Materials Science & Engineering A 695 (2017) 230–238

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

# Dislocation density and mechanical threshold stress in OFHC copper subjected to SHPB loading and plate impact

Qiushi Hu[a], Feng Zhao[a,*], Hua Fu[a], Kewu Li[a], Fusheng Liu[b]

[a] National Key Laboratory of Shock Wave and Detonation Physics, Institute of Fluid Physics, China Academy of Engineering Physics, Mianyang, Sichuan, 621900, China
[b] Key Laboratory of Advanced Technologies of Materials, Southwest Jiaotong University, Chengdu, Sichuan, 610031, China

ARTICLE INFO

*Keywords:*
OFHC copper
SHPB
Momentum trapping
X-ray diffraction
Dislocation density
Mechanical threshold stress

ABSTRACT

The dislocation density and mechanical threshold stress (MTS) of oxygen-free high-thermal-conductivity (OFHC) copper loaded at strain rates in the range of $10^2$ to $10^6\ s^{-1}$ were measured. Moderate-strain-rate ($10^2$ to $10^4\ s^{-1}$) experiments were performed using a Split Hopkinson Pressure Bar (SHPB). A steel collar was placed around each specimen to control the maximum loading strain. High-strain-rate ($10^5$ to $10^6\ s^{-1}$) experiments were carried out using a 57-mm-bore single-stage gas gun. The radial release effect was eliminated using the momentum trapping technique. The loaded samples were recovered, and the dislocation characteristics and dislocation density were determined by X-ray diffraction profile analysis. The fraction of the screw dislocation was found to decrease with increasing loading strain and strain rate. The dislocation density was found to lie between $1.8\times10^{14}$ and $2.2\times10^{15}\ m^{-2}$. Quasi-static reload compression tests were performed on the recovered samples at room temperature. The mechanical threshold stress (or the flow stress at 0 K) was obtained by fitting the reload stress–strain data to the MTS model. The results of analysis of the equivalent strain, mechanical threshold stress, and dislocation density measurements suggest that the relation between the mechanical threshold stress and the dislocation density can be described well by the Taylor relationship.

## 1. Introduction

The dislocation density is an important state variable in constitutive models because it is closely related to the microstructure of plastically deformed materials [1–6]. A variety of methods, such as chemical etching [7–10], transmission electron microscopy (TEM) [11–14] and X-ray diffraction [15–20] have been proposed to evaluate the dislocation density of materials. The TEM method reveals the microstructural information in a very small area of a sample (usually 1 µm × 1 µm scale), and the preparation of TEM sample films is difficult. In contrast, the X-ray diffraction method reveals structural information over a much larger area (usually 1 mm × 1 mm scale), and the specimen preparation is relatively easy. Therefore, X-ray diffraction is the more appropriate method of evaluating the average dislocation density of a bulk specimen. The main principle of the X-ray diffraction method (also referred to as X-ray peak profile analysis) is that the diffraction peaks broaden when the grain size is small or the material contains lattice defects. If only the influence of dislocations on the diffraction peak profile is considered, the analytical expression for the Fourier coefficients of the diffraction profile (denoted by $A$ ($L$)) can be derived. Krivoglaz [21,22], Wilkens [23,24], and Grama [25,26] presented analytical expressions for $A$ ($L$) based on the assumption of a random dislocation distribution, restrictedly random dislocation distribution, and inhomogeneous dislocation distribution, respectively. Balogh examined the validity of Wilkens' theory using the discrete dislocation dynamics method [27]. He found that for specimens with homogeneous dislocation distributions, peak profile analysis yielded good predictions of dislocation densities. Two X-ray diffraction data processing methods, termed Widths and First Fourier Coefficients (WFFC) and Whole-Profile fitting using the Fourier Coefficients (WPFC), were summarised by Ungar in 2001 [28]. These methods have been successfully applied to dislocation density measurements for various materials, such as copper, aluminium, silicon carbide, and silicon nitride [28–33].

To correlate the measured dislocation density with the thermodynamic loading path, it is necessary to design a soft recovery experiment. In a study of the classical Hopkinson bar, Nemat–Nasser developed a new technique that allows a sample to be subjected to a single pulse of pre-assigned shape and duration [34–36]. In a study of plate impact testing, Hartman proposed a tapered plug target structure to protect samples from radial release wave loading [37]. In his structure, the sample was processed into a conical disk and tightly mated to a guard ring. Because the lateral release wave was isolated in the guard ring, the

* Corresponding author.
*E-mail address:* ifpzfeng@163.com (F. Zhao).

http://dx.doi.org/10.1016/j.msea.2017.03.112
Received 5 November 2016; Received in revised form 28 March 2017; Accepted 29 March 2017
Available online 01 April 2017
0921-5093/ © 2017 Elsevier B.V. All rights reserved.

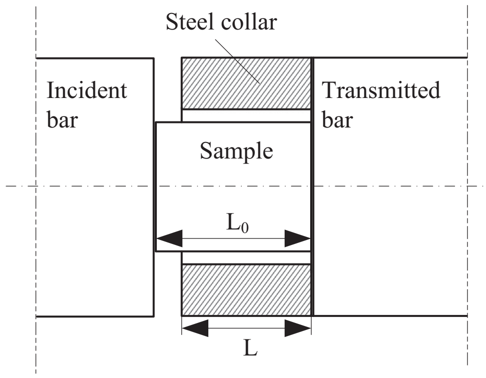


**Fig. 1.** Schematic illustration of the SHPB system.

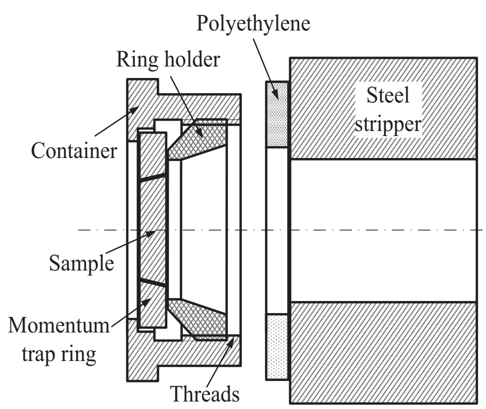


**Fig. 2.** Schematic illustration of the momentum trapping assembly.

sample could experience pure uniaxial strain loading. Gray and Bourne suggested that a spall plate should be placed behind the sample to prevent spallation [38–41]. Orava and Wittman calculated the critical width of the guard ring and the critical thickness of the spall plate [42,43]. Bourne analysed the influence of the number of guard rings and spall plates on the stress state of a sample [44]. Even without a guard ring, the lateral release effect can be eliminated by using a star-shaped flyer. A more detailed description of this technique has been provided by Kumar and Rabie [45,46].

In this study, X-ray diffraction profile analysis was performed to estimate the dislocation density of oxygen-free high-thermal-conductivity (OFHC) copper samples subjected to Split Hopkinson Pressure Bar (SHPB) loading and plate impact. The stress and strain states of the loaded samples were precisely controlled using the soft recovery technique. The results of the X-ray profile analysis were compared with TEM observations. In addition, quasi-static reload compression tests were conducted to study the relationship between the loading path and the reload yield behaviour of the recovered samples. The mechanical threshold stress was determined by fitting the reload compression stress–strain curve to the mechanical threshold stress (MTS) model. Finally, the relations between the measured dislocation density, the mechanical threshold stress, and the equivalent strain were examined.

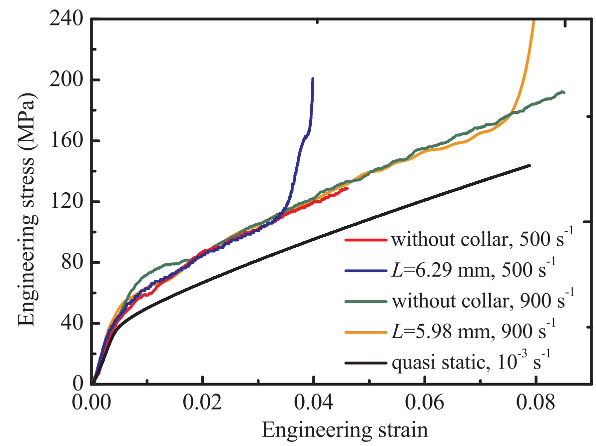


**Fig. 4.** Stress–strain curves of the quasi-static and SHPB tests.

## 2. Experimental details

As-received OFHC copper (99.99% Cu) samples were annealed at 600 °C for 1 h in a vacuum to produce an equiaxed grain structure with an average grain size of 100 µm. The samples were divided into two groups. Those in the first group were loaded to engineering strain levels of 0.032, 0.08, 0.105, and 0.205 (the corresponding logarithmic strain levels being 0.0325, 0.0834, 0.111, and 0.229) using an SHPB apparatus. Those in the second group were loaded to the same logarithmic strain levels of 0.0325 and 0.0834 in plate impact experiments. From the equation $\varepsilon = (4/3)\ \ln(V/V_0)$ [47] and the equation of state, the shock pressures producing logarithmic strain levels of $\varepsilon = 0.0325$ and $\varepsilon = 0.0834$ were calculated to be 3.7 GPa and 10.4 GPa, respectively.

The SHPB apparatus used in this study consisted of a striker bar, an incident bar, a transmission bar, and a measurement system. The bars were made of 20-mm-diameter LY12 aluminium alloy. The lengths of the striker bar, the incident bar, and the transmission bar were 400 mm, 2000 mm, and 1200 mm, respectively. Each cylindrical specimen,

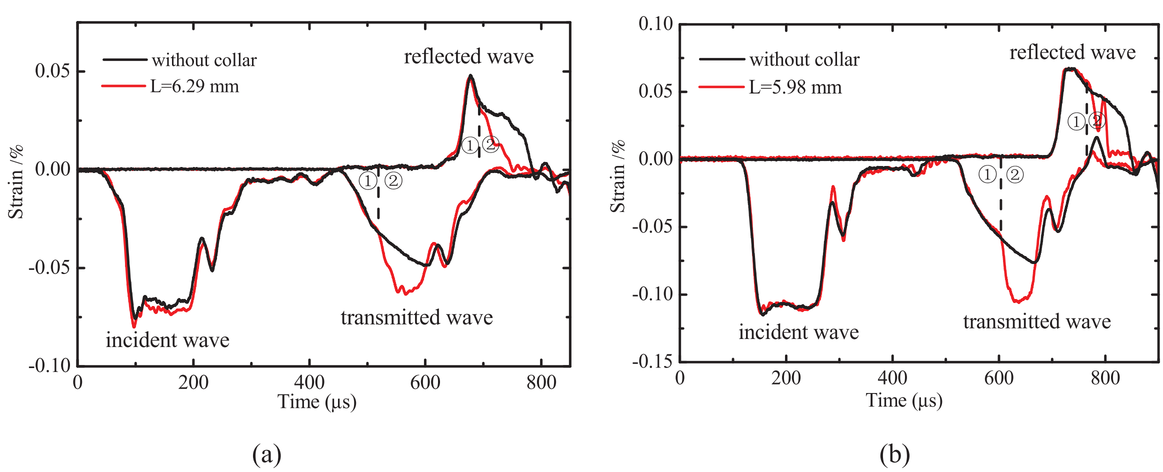


**Fig. 3.** Typical SHPB strain histories at different striker bar velocities: (a) a steel collar with $L$ = 6.29 mm and a striking velocity of 7.4 m/s; (b) a steel collar with $L$ = 5.98 mm and a striking velocity of 11.3 m/s.

Download English Version:

https://daneshyari.com/en/article/5455718

Download Persian Version:

https://daneshyari.com/article/5455718

Daneshyari.com