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Microstructural modifications in α-brass targets after small charge explosions

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Dedicated to the memory of Prof. Riccardo Ferro

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ABSTRACT

Metals exposed to explosions undergo several macro and micro changes. At the microstructural level slip bands or mechanical twins, caused by the pressure and temperature wave, can be detected. Twinning or slip occurs depending on the metal stacking fault energy, the blast wave pressure and the deformation rate. An experimental campaign was performed on different FCC metals. Results concerning α-brass (30% Zn) are presented herein. Specimens exposed to small charge explosion (100 g of plastic explosive) were analyzed by optical and electronic microscopy, by Electron Back-Scattered Diffraction (EBSD) imaging, and by X-ray diffraction. Microstructural plastic deformation marks were detected and their possible attribution, either to mechanical twinning or to cross slip, is discussed on the basis of X-ray diffraction and EBSD results. The detectability target-to-charge distance limit, and hence the critical stress for microstructural changes, are evaluated.

1. Introduction

Effects on metal targets after an explosion include fracture, macroscopic and localized plastic deformations, surface modifications and microstructural crystallographic alterations with ensuing mechanical properties changes [1,2]. At some distance from an explosive charge macro effects vanish; only microstructural variations, such as full or partial surface melting, recrystallization phenomena, intense slip bands and/or mechanical twins, and possibly phase transformations, are present, with the former ones disappearing first as the distance increases. In the case of small charge explosions, macro effects are restricted to very small charge-to-target distances (of the order of tens of millimeters), whereas, at larger distances, most modifications are at the crystallographic level only.

In some forensic science investigations, the above mentioned crystallographic modifications, and particularly the occurrence of twinning, may be among the few remaining clues to a small explosion, and may be useful in hypothesizing the nature and location of the charge.

Competition between slip and twinning is decided by the value of the stacking fault energy (γ_{sf}) of the metals undergoing explosive shocks. Many studies can be found in the literature of the last few decades regarding tests performed in the field of extremely high strain rates and pressures (of the order of tens or hundreds of GPa), that cause twinning phenomena to be clearly apparent [3]. Nevertheless, a systematic analysis of the range of pressures and strain rates which lead to the slip/twinning transition is still lacking, thus preventing a knowledgeable approach to the case of medium to small charge explosions.

By the use of elasticity theory formulations [4] the maximum shear stress arising from the overpressure at the detectability threshold (where overall plastic deformation is absent) can be estimated and results compared with the minimum shear stress necessary to form slip bands or twins [1], in order to try to find correlations between maximum distance of detectability and shock wave overpressures impinging on a metal object.

In order to seek experimental proofs of the validity of the approach, an experimental program has been undertaken to correlate the blast wave properties with the ensuing modifications observed in blast exposed Face Centered Cubic (FCC) metal targets with low to high stacking fault energy values. Results concerning AISI 304 stainless steel, 18 carat gold alloy, OFHC copper, and AA 2014 have already been published [5–7]. Results obtained from α-brass targets are presented herein.

2. Experimental

2.1. Specimens preparation

Disk shaped samples, 20.5 mm in diameter and 3 mm thick, were cut from a rolled and annealed α-brass sheet. The nominal

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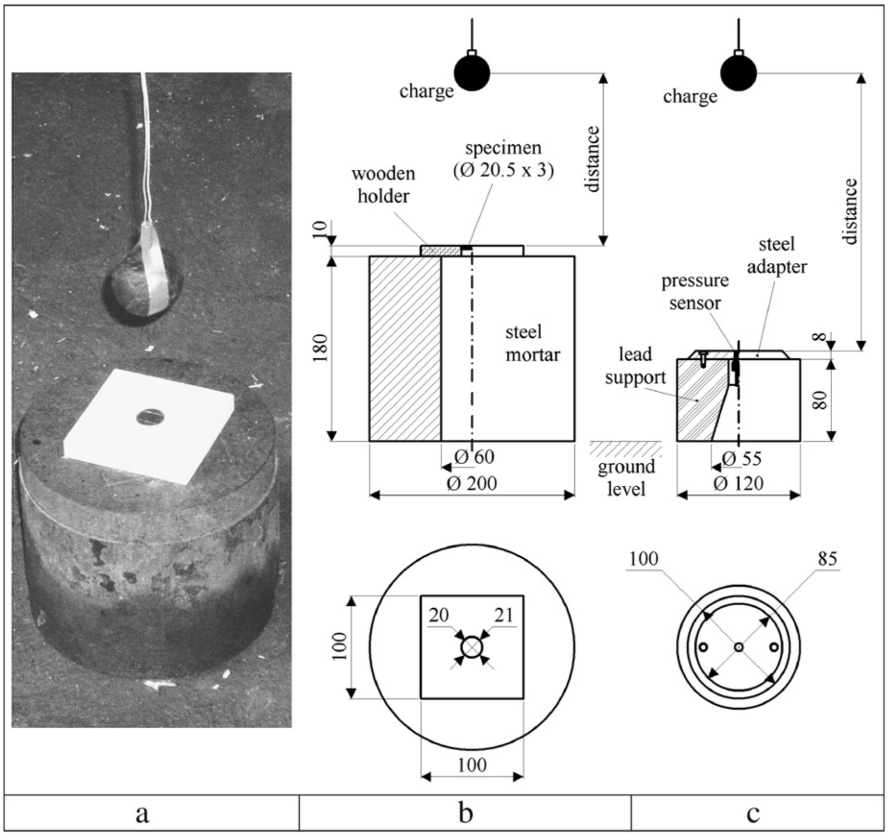

Fig. 1. View (a) and drawing (b) of experimental setup with metal specimens; drawing (c) of experimental setup with pressure sensors (all dimensions are in mm).

composition (wt.%) was Cu 70, Zn 30. The resulting microstructure was fully recrystallized with average grain size of the order of 50 μm.

2.2. Experimental setups and methods

The experimental setups are shown above (Fig. 1) and described in the following. Spherical unconfined charges of plastic explosive (wt.% composition: pentrite 86%, plasticizer 11%, polymer 2%, carbon black 0.45%) were exploded by cylindrical detonators inserted at their cores. The charges were hung from the detonator electrical cables and the samples with previously polished and etched surfaces were placed horizontally below them (Fig. 1a, b). To approximate free-surface conditions on the face not directly exposed to the shock wave, each sample was supported only by a very thin circumferential rim of a wooden sample-holder. The same setup was previously used for all the tested alloys and described in more detail [5,6].

The tests were performed with 100 g charges (TNT equivalent mass: 109 g [5,6]) and with charge-to-sample distances, *d*, in the 70 to 420 mm range (distance between the center of the charge and the sample upper surface).

The sample thickness was measured before and after the tests. The blast exposed surfaces were examined as-such by Optical Microscopy (OM), Scanning Electron Microscopy (SEM), Electron Back-Scattered Diffraction (EBSD) imaging, and X-ray Diffraction (XRD).

2.3. Shock wave properties

For dimensional reasons, the properties of the blast waves depend on the reduced distance, defined as $r = d \cdot m^{-1/3}$, where *m* is the charge's TNT equivalent mass [8,9]. The peak overpressure exercised on the sample's exposed surface, *p*, is estimated (Table 1) either from previous instrumented explosion tests performed in the 0.3–0.88 m kg$^{-1/3}$ reduced distance range [5,6] (Fig. 1c), or from previous literature data concerning the same reduced distance range [9], by considering the pressure increase due to the reflection of the blast wave on the sample [10]. The overpressure rise time was also estimated from experimental results.

In the case of tests at charge-to-target distances close to, or larger than, the microstructural variation detectability thresholds, and causing limited or nil final plastic deformation, the sample stress history can be estimated by using the dynamic elasticity theory. The overpressure rise times are much longer (of the order of 10 μs) than the time needed for a shock wave to travel twice through the sample (about 1.35 μs for an elastic uniaxial-deformation wave). It follows that the stress history of any point inside the sample consists of only one significant pressure rise and pressure decrease (plus negligible oscillations), with an overall maximum value that decreases with the distance from the exposed surface; no relevant negative pressure (i.e. tension) occurs [6]. Thus the maximum shear stress $\sigma_{\max}$ occurs at the most favorable orientation at the exposed surface, and can be calculated according to Meyers [4].

3. Results

3.1. Macroscopic deformation

The specimens' residual deformation has been evaluated by measuring their thickness (t) before and after the explosions with a micrometer caliper (±0.01 mm instrumental uncertainty); Δt values are reported in Table 1.

A slight compressive residual deformation (less than 1%) probably occurred at distances lower than 170 mm, since most