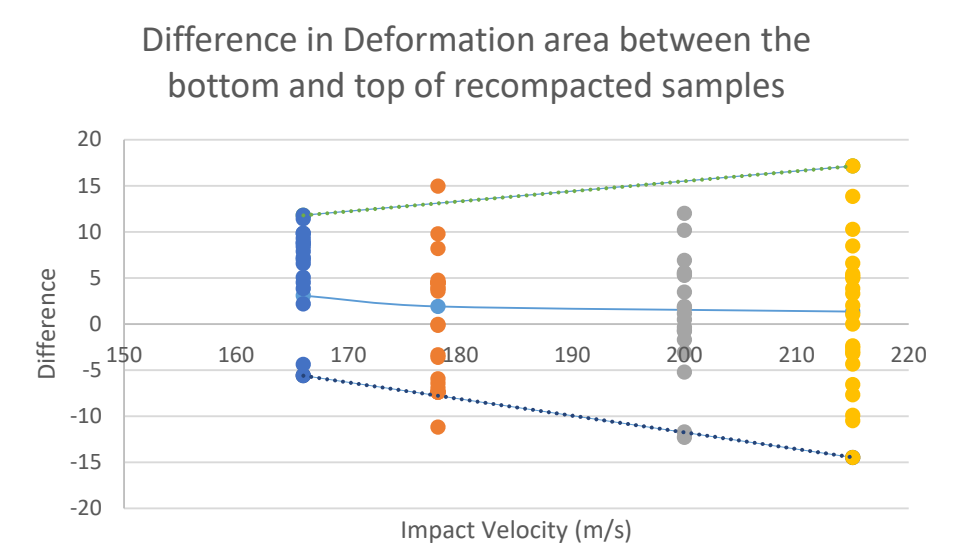


Fig 8. Chart showing the increase in deformation on both sides of the spall plane with increasing secondary impact velocity

Ongoing and Future work

- EBS of recompacted fracture plane to produce IPF and Grain rotation diagrams
- Calculate twin/shear band deformation density from IPF and Grain rotation diagrams
- Microhardness testing across the plane to reveal the strength of recrystallised bonding
- Recompaction shots on Aluminium and Titanium

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References

- Follansbee and Gray, "Dynamic deformation of shock prestrained copper" Materials and Science Engineering, **138**, 23-31 (1991)
- Hawkins, M.C., Hixson, R., Thomas, S. and Fensin, S., 2019. Spall and re-compaction in OFHC copper under high velocity impact, Journal of Applied Physics **128**, 045902 (2020)).
- Jones, D.R., Fensin, S., Morrow, B., Martinez, D.T., Hixson, R, Shock Recompaction of spall damage, Journal of Applied Physics **127**, 245901 (2020)