Using micron-scale hypervelocity impact crater morphologies to validate the ultra-high strain rate strength of Tantalum.

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Introduction

We have used the complementary results of light gas gun (LGG) experiments and hydrocode modelling to validate the very high strain rate behaviour of high purity (99.85%) tantalum. Samples of monodisperse silica and sodalime glass spheres with diameters between 2 – 50 µm were fired onto tantalum targets at a velocity of approximately 6 km s^{-1}. Precise measurements were made of the resulting crater diameter and depth (where possible) using a scanning electron microscope (with a resolution of a few tens of nm) combined with 3-D stereo imaging. Hydrocode modelling was then performed using a strength model derived from literature values of yield stress vs. strain rate in order to reproduce the measured crater dimensions.

Method

Shots were performed using the two-stage LGG at the University of Kent [1]. Projectile materials were monodispersive silica and sodalime glass spheres commercially available from Whitehouse Scientific (UK) and Micromod (Germany). SEM/EDX imaging of the foils was carried out at the Natural History Museum. Craters were measured following the method of [2]; crater diameters were defined as the distance from top of the crater lip to top of the diametrically opposed crater lip. Two measurements were made for each crater to minimise error.

Results

Table 1: Shot IDs; notional (as labelled) projectile diameters, **d;** projectile diameters ('slg' denotes sodalime glass), $\mathbf{D_p}$, (as measured); and crater diameters, $\mathbf{D_c}$; standard deviations of the distributions, **σ**; number of craters measured, **N**; and the impact velocity, **v**; from the LGG shots. The crater depth datum (in '[ ]'s) for the 22 µm impactors was obtained from stereo image analysis utilising Alicona's *MeX* software. 35 µm impactor craters were measured with an optical microscope.

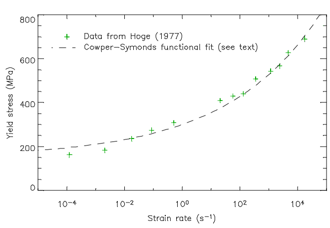
Shot ID	d (µm)	D_p ±σ (µm)	D_c ±σ (µm)	N	V (km s^{-1})
G220709#1	1	1.94 ± 0.16	3.38 ± 0.78	5	6.15
G110909#1	4	4.04 ± 0.17	6.38 ± 0.85	4	5.89
G240909#2	6	6.39 ± 0.33	10.75 ± 1.10	34	5.61
G110909#1	11.58 slg	9.84 ± 2.23	20.7 ± 3.99	15	5.89
G220709#1	22.8 slg	21.87 ± 0.92	54.69 ± 2.88 [14.21 ± 1.24]	20 [3]	6.15
G080210#3	35 slg	34.72 ± 1.01	90.88 ± 6.57 (optical data)	20	6.39

Hydrocode modelling

We have used Ansys AUTODYN [3] to model the impacts utilising a custom strength model (described below) and the equation-of-state given in [4] for tantalum. The model was a 2-D, fully Langrangian half-space model with a graded target mesh size of 200(x) x 300(y) with a projectile comprised of 800 cells (equivalent to 40 cells per diameter). In order to replicate the strain rate behaviour of tantalum we incorporated a Cowper-Symonds [5] strength model fitted to the data presented in [6]. The equation below shows the functional form of the yield strength, Y as a function of the strain rate, $\dot{\varepsilon}$. Here Y_o is the quasistatic yield stress, ε is the plastic strain, B is the strain hardening constant, n is the strain hardening exponent, D is the strain rate constant, and q is the strain rate exponent. Fig. 1 (right) shows the experimental strain rate data and line of best fit which give values of D = 1.0 and q = 7.5. The values of B = 500 MPa, n = 0.5 and Y_o = 130 MPa are taken from [7] & [8].

Figure 1 (right): Yield stress vs. strain rate for tantalum with experimental data (green crosses) from [6] and a Cowper-Symonds fit (dashed line and equation below).

$$Y = (Y_0 + B\varepsilon^n)\left[1 + \left(\frac{\dot{\varepsilon}}{D}\right)^{\frac{1}{q}}\right]$$



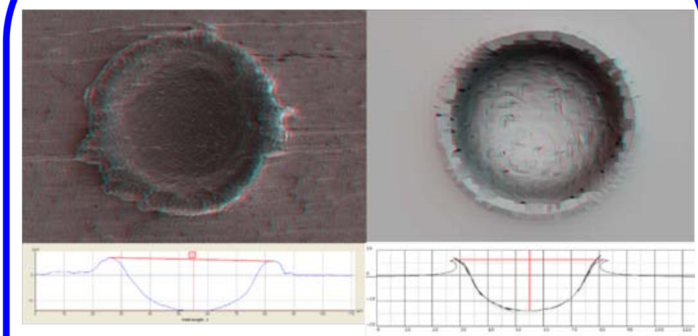


Figure 2: Stereo anaglyphs and depth profiles of a real crater (left) and an AUTODYN (3-D) simulated crater (right). The impactor was a 22 µm sodalime glass projectile impacting at 6.15 km s^{-1}.

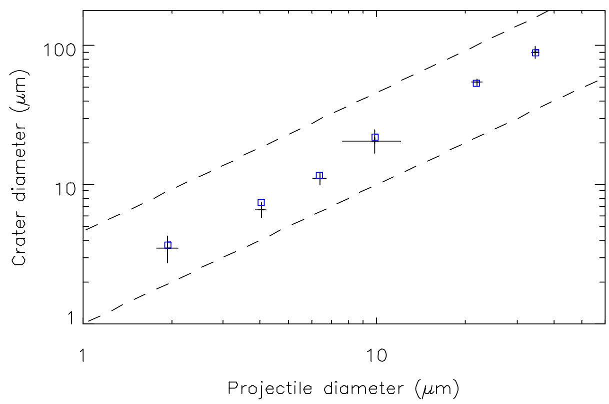


Figure 3: Experimental D_p vs. D_c plus 1-σ uncertainities taken from Table 1 (black lines) and AUTODYN modelled values (blue squares). The upper dashed line shows D_c = 4.6 D_p, the lower dashed line, D_c = D_p.

Discussion & Conclusions

We have used size measurements from impact craters made at accurately measured velocities, and with well known projectile size distributions in tandem with hydrocode modelling to validate the ultra-high strain rate strength dependence of tantalum. We have found that the morphology of the modelled impact craters has a strong dependence on the strain rate behaviour of the target material. Without using the experimentally measured strain rate strength, the models yield crater sizes that deviate markedly from the actual laboratory results. We intend to extend this methodology to other materials to infer their ultra-high strain rate strength where this dependence is not so well measured.

Acknowledgements

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References

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