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PII: S0734-743X(17)30578-X
DOI: 10.1016/j.ijimpeng.2017.10.001
Reference: IE 2996

To appear in: *International Journal of Impact Engineering*

Received date: 7 July 2017
Revised date: 6 September 2017
Accepted date: 3 October 2017

Please cite this article as: Jianfeng Liu , Yuan Long , Chong Ji , Qiang Liu , Mingshou Zhong , You Zhou , Influence of layer number and air gap on the ballistic performance of multi-layered targets subjected to high velocity impact by copper EFP, *International Journal of Impact Engineering* (2017), doi: 10.1016/j.ijimpeng.2017.10.001

Influence of layer number and air gap on the ballistic performance of multi-layered targets subjected to high velocity impact by copper EFP

Jianfeng Liu[1], Yuan Long[1], Chong Ji[1,2], Qiang Liu[1], Mingshou Zhong[1], You Zhou[1]

[1]*College of Field Engineering, PLA Army Engineering University, Nanjing Jiangsu 210007, China*

[2]*State key Laboratory of Explosion Science and Technology, Beijing Institute of technology, Beijing 100081,China*

ABSTRACT: Ballistic performance of monolithic and multi-layered steel targets penetrated by EFP is investigated both experimentally and numerically. Terminal effects of multi-layered targets are summarized to assess the pros and cons of composite structures from a macro perspective. Correspondingly, morphology features of fracture surfaces and microstructure evolution of the craters are analyzed to reveal failure mechanisms of sub-structures. The results show that the monolithic target presents less effective than in-contact or spacing multi-layered targets as the dominant response of multi-layered targets is global plastic deformation and bulging which involved bending and stretching behavior. When the number of layers grows, the local plastic deformation increases rapidly and may lead to the failure of multi-layered targets. Moreover, the air gap increases the ballistic resistance of multi-layered targets especially as the width of air gap is larger than half length of projectile.

***Keywords*:** Multi-layered targets; Explosively formed projectile; Ballistic performance; Experimental tests; ANSYS/LS-DYNA

1. Introduction

Civil and military ballistic protection systems often consist of multi-layered targets which may either be monolithic or layered with or without spacing[1,2]. An structural optimization of the composite targets[3,4] against projectile impact has a practical interests in application to increase the ballistic resistance performance of armors[5,6].

According to the earlier studies, effects of layer number and air gap on the ballistic resistance of multi-layered targets subjected to high velocity impact by projectile are two major areas of research[7-17]. On the basis of an extensive experimental programs related to composite structures of varies configurations impacted by standard 7.62 mm bullet projectiles, Almohandes et al.[7] find that the ballistic performance of monolithic plate is always higher than that of a multi-layered target of the same total thickness. This finding and similar results are also confirmed by Radin et al.[8], Liang et al.[9], Elek et al.[10] and Holmen et al.[11] through experimental results or theoretical analysis. An opposite conclusion is obtained by Corran et al.[12]. They investigate the performance of multi-layered steel plates under impact and find that layered plates in-contact are superior to monolithic targets if the response changed from one being dominated by plate bending and shearing to one dominated by membrane stretching. Corresponding similar results are also certificated by Dey et al.[13], Teng et al.[14], Marom et al.[15] and Woodward et al.[16]. As relation to the air gap, Ben-Dor et al.[17] present an analytical model for the ballistic resistance of multi-layered ductile targets. They find that ballistic resistance is independent of the air gap width between the layers and on the sequence of the plates in the target when impacted by conical projectiles. The obtained results are in good agreement with experimental datas from Almohandes et al.[7] and Deng et al.[2] also find the air gap size has slight influence on the ballistic resistance of multi-layered targets. Radin et al.[8], Marom et al.[15], Alavi et al.[18] and Børvik et al.[19] point that the spaced layers are less effective at impact loading than layers in-contact. Iqbal et al.[1] recently point that the variation of width space at normal impact is found to have an important influence as long as the spacing is smaller than the projectile length. Considering different experimental conditions, researchers often derive conclusions from a certain kind shape of projectile against the particular structural targets[20,21]. The literature reviews indicate that the protection effectiveness of multi-layered targets remain a subject of debate[22,23]. Therefore, making comparisons or referencing the results from different investigations are also difficult due to the existence of various variables.

As another key component in the projectile-target system, the projectile is usually dealt with a rigid body[3,5,24,25] ignoring the deformation of projectile itself. However, as a chemical energy projectile which is one of the most common weapon used to defeat the armor in the military applications[26-28], EFP(Explosively formed projectile) will experiences essentially plastic strains up to 300%, at strain rates of the order of $10^4 s^{-1}$[29,30]during the formation and penetration process and the projectile can not be treated as a rigid body anymore[25,31,32]. Actually, the main body of EFP will be fragmented or