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Analysis of the formation mechanism of the slug and jet center hole of axisymmetric shaped charges

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ABSTRACT

In the jet formation process of axisymmetric shaped charges, the slug is also formed. There is always a central hole in the symmetry axis of the jet and slug. The phenomenon was rarely mentioned and analyzed by the classical theory of shaped charges. For this problem, this paper attempts to explain the existence of the central hole in the jet and slug. Based on the analysis of recovery slug, we know that the jet and slug are in solid state in the process of formation. Through the analysis of X-flash radiographs of the stretching jet and particulation fracture, it is confirmed that the center holes in the jet are also present. Meanwhile, through the analysis of the microstructure of the recovered slug, it is found that there is a wave disturbance near the surface of the central hole. It can be speculated that the wave disturbance also exist in the jet. This effect may be one of the reasons for jet breakup. Due to the presence of the central hole in the jet, the density deficit of the jet obtained by other tests is very reasonable.

Introduction

The mechanism of the jet formation of the shaped charges based on the quasi-steady incompressible fluid theory of the plane symmetry liner collapsed is described by many literatures [1–4]. But in fact, most of the shaped charges are axisymmetric, so the effect of symmetric modes on the formation of the jet and slug must be taken into account.

For the axisymmetric shaped charge, there is always a straight line center hole. But this phenomenon was rarely mentioned and analyzed by classical theory in the literatures [1–4]. In fact, this problem is directly related to understanding the formation mechanism of the jets of the axisymmetric shaped charges, the dynamic yield strength of the liner material under high pressure, the dynamic superplasticity, and whether there is a central hole in the jet. These issues are directly associated with the dynamics properties of the liner materials under extreme conditions. In another word, density variation [5–7] caused by the phenomenon will greatly affect the performance in shaped charges application [8]. To investigate the density variation in shaped charge jet [9–12], the immediate way is to recover jet and identify the composition. And some researchers tried to capture the flying jet in the air by flash X-ray photography and obtain the relative density through the grey level of the image [13]. Other researchers have used the principle of jet exhibiting a deviation in the asymmetric shaped charge to obtain density changes indirectly [14,15]. Meanwhile, it is difficult to observe and measure their dynamics parameters directly and to study these phenomena. The objective of the present investigations on these problems is to study the underlying mechanisms of the jet formation and obtain some beneficial results.

In this study, we obtained the required slug samples by standard shaped charge tests and analyzed them. The mechanisms of the central hole formation and the density deficit of the jet are analyzed theoretically and the results are in good agreement with the test data.

Test results and analysis

The tests used 82 mm standard shaped charges to form jets and slugs and reclaimed the slugs through the water recovery equipment. In order to observe the deformation path of the liner element, the brass nails were embedded into the original liner along the generatrix of liner.

The recovered slug was cut along the symmetry plane, as shown in Fig. 1. The positions of 1, 2 and 3 in the diagram are corresponding to Figs. 3–5, respectively. From Fig. 1, it can be seen that there is a central hole along the axis symmetry and its diameter is about 1

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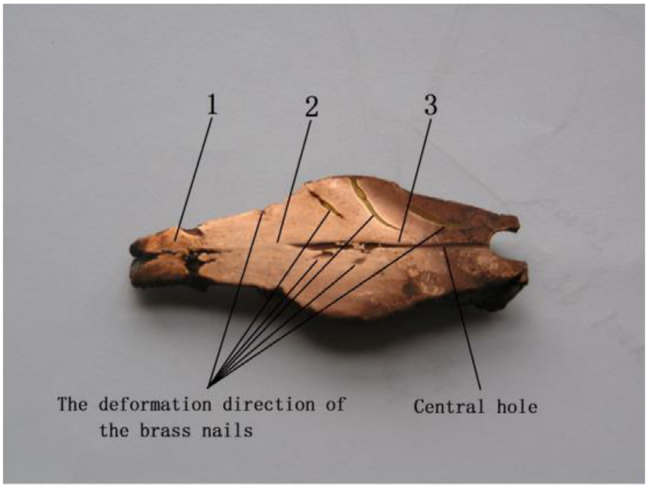

Fig. 1. The recovery slug photo along the symmetry plane.

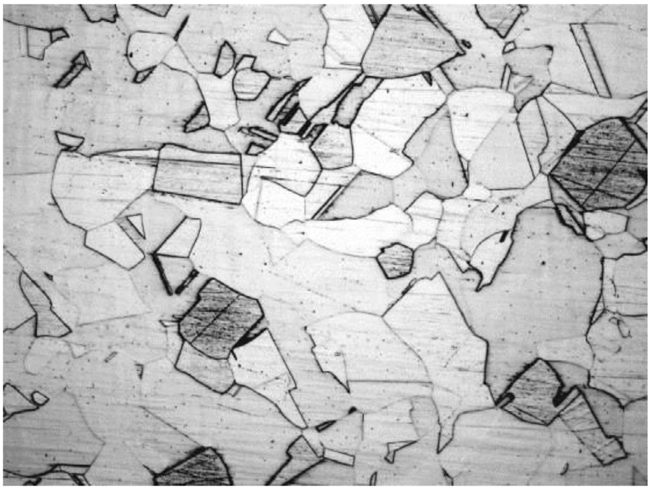

Fig. 2. The original liner materials microstructure (×100).

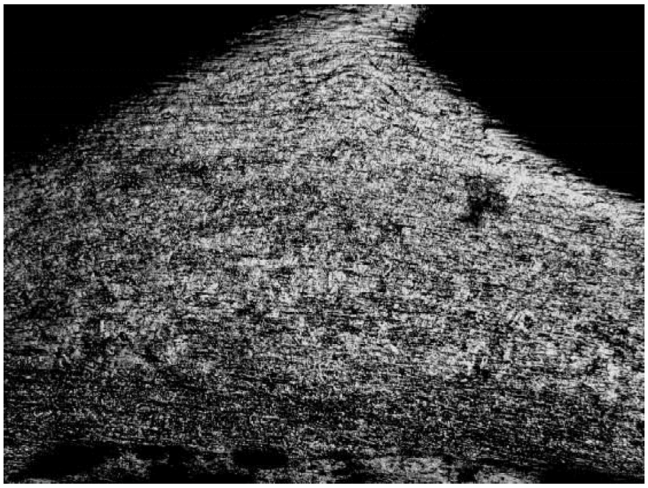

Fig. 3. The deformation microstructure of the liner element at the marker 1 in Fig. 1 (×25).

mm. The deformation path of the liner elements were shown by the deformation way of the brass nails from the slug into the jet.

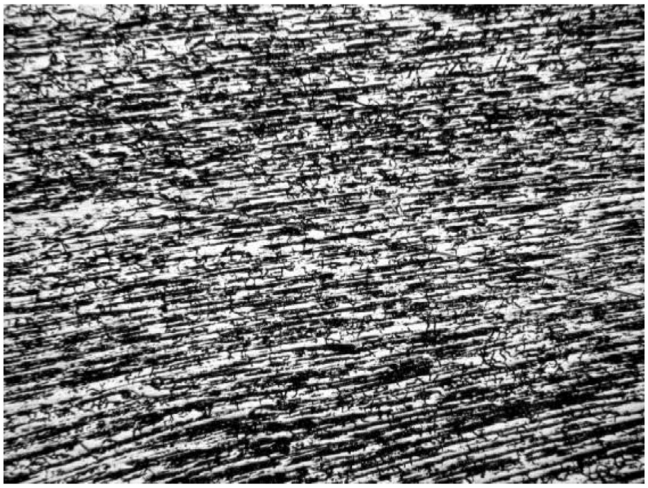

Fig. 4. The liner metallographic photo at the marker 2 in Fig. 1 (×100).

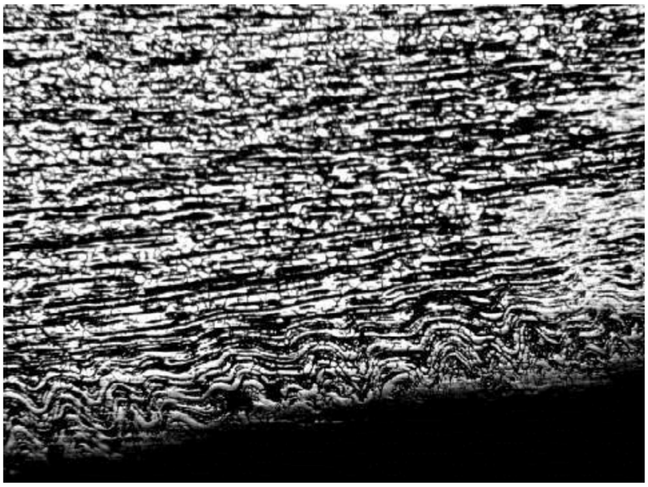

Fig. 5. The liner deformation microstructure at the marker 3 in Fig. 1 (×100).

The original microstructure of the liner material copper is shown in Fig. 2, in which there are a lot of annealing twins with the average grain size of 89.4 μm.

Fig. 3 is the liner microstructure of the marker 1 in Fig. 1. The upper part is near the outside surface of the slug and the lower part is near the slug central hole. It shows the layered deformation path of the liner microstructure. Obviously, the closer the liner element to the center axis of the liner, the larger deformation amount is and the smaller the grain size is.

Fig. 4 is the metallographic photo of position 2 in Fig. 1. The upper part is near the outside surface of the slug and the lower part is near the central hole. It can be seen that the deformation direction of the liner grain is always parallel to the axis symmetry of the liner; the grain size is about 1 μm. Here, the liner grain was deformed continuously, stretched, broken and refined.

Fig. 5 is the metallographic photo at the marker 3 in Fig. 1. The upper part is near the outside surface of the slug and the black part is central hole of the slug. We can see the waveform image of the grain deformation near the inner surface of the center hole of the slug, which shows that the liner materials deformation near the surface of the central hole has a fluid instability characteristic.

The metallographic photo of the slug meridian profile section is shown in Fig. 6. The upper part is close to the outer surface of the slug and the lower part is close to the axisymmetric center hole of