The effect of shock wave and quasi-isentropic loading on the shear and spalling strength of metals with natural and microcrystalline structure

O. N. Ignatova*, I. I. Kaganova*, A. B. Kal'manov*, A. N. Malyshev*, V. I. Skokov*, A. M. Podurez*, B. A. Raevsky*, O. A. Tyupanova*, G. A. Salishev†, C. V. Razoryonov‡, Marvin A.Zocher**

*RFNC-VNIIEF, 37 Mira av., Sarov, Nizhegorod region, 607190, Russia
†BelGU, 2a Korolyov st., Belgorod, 308015 Russia
‡IPHF RAN, 1 acad. Semenov pr., Chernogolovka, Moscow region, 134432 Russia
**LANL, Los Alamos, USA

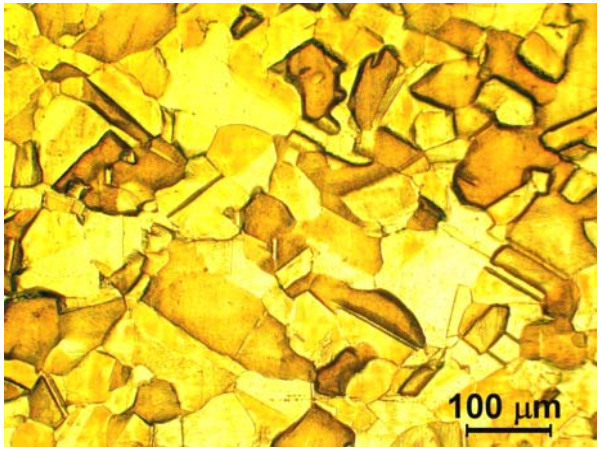
Introduction

To develop wide range models of shear and spall strength for metals with varying crystalline structure one has to know their mechanical properties in various stress-strain states. The response of metals to shear and tensile stresses is governed by a number of parameters such as deformation ε_l, pressure *P*, temperature *T*, strain rate, deformation history, grain size, dislocation density, etc., the effect of which depends on this or that zone of stress-strain states.

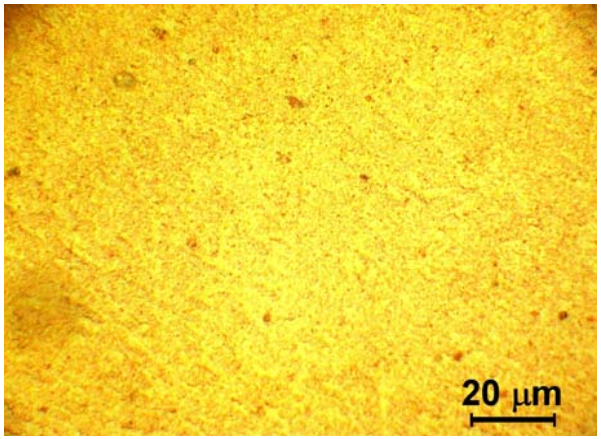
Here simulation and experimental studies of the effect of the preliminary loading on the response of materials to shear and tensile stress are presented.

Material and experimental procedure

M1 copper

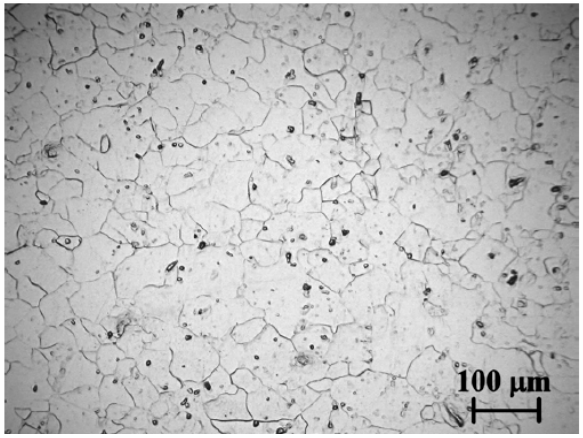


d=110 μm

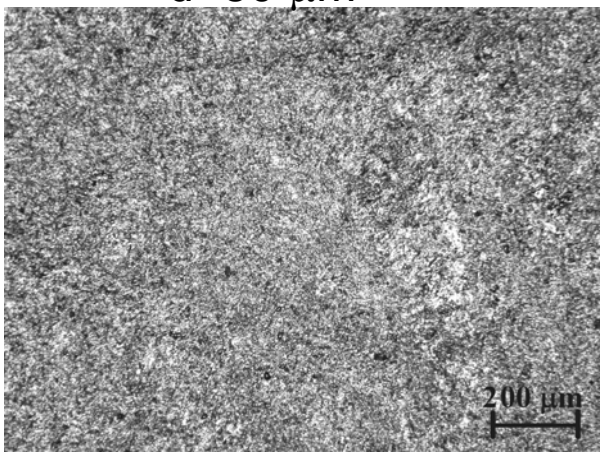


d=0.5 μm

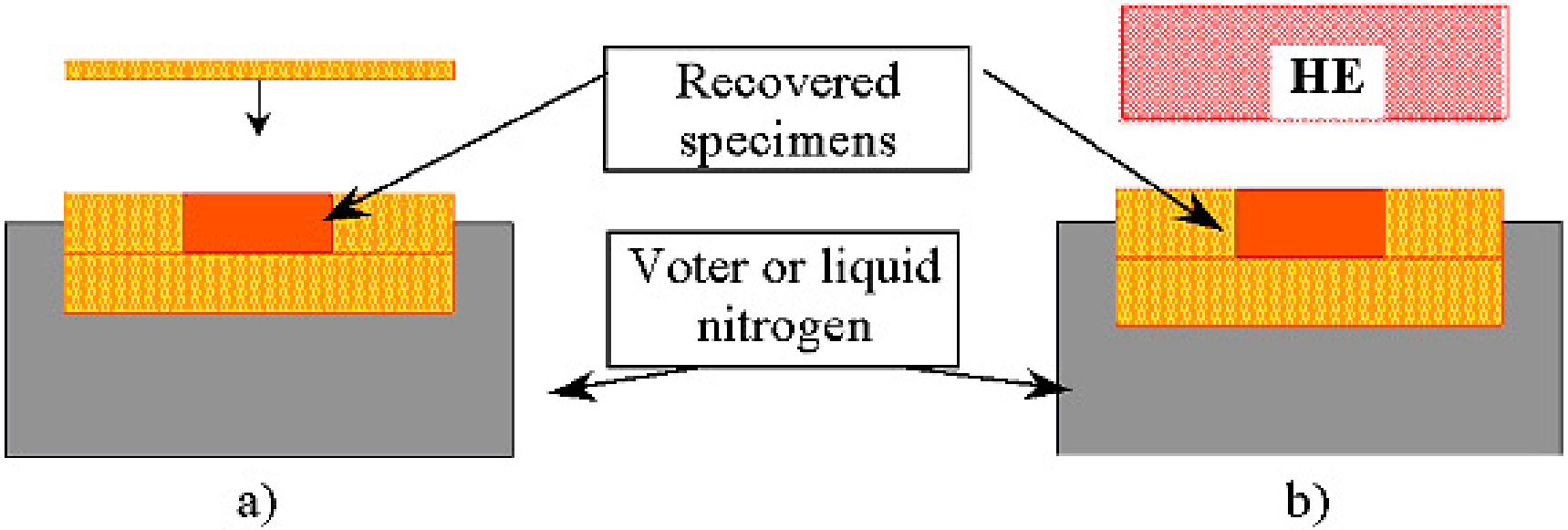
TVC tantalum



d=80 μm



d=1 μm



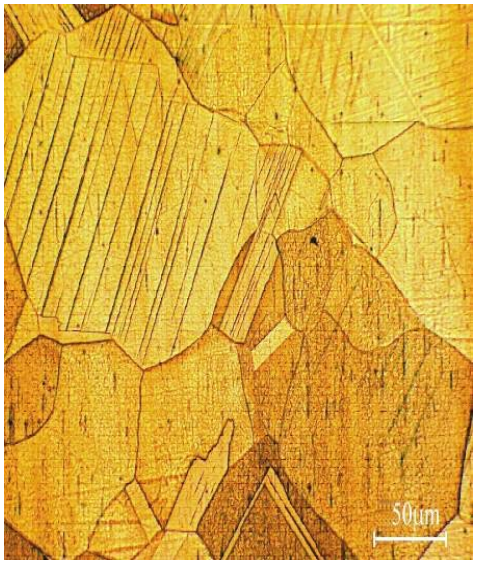
Sample loading by a flat shock wave (a) and a quasi-isentropic compression wave (b)

Loading parameters are as follower:

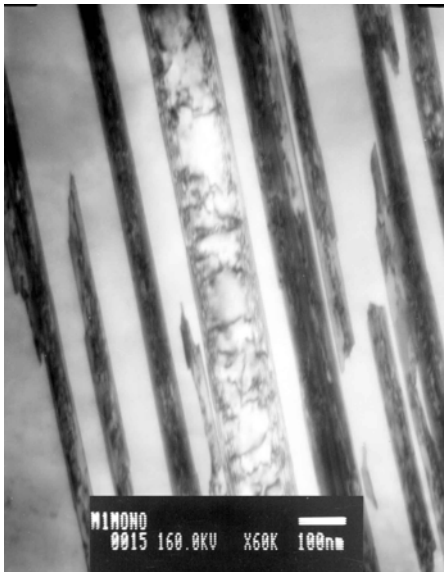
Shock wave loading: P~20-120 GPa, ε_i~0.11-0.4, $\dot{\varepsilon}_i$~ 10^8-10^{10} s^{-1} ;

Quasi-isentropic loading: P~28-32 GPa, ε_i~0.11-0.12, $\dot{\varepsilon}_i$~ 10^6-10^7 s^{-1} .

Results of metallographic studies



a) P=35 GPa

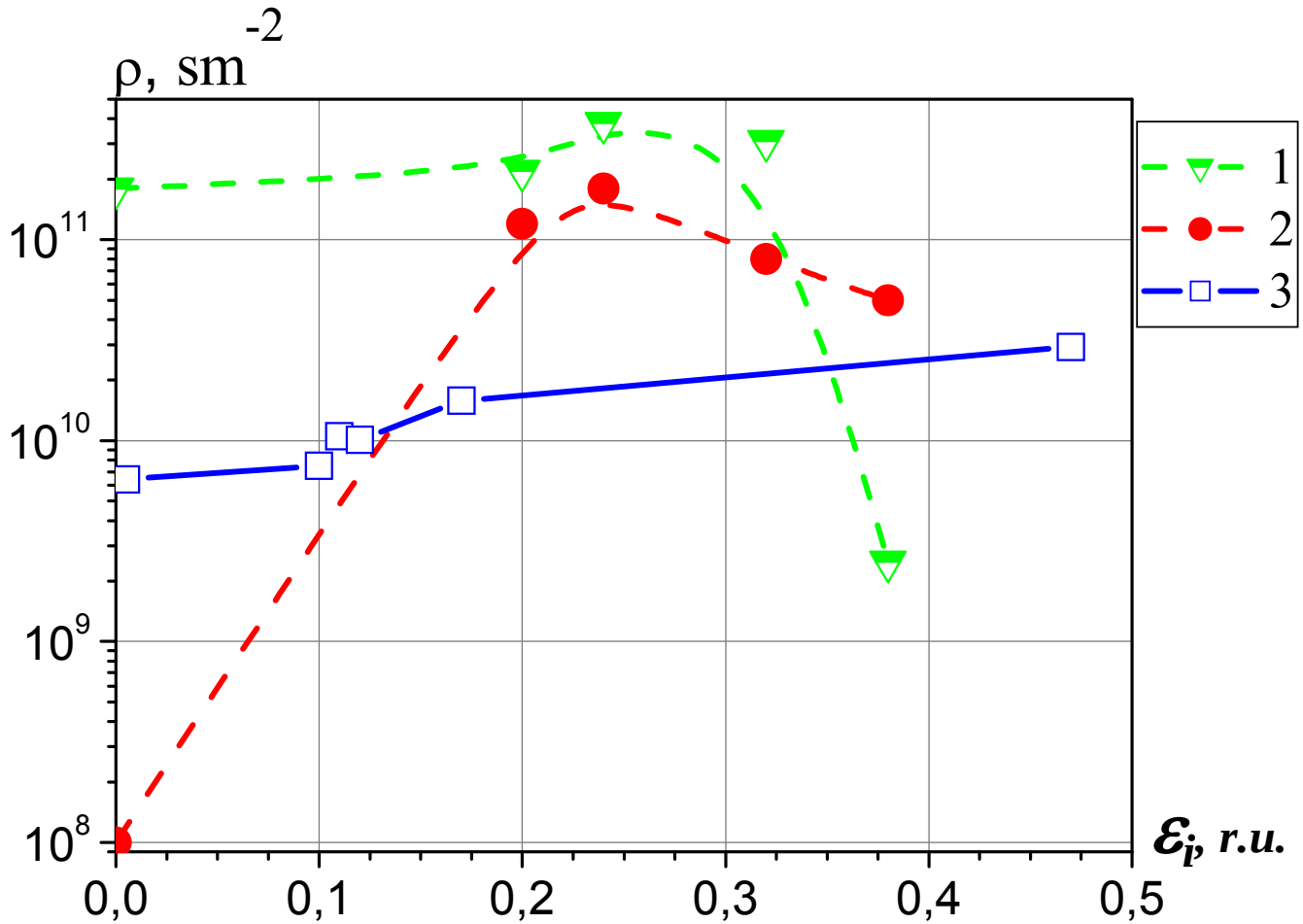


b) P=30 GPa

c) P=70 GPa

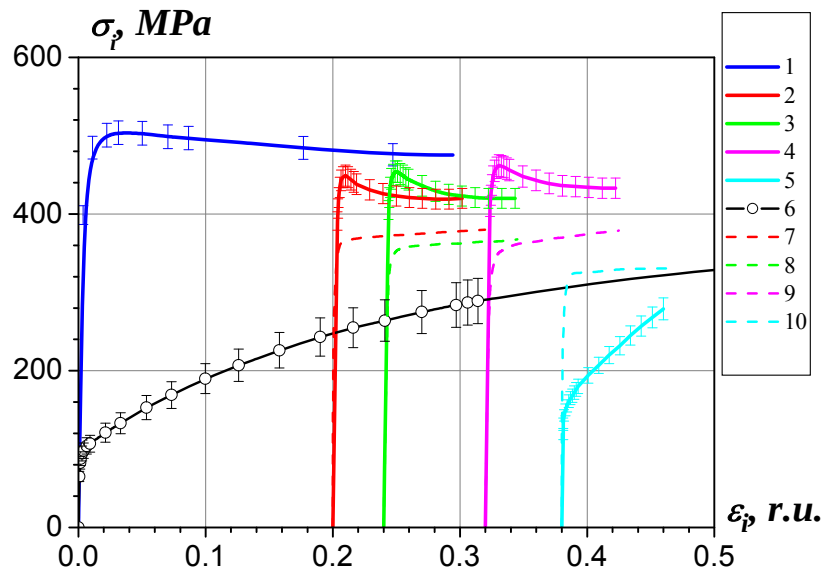
Twin structure in polycrystalline copper (a, b) and tantalum (c) formed after shock wave loading at room temperature

Measurement of dislocations

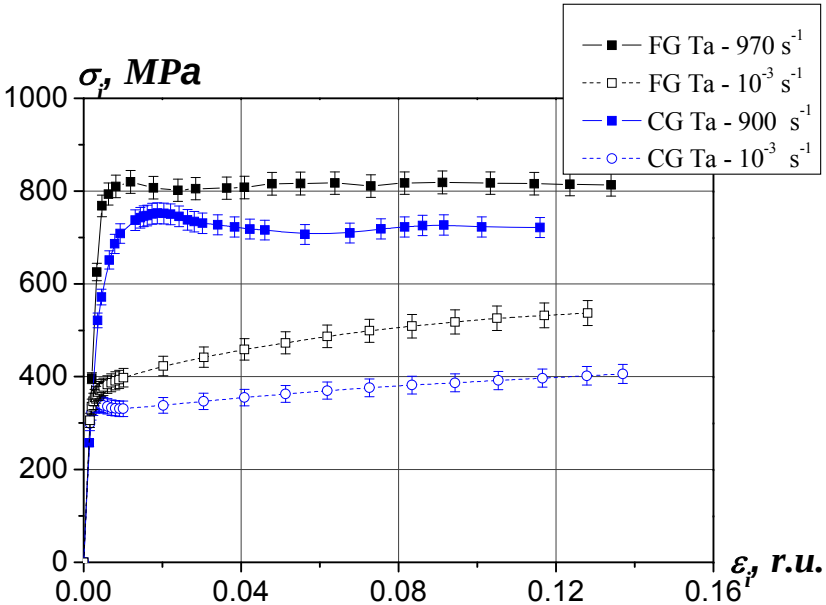


Dislocation density in copper (1, 2) and tantalum (3) with different grain size as function of deformation: 1 – FG copper, 2 – CG copper, 3 – CG tantalum.

Shear strength before and after SW loading



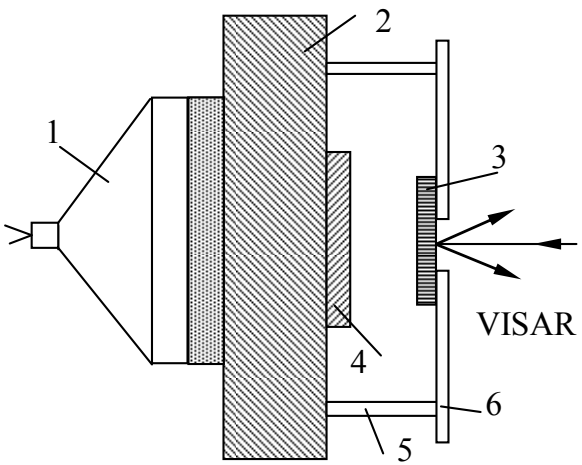
a)

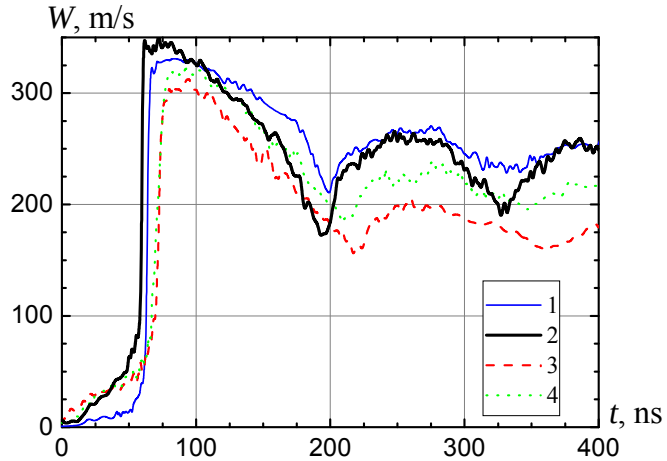


b)

σ-ε diagrams of static compression of FG and CG copper (a) and tantalum (b) at normal temperature before and after SW loading with different intensity:
1 – FG in initial state, 2- 5 – FG copper, σ_X~25-75 GPa; 6 – CG copper in initial state, 7-10 – CG copper after SW loading 75-25 GPa.

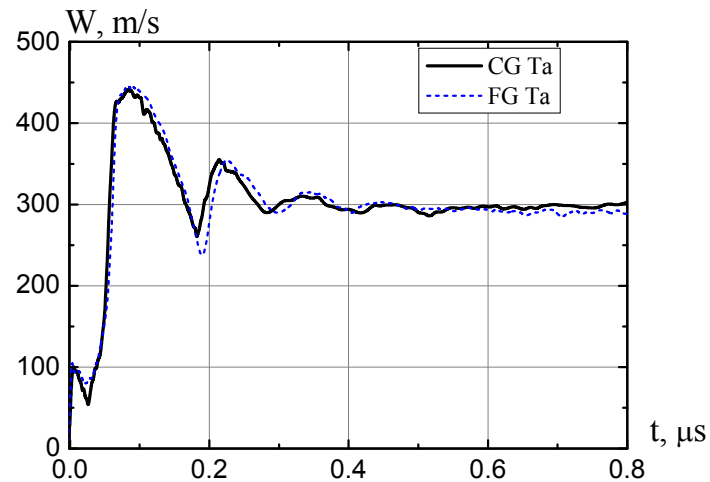
Continuous registration of the velocity of traveling W(t) of the free real surface of the specimens is done using VISAR





Cu

a)



Ta

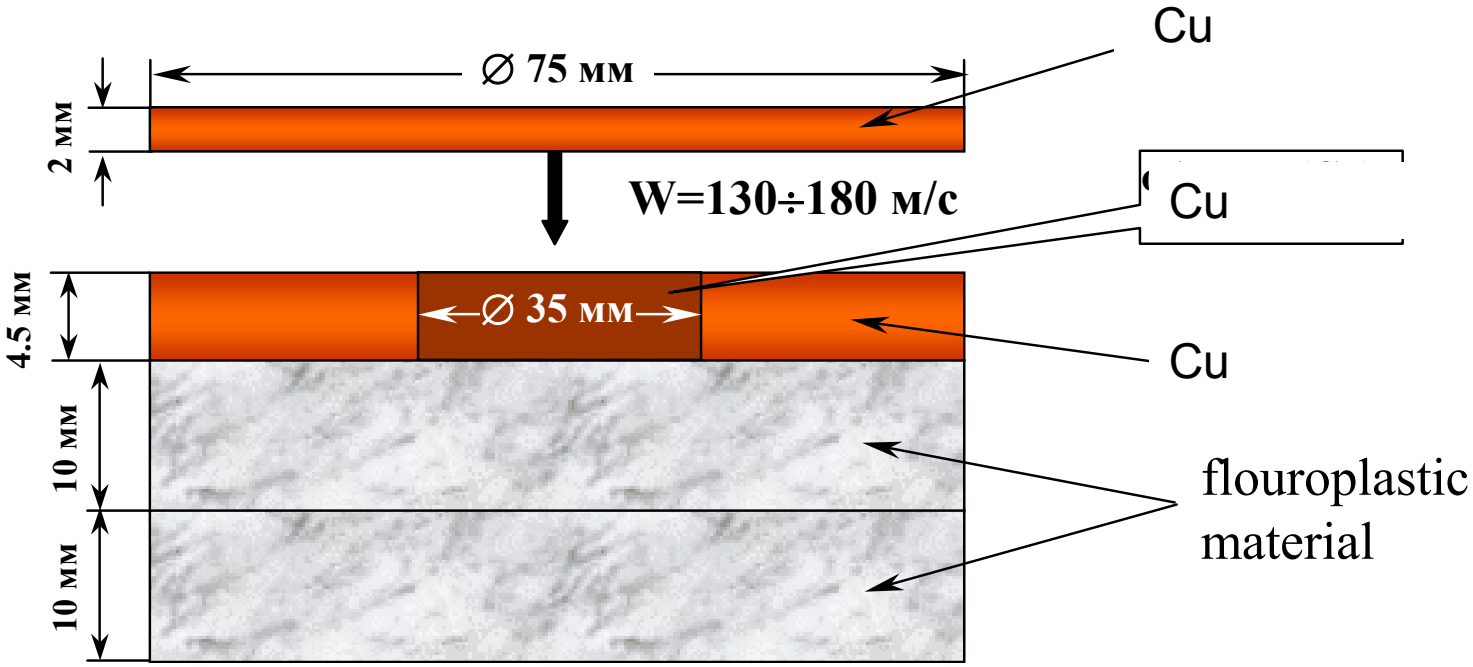
b)

Spallation study of copper:

- metallographic measurement of the spallation zone in recovered samples and finding the correlation between the damage amount and the loading history;

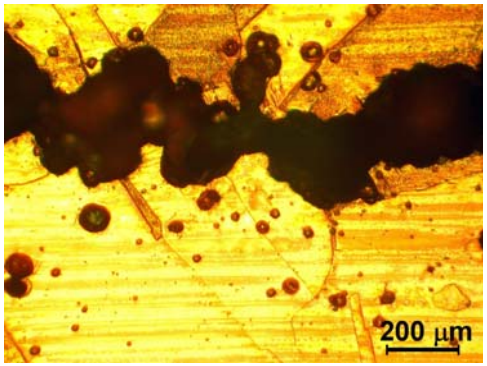
- examination of the unloading wave structure after the sample explosive to shock wave.

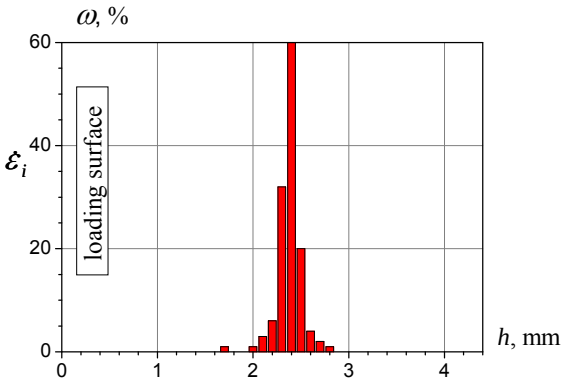
Metallographic measurement of the spallation zone in recovered samples and finding the correlation between the damage amount and the loading history



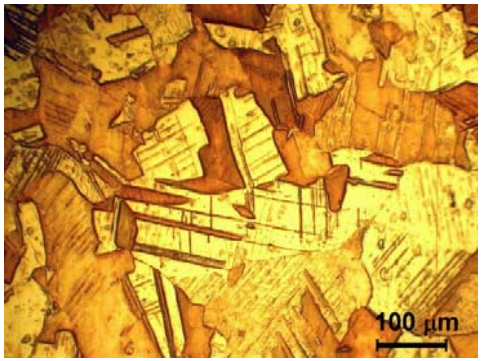
Metallographic studies

$$\omega = \frac{L_W}{L_L} \cdot 100\%$$



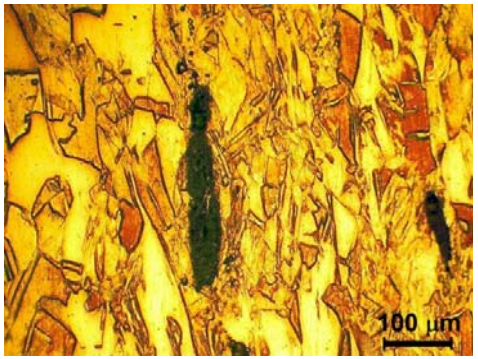


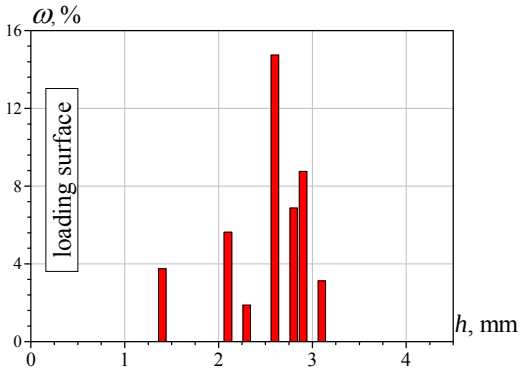
a) W=162 m/s,



$\omega \sim 0$

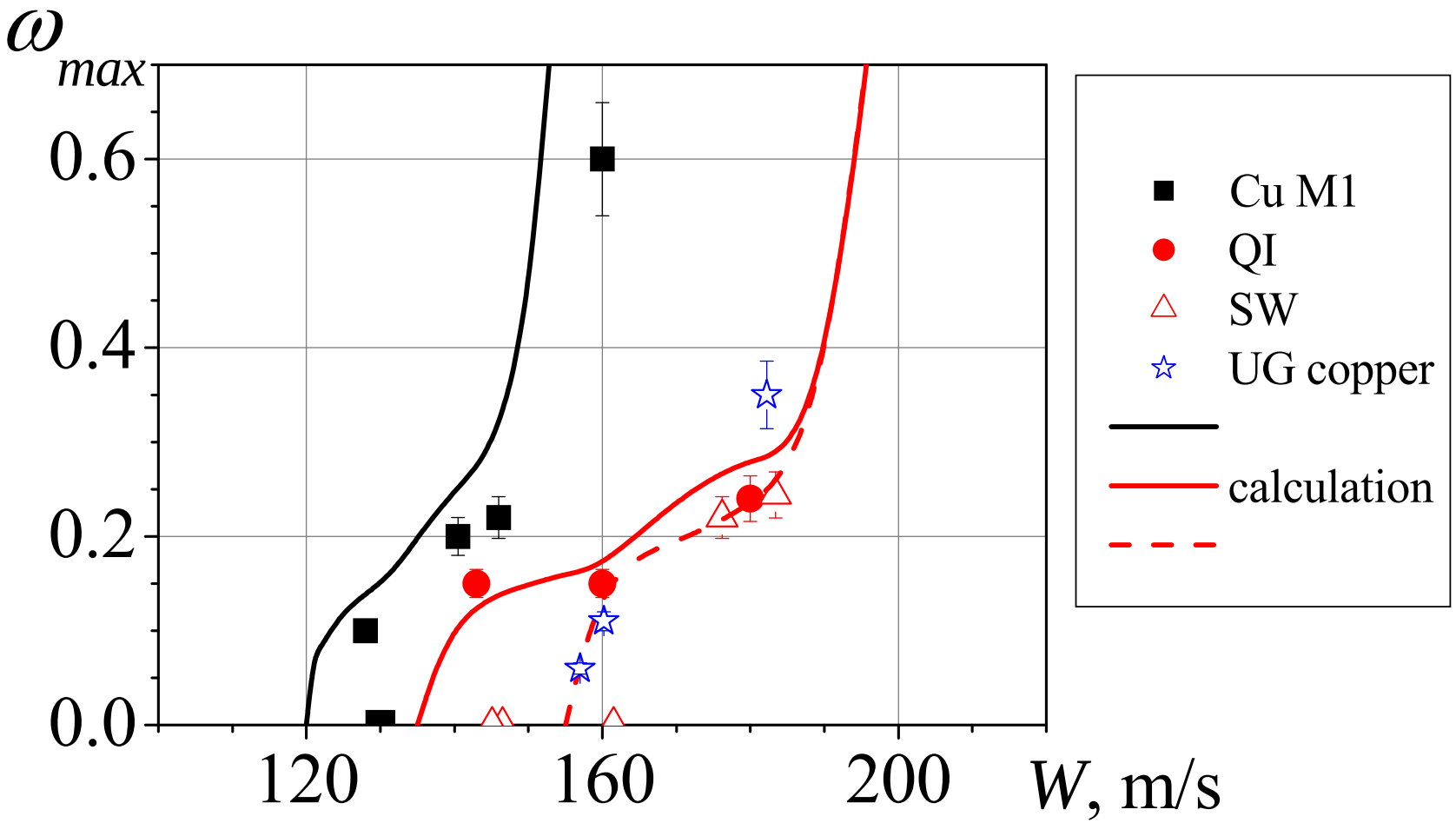
b) W=161 m/s,



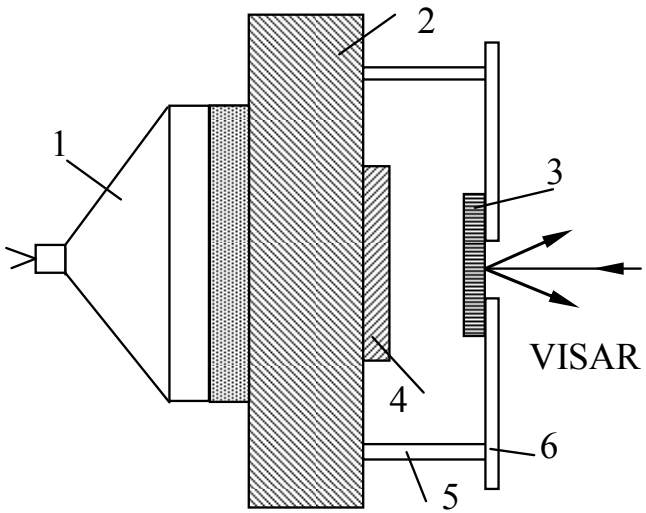


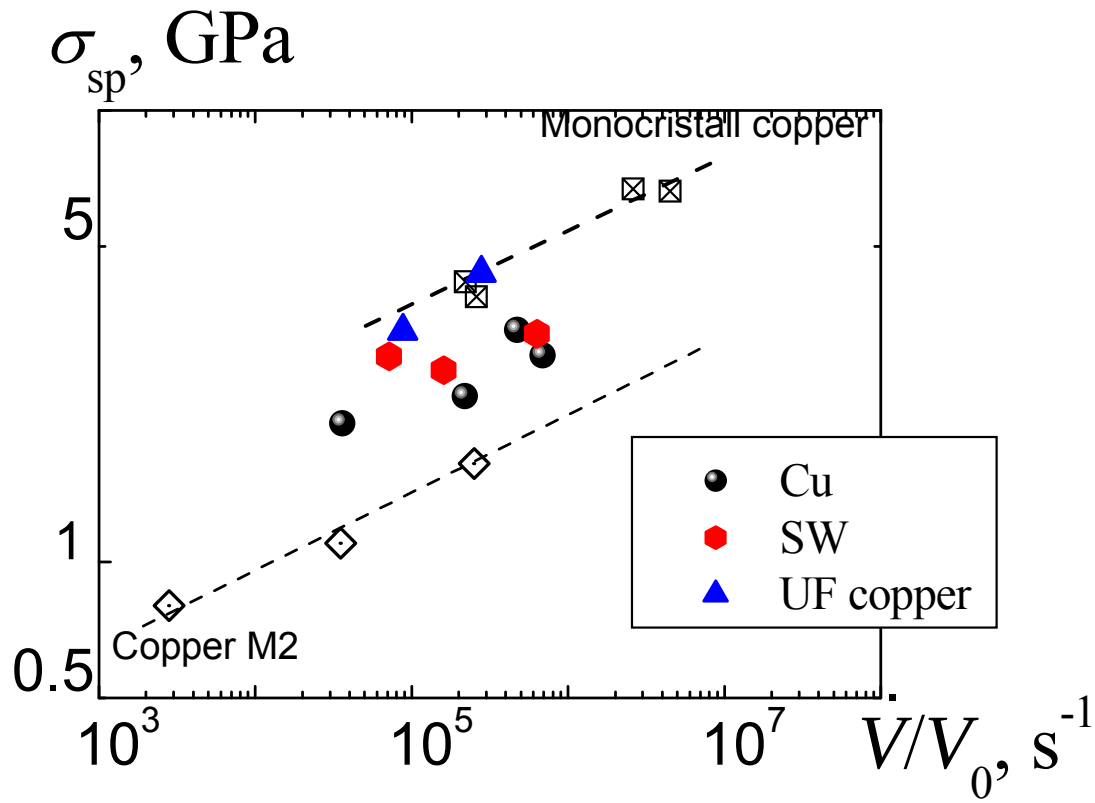
c) W=160 m/s.

Microsection for copper loaded to initial state (a) after SW (b) and QI (c) loading


ω_{max}
0.6
0.4
0.2
0.0
120
160
200
W, m/s
Cu M1
QI
SW
UG copper
calculation

Examination of the unloading wave structure after the sample explosive to shock wave





Conclusion

The studies performed enable us to make principal conclusion as follows.

The preliminary SW and QI loading significantly affect the microstructure and mechanical properties in coarse scale

bcc metals:

•one observes many of microtwins,

•the increase in dislocation density by a factor of three,

•a 5-6 fold increase of the nominal yield stress and the enhancement of ~20% of the metal response to tensile stress?

•under the action of SW of more than 60 GPa, the copper sample undergoes annealing that results in recovery of mechanical properties to their original state.

fcc metals

• slightly changes their internal microstructure and dislocation density,

•variation in tantalum grain size up to 1 μm does not in effect lead to the improvement of its mechanical properties.

The date obtained are used to develop wide range models of shear and spall strength of bcc and fcc metals.

Acknowledgements

The work has been carried out under the auspices of the

- LANL: Contract № 37713-000-02-35 TO 021;

- RFFI: Project № 08-02-00087a.