Experimental Observations to The Spall of Metal Tubes Under Inward Sliding Detonation

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Abstract: The spallation of steel and OFHC copper (oxygen-free heavy copper) cylindrical tubes under inward sliding detonation were primarily studied using soft recovery, DISAR (Displacement Interferometry System of Any Reflector), and flash-radiography techniques. For steel, the soft-recovered section images were obtained. For OFHC copper, the inner-surface velocity profile was measured by DISAR, and the flash-radiograph was used trying to obtain its instantanous damage state.

1. Introduction

Researches on the dynamic responses of cylindrical metal tube to inward detonation loadings have experienced more than half a century. However, most of these researches were about adiabatic shear bands, little attentions have been paid to the converging deformation stabilization and the spallation of cylindrical metal tubes or spherical shells caused by the interaction of two head-on rarefactive wave[1~3]. In this paper, we focus on the spallation of cylindrical metal tubes loaded by sliding inward detonation. Experiments were performed on steel and OFHC copper, soft recovery, DISAR [4], and flash-radiography techniques were applied to do the observations. By changing the thickness of high explosives and the shield shell, the influences of loading conditions on the spall of the tubes were investigated and discussed.

2. Experiment setup

Fig.1 shows the schematic view of the experimental arrangement. High explosive shell was firmly attached to the OFHC copper or steel tube's outer wall, and was initiated with a detonator centered on the top. For the case of OFHC copper, the explosive TNT/Tetryl (40/60) was used, the inner surface velocity in the direction of radius was measured using DISAR technique, and a frame of high energy X-ray radiography had been taken at a scheduled time trying to obtain the instantaneous image of the tube's damaged state. For steel, recovery experiments were performed in order to examine the final damaged states of the tube samples. In these experiments, two kinds of plastic adhesive high explosives GI-920 and GH-925 were used. In the case using GH-925, an additional outer-shield was added to the experimental device to enhance the explosive power which is not shown in Fig.1. The basic parameters for the explosives used are listed in Tab.1.

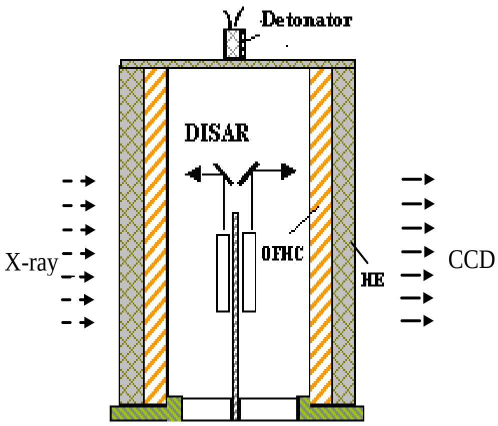


Fig.1 Schematic map for device of OFHC tube

Table 1. Basic parameters for high explosives used in our experiments

Type of HE	Density ρ_0 /[g/cm^3]	Detonation velocity D_{CJ} [km.s^{-1}]	Polynomial constant κ	Chapman-Jouguet pressure P_{CJ} [GPa]
GI-920	1.53	7.3	2.88	21.0
GH-925	1.65	8.1	3.17	26.1
TNT/Tetryl (40/60)	1.684	7.786	2.787	27.0

3. Results and discussions

All the steel tubes were 7.5 mm in thickness, 63 mm in outer diameter, and 200 mm in length which is long enough to provide us a segment with stable and uniform deformation. Fig.2 shows the sections of soft-recovered steel tubes after inward detonation by exposed viscous high explosive GI-920 with different thicknesses changing from 3.3 mm to 7.75 mm. Fig.3 is the sections of the same steel tubes after detonation by more intense GH-925, where the HE thickness changed from 3.3 mm to 5.5 mm and extra shield shells were attached outside the HE.

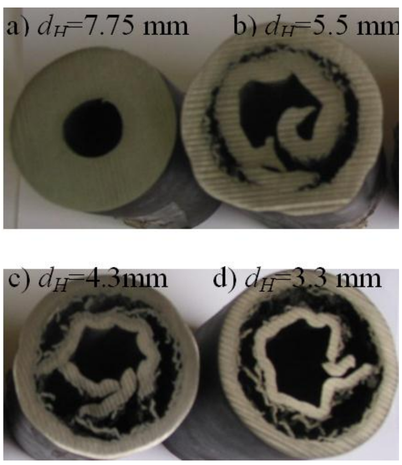
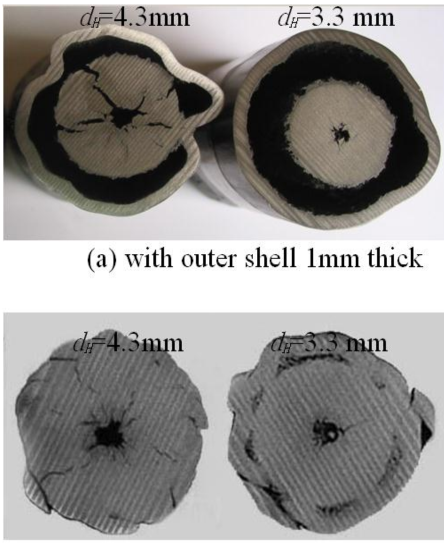


Fig.2 Sections after implosion by HE GH-920 with different HE thickness of d_H



(a) with outer shell 1mm thick

(b) with outer shell 2mm thick

Fig.3 Sections of steel tube after sliding implosion by HE GH-925 with an shield shell (d_H --HE thickness)

It can be seen definitely from Fig.2 and Fig.3 that spall occurred in some tubes. Here we define the spall scab as the inner separated part, and the outer separated part is then called the residual. Our experiments showed that the thickness of the spall scab increases with the increase of the HE thickness. When keeping the other experimental devices unchanged, increasing the thickness of the HE to a value in excess of one limit value would result in no spall. Of course, this limit value changes with the experiment conditions such as the intense of the high explosive and the material of the tube to be studied.

Fig.2 gives an important information that spall may prevent the tube from converging to its center, and this deserves much attention for some engineering applications in which convergence deformation is needed. Moreover, another interesting phenomena can be seen by comparing Fig. 2 and Fig. 3 that in all these experiments where spall occurred under the condition of no shield outside the HE (see Fig.2), the residual parts kept their cylindric symmetric shapes well on the whole, but the spall scabs collapsed to unstable outlines. However, for the experiments with an shield outside the HE in Fig. 3, the results were totally contrary. The reason, we think, is an interesting problem that needs further studies.

One experiment was performed on OFHC copper tube which had the size of 14 mm in thickness, 120 mm in outer diameter and 200 mm in height, and was loaded by TNT/Tetryl (40/60) explosive that was 9 mm in thickness. In this experiment, DISAR was applied to try to capture the inner surface velocity profile, and Fig. 4 shows the result. Flash radiography was also used in this experiment expecting to get some information of the tube's instantanous damage state, and the picture is presented in Fig. 5.

The inner surface velocity profile in Fig. 4 indicates a typical reverberation pull-back spallation signal arising from the interaction of the rarefactive waves. An approximate one-dimensional analysis from the profile gives the spall strength 1.9 GPa, in accordance with the result of Ref. [5] which was measured via plate impact experiments. Our result is slightly lower than the value given in Ref. [3] in which an hemispherical OFHC was inward detonated by an intense explosive PBX-9501.

The flash-radiograph in Fig.5 shows both the static and dynamic left-side image of OFHC tube. In spite of the low resolving power, the instantanous damage distribution can roughly be investigated. Of course, a better result is needed for the quantitative analysis but this asks for higher energy of the device.

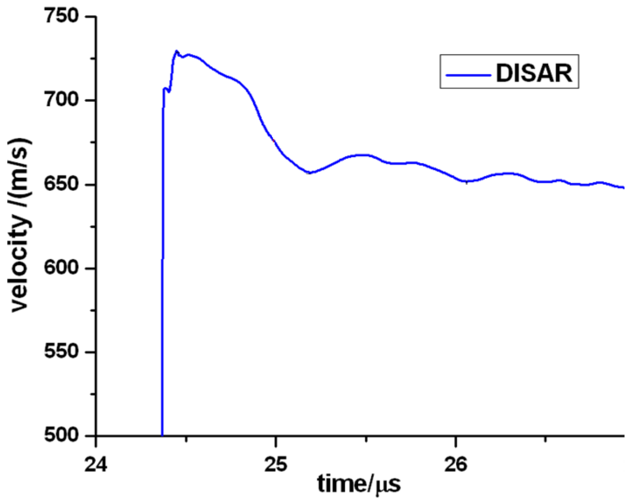
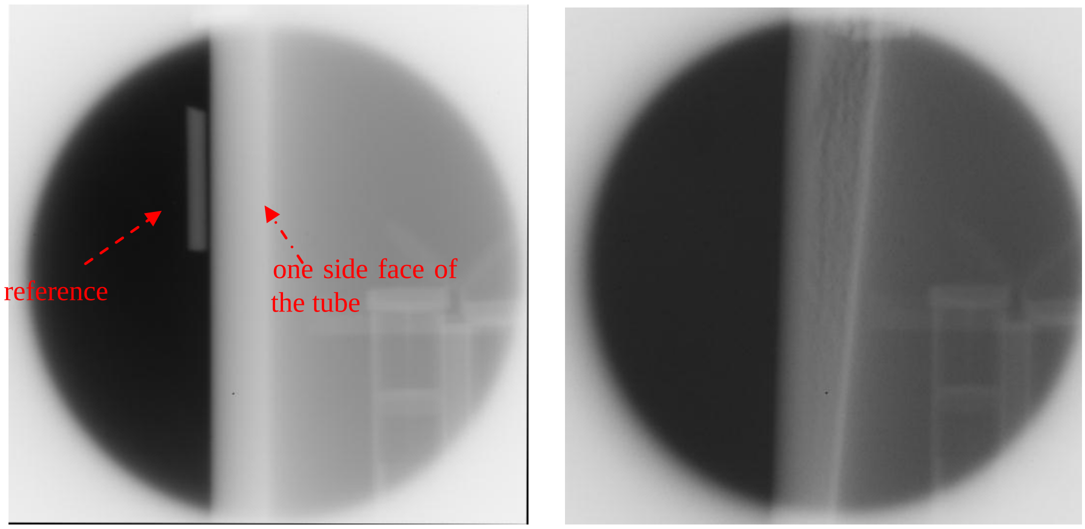


Fig.4 Inner-surface velocity profile of OFHC copper tube



a) static image b) dymaic image

Fig.5 The flash-radiography image of the OFHC copper tube

4. Summary

This paper report some experimental observations to the spall fracture of steel and OFHC copper tube under non one-dimensional sliding implosion loading. The soft-recovered section images or the primary measurement of time-resolved velocity profile by DISAR and the flash-radiograph for these experiments were given. A detailed analysis to our results would be given in other papers.

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