Materials Physics and Mechanics 26 (2016) 23-25 Received: October 20, 2015

EXPERIMENTAL AND NUMERICAL INVESTIGATIONS OF THE SCALE LEVELS IN SPALL FRACTURE OF D16 ALUMINUM

A.E. Mayer[1], S.A. Atroshenko[2], E.N. Borodin[1-3*]

[1]Chelyabinsk State University, Br. Kashirinykh 129, Chelyabinsk, 454001, Russia

[2]Institute of Problems of Mechanical Engineering of RAS,

Bolshoj pr. 61, V.O., St. Petersburg, 199178, Russia

[3]Ural Federal University, Mira str. 19, Ekaterinburg, 620002, Russia

*e-mail: elbor7@gmail.com

Abstract. Results of microstructural investigation of the D16 aluminum spall surface are presented in comparison with the numerical simulation of the fracture process. A fracture model based on the plasticity driven growth of voids is used in simulation. Different scale levels of fracture are discussed, and the main level of fracture is attempted to be allocated, which is about 1–5 micrometers in the investigated case.

1. Introduction

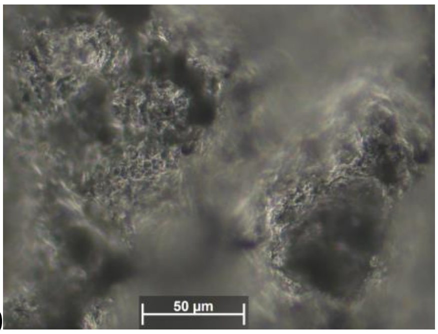
Fracture of metals is a multiscale process with several significant scale levels [1]. Simulation of the spall fracture requires the modeling of a shock wave reflection from the rear surface of sample with accounting of the metal plasticity, as well as the modeling of the formation and subsequent growth of a number of micro-voids, which unite into a main crack in the end that leads to separation of a spall plate. Structural models of plasticity [2, 3] and fracture [2] allow one to perform such simulations. For additional verification of these models, detailed microstructural investigations of fracture surfaces are required.

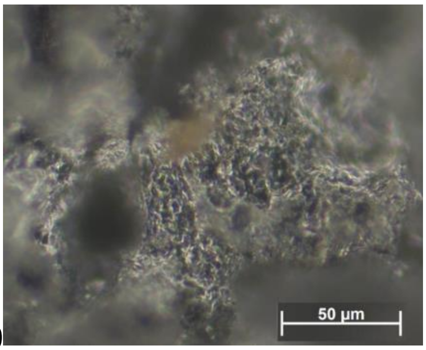
2. Results of microstructural investigations

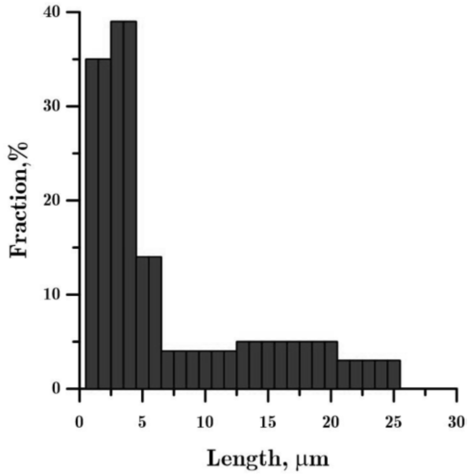
Dynamic tests were performed by Yu.I. Mescheryakov with coworkers [4] using the gas gun. Aluminum impactors 1.8-1.9 mm in thickness and 30 mm in diameter strike D16 aluminum samples 4.5-12 mm in thickness and 50 mm in diameter with velocities 271-434 m/s. The rear spallation occurs at the impact velocities above 290 m/s with separation of spall plate with thickness of 1-2 mm depending on the sample thickness. We performed the microscopic examination of the formed fracture surfaces using the Axio-Observer-Z1-M microscope with magnifications from 50 to 1000. Viscous cavities and other elements of the fracture surface structure on various scale levels were observed and measured in size (see Fig. 1).

There are not-in-plane elements of large-scale structure with sizes 100–400 μm, protruding above the fracture surface and often elongated. There are both viscous and brittle fracture areas with predominating of viscous one (Fig. 1(a)) near the fracture surface and predominating of brittle one (Fig. 1(b)) on the protruding parts of the large-scale structure elements. The following scale level consists of elements with sizes 10–80 μm, which are seen as dark spots at low magnification. Higher magnification reveals inside them the smaller pits of viscous fracture with sizes 1–7 μm (Fig. 1(a)); brittle fracture takes place between these pits. Fig. 1(c) shows the histogram of size distribution of fracture elements on this scale level that is the smallest level available for optical microscopy. Most of elements have sizes less than 5 μm.

The finer elements with sizes less than 1 µm are also seen, but this structure cannot be properly investigated by means of optical methods.

(a)


(b)




(c)

Fig. 1. (a,b) Micrographs of the D16 aluminum fracture surface with (a) predominantly viscous and (b) predominantly brittle fracture. (c) Histogram of size distribution of the microstructure elements on the fracture surface.

3. Numerical simulation of spall fracture

Numerical simulation was performed by means of the finite-difference code [5] that takes into account the dislocation plasticity model [2, 3] and a fracture model based on the equation of the plasticity driven growth of voids [6] and the equation of voids nucleation by means of thermal fluctuations similar to [2].

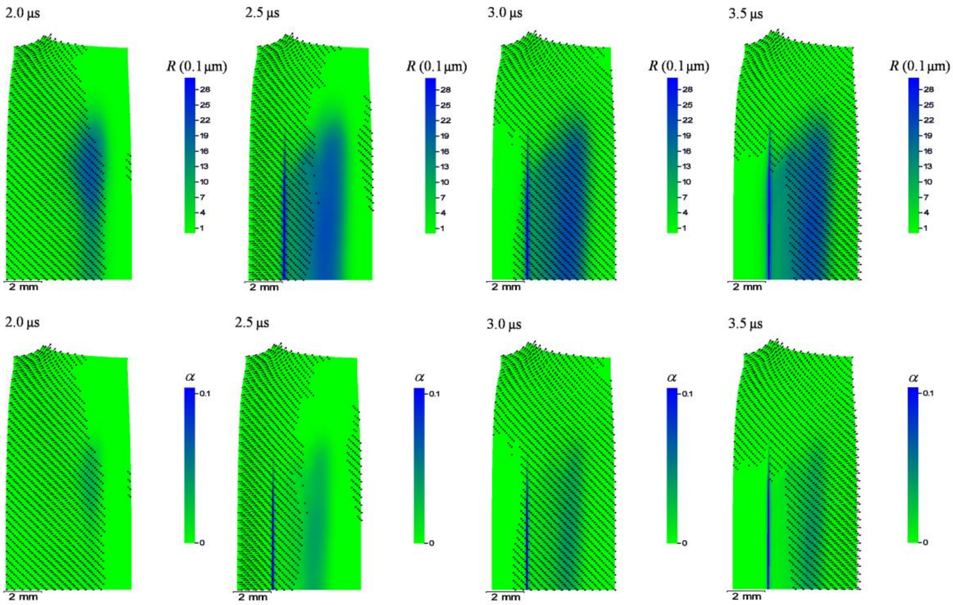


Fig. 2. Spatial distributions of diameters and volume fraction of voids: impact velocity is 329 m/s, impactor thickness is 1.9 mm; sample thickness 4.5 mm. The sample and impactor radii are 12 mm, which is less than in the experiments.

The fracture model has a sole parameter that is the surface energy controlling the voids nucleation. This parameter was preliminary determined by means of comparison with the experimentally determined back surface velocity profiles [7]. Figure 2 shows an example of simulation results: the calculated diameters of voids are 1-5 μm; voids of similar sizes are experimentally observed on fracture surfaces.

4. Conclusions

The microstructural investigations revealed at least 4 scale levels on the D16 aluminum fracture surfaces: i) the macrolevel with fragments sizes 100–400 μm; two average levels with elements sizes 10–80 μm and 1–7 μm, respectively; and the microlevel with the elements sizes less than 1 μm. These levels are often embedded in each other: the elements of smaller level are the parts of surface of the larger elements. The numerical simulations can be used in order to reveal the primary level of fracture. Our simulation shows that the voids with sizes of about 1-5 μm leads to the viscous fracture that agrees with the experimental results.

Acknowledgments

The work is supported by the Russian Science Foundation (Project No. 14-11-00538).

References

[1] M.A. Meyers, *Dynamic Behavior of Materials* (Wiley, New York, 1994).

[2] A.E. Mayer, K.V. Khishchenko, P.R. Levashov, P.N. Mayer // *Journal of Applied Physics* **113** (2013) 193508.

[3] E.N. Borodin, A.E. Mayer // *International Journal of Plasticity* **74** (2015) 141.

[4] Yu.I. Mescheryakov, A.K. Divakov, In: *Shock Compression of Condensed Matter- 2003*, edited by M.D. Furnish, Y.M Gupta, and J.W. Forbes (American Institute of Physics, Melville, New York, 2004), p. 587.

[5] A.E. Mayer, E.N. Borodin, V.S. Krasnikov, P.N. Mayer // *Journal of Physics: Conference Series (JPCS)* **552** (2014) 012002.

[6] V.S. Krasnikov, A.E. Mayer // *International Journal of Plasticity* **74** (2015) 75.

[7] G.I. Kanel, S.V. Razorenov, A.V. Utkin, K. Baumung, *Experimental Profiles of Shock Waves*, Preprint of IVTAN RAS (LNT RAS, Moscow, 1996).