Elastic Behavior of Zirconia under Ramp Compression

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Abstract. Dynamic properties of single crystal cubic zirconia were investigated under magnetically driven ramp wave compression on pulsed power generator CQ-4. Photonic Doppler Velocimeter (PDV) was employed to measure the free surface velocities of stepped samples. The elastic particle velocity and Ramp Elastic Limit (*REL*) of <100> cubic zirconia under ramp wave compression are 475 m/s and 25.4 GPa respectively, which are much higher than shock results reported in literature. The <110> cubic zirconia was loaded to maximum particle velocity 460 m/s and pressure 20.8 GPa in elastic region, but no distinct elastic-plastic transition was observed. Inverse characteristic method was used to process the velocity data. The results show that the Lagrangian sound speed increases linearly with particle velocity in elastic region, and there exists distinct orientation effects.

1 Introduction

Single crystal cubic zirconia is a potentially useful window for dynamic compression research due to its transparent in 400 nm – 5000 nm spectrum range [1] and relative high mechanical impedance and hardness. Previous shock compression experiments show that single crystal cubic zirconia has obvious anisotropy, and its Hugoniot Elastic Limit (HEL) stresses parallel to the <100> and <110> axes are approximately 14 GPa and 25 GPa respectively [2]. Symmetric impact experiments conducted by Dolan [3] show that in elastic region the shock velocity of <100> cubic zirconia increases linearly with particle velocity, with a slope of 1.40 and intercept of 8.279 km/s. with different amount of doped yttrium, initial properties of zirconia such as density and ambient longitudinal wave speed change slightly.

Despite it has been used as window material in ramp compress-shear loading experiments [4, 5], there are seldom ramp compression results of single crystal cubic zirconia. In this paper, we report mechanical results of <100> and <110> single crystal cubic zirconia to give optimized and critical design when it is used as window material.

2 Experiments

Magnetically driven ramp compression experiments of <100> and <110> single crystal cubic zirconia were conducted on CQ-4 device to investigate the elastic behaviours and yield properties in different orientations. The principle of magnetically driven ramp compression can be found elsewhere [6]. The sketch map of target is shown in Fig. 1, four samples arrangement is used in experiments. Aluminum stripe lines conductors with 8mm width were used as electrode, and zirconia samples were glued on the bottom of counter bore in electrode. A Photon Doppler Velocimeter (PDV) was employed to measure the free surface velocity of cubic zirconia samples, and the velocity profiles are shown in Fig. 2.

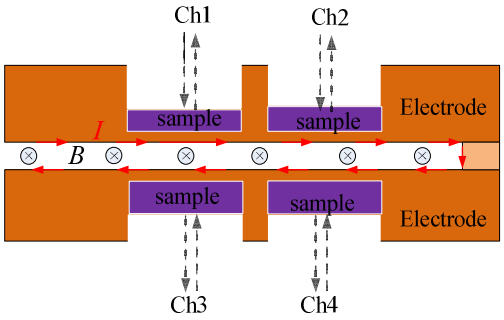

Fig. 1. Sketch map of target region.

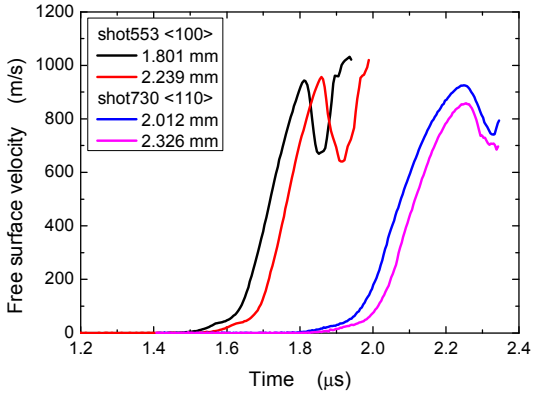

Fig. 2. Free surface velocity profiles of single crystal cubic zirconia under ramp compression.

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3 Results and discussion

Under ramp compression, the elastic-plastic transition velocity in <100> orientation is identified by the abrupt drop after elastic loading, and the amplitude is 950 m/s. In <110> orientation, peak velocity of elastic loading followed by smooth drop means that rarefaction wave affected the loading process, indicating elastic-plastic transition velocity in <110> orientation is above 920 m/s. Particle velocity at ramp elastic limit (REL) in <100> orientation is 475 m/s, which is much higher than the value at HEL 270 m/s measured by Tsutomu Mashimo[2]. However, the particle velocity at REL in <110> orientation (above 460 m/s) may be consistent with the value at HEL 510 m/s.

Inverse characteristic method was used to explore the Lagrangian sound speed (C_L) versus particle velocity (up) relation from stepped sample velocity profiles. The results are shown in Fig. 3. In elastic region, Lagrangian sound speed of <100> cubic zirconia increases linearly with particle velocity, with a relation of C_L=8.26+ 3.20u_p. The intercept is consistent with the results reported by Dolan 8.279 km/s [3] and Tsutomu Mashimo 8.231 km/s [2]. The slope 3.20 is larger than twice of 1.40 reported by Dolan under shock compression [3]. In <110> orientation, Lagrangian sound speed versus particle velocity have relation as C_L=7.24+ 1.81u_p. The REL of single crystal cubic zirconia can be calculated as

$$REL = \rho_0 \int_0^{u_{ins\_ep}} C_{el}\, du \qquad (1)$$

where ρ_0 is initial density of material, C_{el} is elastic longitudinal sound speed, u_{ins_ep} is elastic limit of particle velocity. With a linear relation of C_L and u_p, calculated REL of <100> and <110> zirconia are 25.4 GPa and above 20.8 GPa respectively. The REL of <100> zirconia is larger than the HEL 14GPa reported in ref [2] , while the REL of <110> zirconia may be close to the HEL 25 GPa. The Poisson's ration of <100> cubic zirconia calculated from ultrasonic data in ref [2] is 0.414, and the strength of <100> zirconia calculated from Y =(1-2ν)/(1-ν)REL is 7.3 GPa.

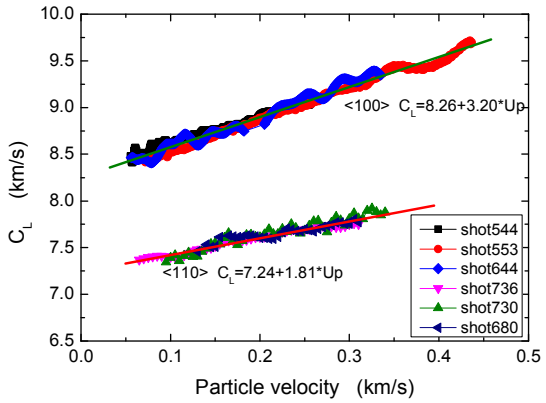

Fig. 3. Lagrangian sound speed versus particle velocity relation of <100> and <110> cubic zirconia.

4 Conclusions

Ramp compression experiments were conducted on CQ-4 device to study the elastic properties of single crystal cubic zirconia. The ramp elastic limit of <100> cubic zirconia is 25.4 GPa, with elastic velocity amplitude 950 m/s in free surface velocity. In free surface velocity of <110> cubic zirconia up to 920 m/s, no distinct elastic-plastic transition is observed. The ramp elastic limit of <110> cubic zirconia is estimated to be above 20.8 GPa. In elastic region, the Lagrangian sound speed C_L of <100> and <110> cubic zirconia increase linearly with particle velocity u_p. For <100> cubic zirconia, C_L=8.26+ 3.20u_p, for <110> cubic zirconia, C_L=7.24+ 1.81u_p.

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