EPJ Web of Conferences **94**, 02002 (2015)
DOI: 10.1051/epjconf/20159402002

Beryllium strain under dynamic loading

Victor Pushkov[1,2,a], Alexey Yurlov[1,2], Andrew Okinchits, and Tatiana Naydanova[1]

[1] Russian Federal Nuclear Center - VNIIEF, 607190, Sarov, Nizhniy Novgorod region, Russia
[2] Sarov Physico-Technical Institute NIYaU MEPhI, 607186, Sarov, Nizhniy Novgorod region, Russia

Abstract. There are some data (not much) on dynamic characteristics of beryllium that are important, for example, when estimating construction performance at NPP emergencies. A number of data on stress-strain curves, spall strength, shear strength, fracture and structure responses of shock loaded beryllium have obtained in US and Russian laboratories. For today the model description of this complex metal behavior does not have a reasonable agreement with the experimental data, thus a wider spectrum of experimental data is required. This work presents data on dynamic compression-test diagrams of Russian beryllium. Experiments are performed using Hopkinson bar method (SHPB). Strain rates were $\dot{\varepsilon} \sim 10^3\,\mathrm{s}^{-1}$.

1. Introduction

Beryllium has an asymmetric hexagonal close-packed (hcp) lattice and has a number of unique properties: the highest (among all other metals) specific strength and heat capacity [1]. The combination of low density, high modulus of elasticity, strength and heat conductivity makes beryllium needed in aeronautical and space engineering [2]. Due to small beryllium atomic mass, small capture cross section and radiation resistance, it is one of the best materials for reflectors and moderators in nuclear engineering [2]. However, data on its mechanical properties are mainly obtained at static loading. There are some data (not much) on dynamic characteristics of beryllium that are important, for example, when estimating construction performance at NPP emergencies. A number of data on deformation curves for different types of beryllium, in particular S200F (USA) at strain rates $\dot{\varepsilon} = 1500 - 8000\,\mathrm{s}^{-1}$ are given in [3,4]. For the same type of beryllium, mechanical characteristics at higher strain rates $\dot{\varepsilon} = 10^4 - 10^5\,\mathrm{s}^{-1}$ (spall strength) [4,5] as well as fracture and structure responses of shock loaded beryllium [6] are known. In [7–9] the data are given on investigation of spall and shear strength of Russian beryllium at strain rates $\dot{\varepsilon}\cdot \sim 10^4 - 10^5\,\mathrm{s}^{-1}$ using various methods.

Researchers perform a model description of beryllium behavior under dynamic and shock-wave loading, e.g. [4–6]. For today the model description of this complex metal behavior does not have a reasonable agreement with the experimental data [4], [6], thus a wider spectrum of experimental data is required.

This investigation provides data on dynamic compression-test diagrams of Russian beryllium. Experiments are performed using Hopkinson bar method (SHPB). Strain rates were $\dot{\varepsilon} \sim 10^3\,\mathrm{s}^{-1}$.

2. Experimental

Beryllium is prepared using the method of hot vacuum pressing [1], [7] with addition of preprepared beryllium powder. Beryllium density is $1,85\,\mathrm{g/sm}^3$, Be content is > 98 weight %, $O_2 \sim 1{,}5$ weight%, other major impurities are Fe and C, and grain size is $\sim 50\,\mu\mathrm{m}$.

Experiments were performed using the SHPB method at strain rates $1000–1600\,\mathrm{s}^{-1}$. The experimental setup is given in Fig. 1.

The bars were made of titanium BT-20 (Ø20 × 1500 mm), samples had the size Ø10 × 7 mm.

3. Results

Figure 2 presents dynamic "σ-ε" compression-test diagrams of Be based on experimental results. It is obvious from Figure 2 that Be has considerable strain hardening. The degree of hardening is 7,5–12,0 GPa/rel. units, which is close to data in [3]. In tests 1–5 samples did not fail, the residual strain measured after tests was $\varepsilon_{res} = 4{,}3–9$ %.

Dynamic "σ-ε" compression-test diagrams of Be were used to determine yield strength values presented in Table I. The yield strength dependence on strain rate was not revealed within the range of $\dot{\varepsilon} = 1000–1600\,\mathrm{s}^{-1}$.

In terms of the behavior of diagrams and the values of strength yield $\sigma_{0.2}$, beryllium is very similar to preloaded (P = 59 GPa) uranium [10]. However, the values $\sigma_{0.2}$ are considerably higher than in [3].

In test No. 6 at $\dot{\varepsilon} = 1280\,\mathrm{s}^{-1}$, the sample failed; Be strength yield was $\sigma_в = 1490$ MPa, the residual strain was 9%. Failure behavior was quasi-brittle.

Figure 3 presents a photo of the damaged sample in test No. 6.

In test No. 4 the sample deformed by ∼ 7,5%. The sample from test No. 4 was subjected to the secondary compression at the strain rate $\dot{\varepsilon} = 1150\,\mathrm{s}^{-1}$. Diagrams of Be double dynamic compression are provided in Fig. 4. In the second test the sample failed. In that case Be strength was $\sigma_в = 1450$ MPa.

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[a] Corresponding author: `postmaster@ifv.vniief.ru`

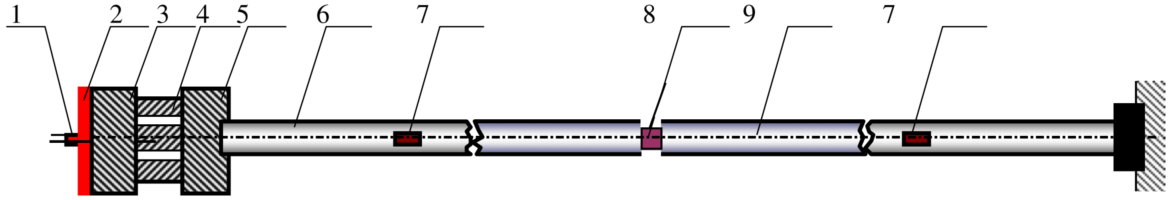

Figure 1. Experimental setup. 1,2 – HE; 3 – impactor; 4 – aluminum damper; 5 – connecter; 6 – loading bar; 7 – strain gauges; 8 – sample; 9 – support bar.

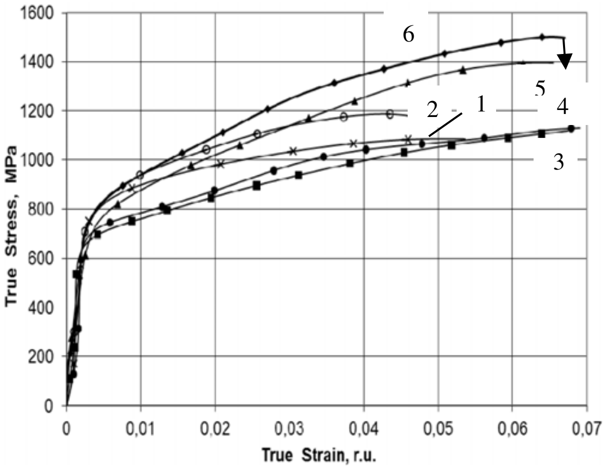

Figure 2. Be dynamic compression-test diagrams at various strain rates. 1 – $\dot{\varepsilon} = 1600\,\mathrm{s}^{-1}$; 2 – $\dot{\varepsilon} = 1000\,\mathrm{s}^{-1}$; 3 – $\dot{\varepsilon} = 1550\,\mathrm{s}^{-1}$; 4 – $\dot{\varepsilon} = 1200\,\mathrm{s}^{-1}$; 5 – $\dot{\varepsilon} = 1250\,\mathrm{s}^{-1}$; 6 – $\dot{\varepsilon} = 1280\,\mathrm{s}^{-1}$.

Table 1. Be yield strength values.

Test No.	Strain rate $\dot{\varepsilon}$, s^{-1}	Yield strength $\sigma_{0.2}$, MPa	Yield strength average value $\sigma_{0.2}$, MPa	Yield Strength $\sigma_в$, MPa
1	1600	790	772 ± 43	
2	1000	810		
3	1550	720		
4	1200	730		
5	1250	765		
6	1280	815		1490

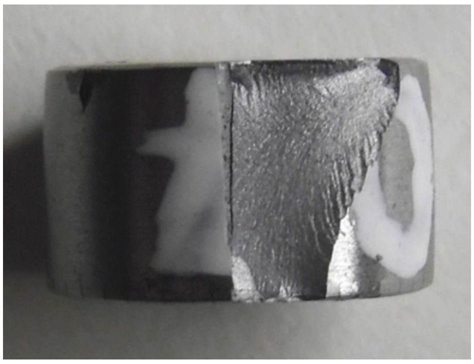

Figure 3. Fracture pattern of the sample in test No. 6.

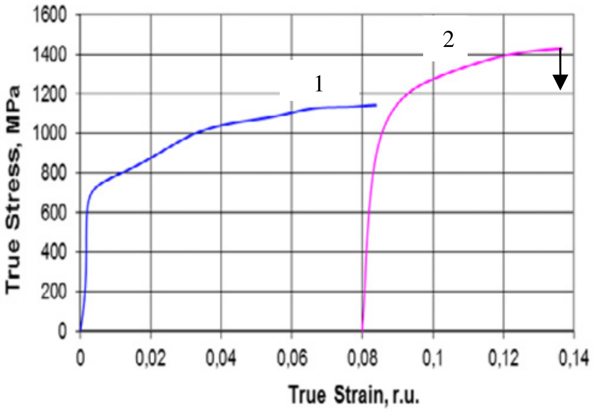

Figure 4. Diagrams of sequential double compression of beryllium at $\dot{\varepsilon} = 1200\,\mathrm{s}^{-1}$ (1) and $\dot{\varepsilon} = 1150\,\mathrm{s}^{-1}$ (2).

4. Conclusion

Using SPHB method, dynamic compression "stress-strain" diagrams of Russian beryllium were examined. Beryllium was prepared using the method of hot vacuum pressing with admixture of preprepared beryllium powder. Experiments were made at strain rates of 1000–1600 s^{-1}. Obtained data will be useful for testing the available models of Be behavior and developing new ones which describe Be behavior under various loading, including those typical for accidents in nuclear engineering, more adequately.

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