Quantitative analysis of microcracks ensemble induced by shock-wave loading of metallic targets (vanadium and iron).

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Abstract Results of analysis of microstructure evolution of metallic samples (vanadium and iron) subjected to shock-wave loading are presented. The influence of loading velocity both on predominant mechanisms of structure deformation and fracture as well as regularities of microcracks ensemble evolution is investigated.

Keywords shock-wave loading, spall, microstructure analysis

1. Introduction

Understanding the material behavior under shock-wave loading has been paid a much attention for several decades because of its both practical and theoretical issues. Experimental results obtained till nowadays reveal highly complicated character of spall fracture. Changes of microstructure of material is one of the key factors among others, which reveals in nucleation, growing and coalescence of microcracks and microvoids, recrystallization processes, ets. It is not trivial problem to consider several microstructure mechanisms, for example nucleation and growing of recrystallized grains and evolution of defects (cracks, microvoids). Different kinetic models of metal behavior under dynamic loading usually use quantitative parameters characterizing size, shape or orientation of defects (microcracks or microvoids) in order to describe the role of microstructure. However there is still a big gap between experimental data and modeling results since the lack of complex information about kinetics of fracture and defect distribution corresponding to different loading rates. In the current work results of experiments on shock-wave loading of metallic targets are presented and microdefects evolution regularities during spall formation are discussed.

2. Experiment

Shock-wave loading of flat metallic samples was carried out one stage gas gun. Using of coarse-grained vanadium and polycrystalline iron as a target material allowed us to investigate deformation and fracture behavior of single crystallites (on vanadium samples) as well as typical polycrystalline metal behavior (iron samples). Dimensions of cylindrical samples and corresponding mean grain size are presented in table 1. In order to obtain different loading conditions, velocity of accelerated plate-projectile was varied in the interval 230… 375 m/s which is slightly above the velocity at which spallation occurs. Analysis of spall surface and inner microstructure changes was made with using of SEM (Quanda 600) and digital optical microscope Hyrox 7700. Preparation for investigation of inner microstructure included mechanical polishing and etching of sample sections made along the loading direction.

Table 1. Dimensions of samples

Material	Diameter, mm	Thickness, mm	Mean grain size
Vanadium	200	5	4 mm
Iron	200	10	50 mkm

3. Fracture surface analysis

Figure 1 represents the microphotographs of spall fracture surfaces of two materials under study. A highly coarse-grained structure of vanadium samples allowed one to define boundaries between crystallites (figure 1, left), and study the fracture regularities inside separate crystallites. It was shown that fracture surfaces of such crystallites consist of cleavage facets, ad the fraction of plastic deformation is significantly low (figure 2, left). Evidences of low fraction of plasticity in fracture of vanadium samples were obtained also from measurements of free surface velocity. In the central part of each cleavage facet a crack formation occurs, different stages of such cracks growing were observed. With increasing of projectile velocity relief of cleavage facets becomes smoother, which reflects higher fracture velocity, and the fraction of plastic deformation is getting lower.

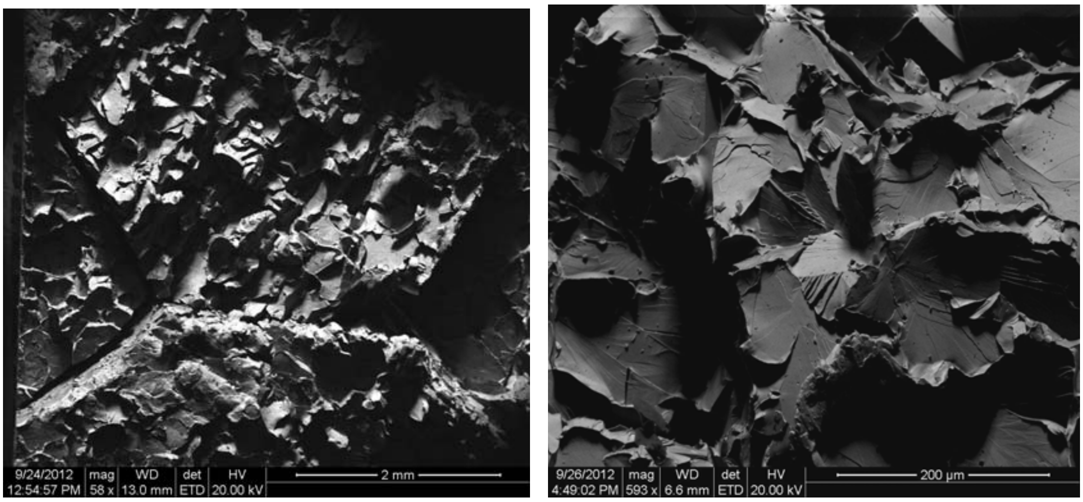

Figure 1. Microphotographs of fracture surfaces of two materials: left - coarse-grained vanadium (projectile velocity 280 m/s), right – polycrystalline iron (projectile velocity 300 m/s).

Fracture surfaces of polycrystalline iron-targets consist of intergranular cleavage facets with more inhomogeneous character because of much lower grain size (figure 1, right). In central part of facets, which size is corresponding to grain size scale, a formation of microvoid is usually occurs. Typical picture of such fracture surface elements is presented on figure 2, right. Increasing of projectile velocity in investigated interval didn’t reveal any qualitative changes in fracture surface relief.

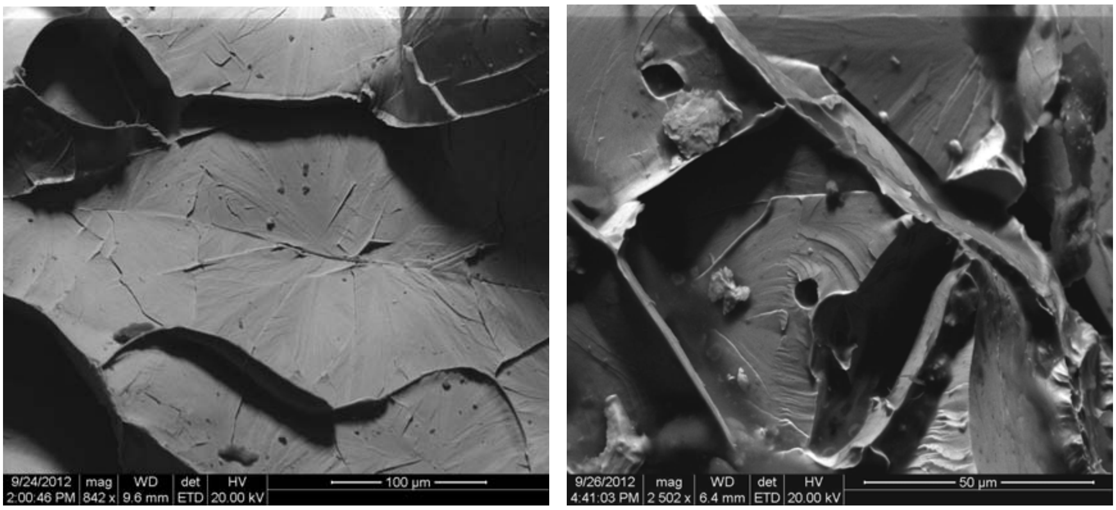

Figure 2. Elements of fracture surface relief on two materials: left picture – vanadium, right picture – polycrystalline iron.

3. Inner structure changes

Increasing of loading velocity for iron samples leads to qualitative changing of structure deformation: in the case of minimum developed projectile velocity there are some separately arranged highly deformed grains (fig. 3, left), whereas the number of such grains in target corresponding to maximum loading velocity is much bigger (fig. 3, right).

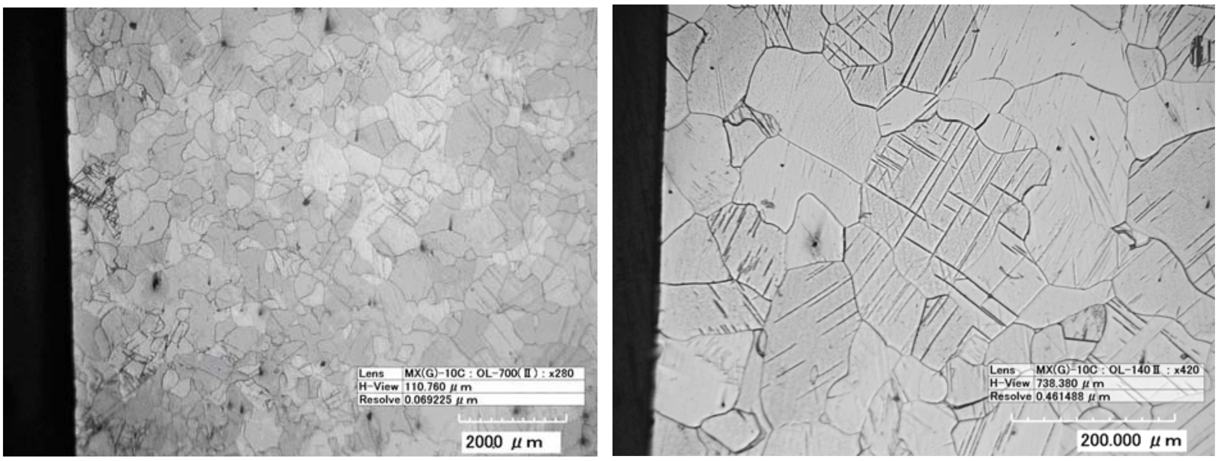

Figure 3. Microstructure near the loaded surface of deformed iron samples corresponding to different projectile velocity: left picture – 230 m/s, right picture – 260 m/s.

Shock-wave loading initiates dynamic recrystallization processes in iron targets. Near the loaded surface dynamic recrystallization usually takes place on grain boundaries, while near the spall area new grains can nucleate on microcracks (fig. 4). Besides, the higher projectile velocity the less deviation of grain size caused by intensive growing of recrystallized grains.

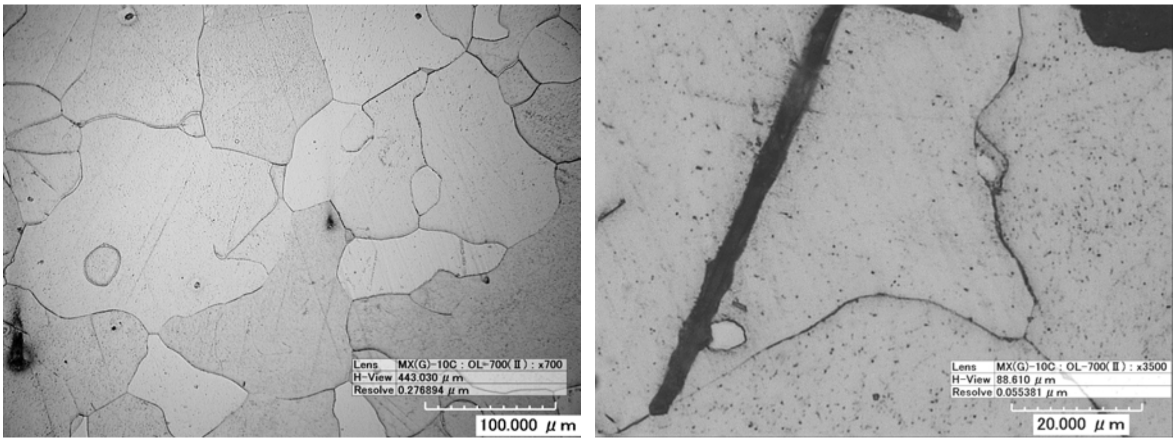

Figure 4. Microstructure of deformed iron samples corresponding to different projectile velocity: left picture – 230 m/s, right picture – 260 m/s.

Another feature of high-speed loading of targets is accumulation of misorientations in subgrain boundaries, resulting in fragmentation of initial grains. Far enough from spall region this transformation of low-angle boundaries to high-angle boundaries has crystallogeometrical character (fig. 5, left) whereas near the spall fracture surface presence of shear mode of deformation is observed (fig. 5, right).

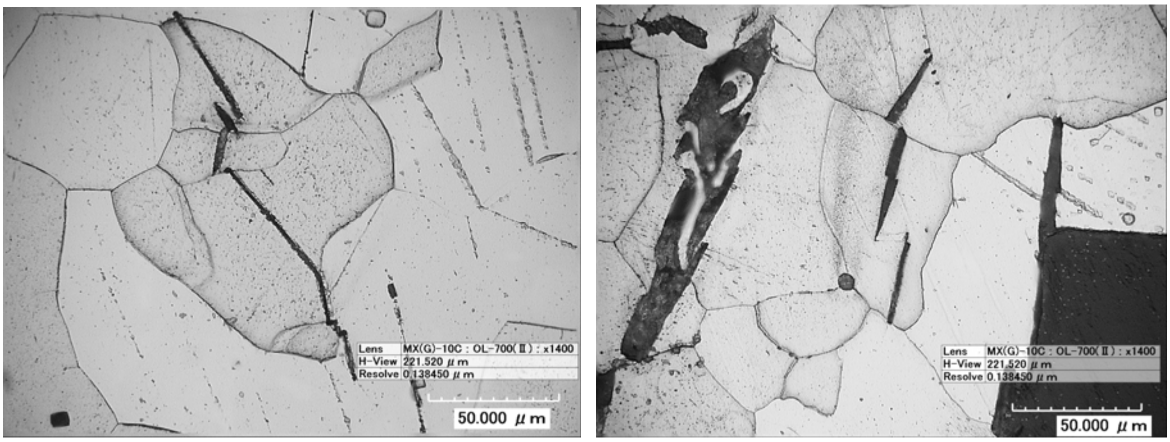

Figure 5. Fragmentation of initial grains: left picture – far from fracture surface, right picture – directly near the fracture surface. Projectile velocity 245 m/s

4. Conclusions

Results of microstructure analysis of metallic samples (coarse-grained vanadium and typical polycrystalline iron) subjected to shock-wave loading of different intensity are presented and structure relaxation mechanisms taking place during such loading in two investigated materials are discussed. An important role of dynamic fragmentation in the case of iron samples was established. Obtained data will be used for quantitative analysis of structure changes under high-speed loading of different intensity.

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