Defence Technology xxx (2017) 1–10

Contents lists available at ScienceDirect

Defence Technology

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

The effects of compressibility and strength on penetration of long rod and jet

Weng-jie Song [a], Xiao-wei Chen [b, c, *], Pu Chen [a]

[a] Department of Mechanics and Engineering Science, College of Engineering, Peking University, Beijing 100871, China
[b] Centre for Applied Physics and Technology (CAPT), Peking University, Beijing 100871, China
[c] State Key Lab of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, China

ARTICLE INFO

Article history:
Received 3 October 2017
Received in revised form
22 November 2017
Accepted 28 November 2017
Available online xxx

Keywords:
Compressibility
Strength
Long rod
Jet
Compressible model
Virtual origin model

ABSTRACT

The approximate compressible model is adopted to study the effects of strength and compressibility on the penetration by WHA long rod and copper jet into semi-infinite target in detail. For WHA rod penetrating PMMA at 2 km/s < V < 5 km/s, the compressibility has a significant effect on the penetration efficiency. We clarify how compressibility affects the penetration efficiency by changing the stagnation pressures of the rod and target. For WHA rod penetrating 4340 Steel and 6061-T6 Al at 2 km/s < V < 10 km/s, the effect of strength is strong and the effect of compressibility is negligible at lower impact velocity, whilst the effect of strength is weak and the effect of compressibility becomes stronger at higher impact velocity. For the copper jet penetrating 4030 Steel, 6061-T6 Al and PMMA, the virtual origin model is adopted, and the compressibility and strength are implicitly considered by the linear relation between the penetration velocity and impact velocity. The effects of compressibility and target resistance on penetration efficiency are studied. The results show that the target resistance has a significant effect on the penetration efficiency. However PMMA is much more compressible than copper and the huge difference of compressibility has a significant effect on the penetration by hypervelocity copper jet into PMMA.

© 2017 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

1. Introduction

Penetration by projectile with velocity of a few km/s into various targets is an important problem. The representative projectiles are long rod penetrator and high explosive anti-tank warhead which uses the jet formed by shaped charge to penetrate target.

The process of long rod or jet penetrating semi-infinite target is usually analyzed by incompressible hydrodynamic theory [1–5]. The long rod is usually made of the material with high strength, high density and high bulk modulus. So in practical ordnance velocity, the volumetric strain of long rod is small and the relative theories about penetration by long rod treat it as incompressible material. Meanwhile the strength has a significant effect. However the research and development of kinetic-energy weapon never cease, such as the electromagnetic rail gun and new ultra high-energetic materials. The future long rod can reach higher velocity and the penetration is hypervelocity, in which the pressure at the rod/target interface is extremely high and so are the volumetric strains of the rod and target. Anderson and Orphal [6] conducted numerical simulations to examine the effect of compressibility at 1.5 km/s to 6 km/s and both the pressure and density at the rod/target interface deviate more from incompressible hydrodynamic theory at higher impact velocity. Thus, long rod cannot be treated as incompressible and the effect of compressibility on penetration by hypervelocity long rod has to be considered. On the other hand, the velocity of tip of the jet formed by ordinary military shaped charge is up to 8 km/s and even can be larger than 10 km/s for special design. In such hypervelocity penetration, the compressibility of the projectile and target cannot be really ignored.

WHA (tungsten heavy alloy) is a common material for long rod and copper is the most frequently-used material for the liner of shaped charge, so it is necessary to study the effects of compressibility and strength on the hypervelocity penetration by WHA long rod and copper jet. In the present work, we use the approximate compressible model to study the effects of compressibility and strength on hypervelocity penetration by WHA long rod in detail

---

[*] Corresponding author. State Key Lab of Explosion Science and Technology, Beijing Institute of Technology, Beijing 100081, China

E-mail address: chenxiaoweintu@bit.edu.cn (X.-w. Chen).

Peer review under responsibility of China Ordnance Society

https://doi.org/10.1016/j.dt.2017.11.010
2214-9147/© 2017 Published by Elsevier Ltd. This is an open access article under the CC BY-NC-ND license (http://creativecommons.org/licenses/by-nc-nd/4.0/).

and clarify how compressibility affects the penetration efficiency by changing the stagnation pressures of the rod and target. For the hypervelocity copper jet, the effects of compressibility and penetration resistance of the target on penetration efficiency are also studied. In which, the virtual origin model is adopted, and the compressibility and strength are considered by the linear relation between the penetration velocity and impact velocity.

2. Basic theory

Birkhoff et al. [1] and Hill et al. [2] suggested a hydrodynamic theory of penetration (HTP) during WWII, respectively, invoking the incompressible Bernoulli equation

$$\frac{1}{2}\rho_{\mathrm{p}}(V-U)^2=\frac{1}{2}\rho_{\mathrm{t}}U^2 \tag{1}$$

where ρ_{p} and ρ_{t} stand for the projectile and target densities, respectively, and are assumed to be constants. V and U are the impact and penetration velocity, respectively.

The penetration efficiency is defined as the increment ratio of the penetration depth to the erosion length of rod

$$PE\equiv-\frac{\mathrm{d}P}{\mathrm{d}l}=-\frac{U\mathrm{d}t}{(U-V)\mathrm{d}t}=\frac{U}{V-U} \tag{2}$$

where P is the penetration depth and l is the length of rod. For the hydrodynamic limit, according to Eq. (1) we can get

$$U_{\mathrm{h}}=\frac{k}{k+1}V,\ PE_h=k \tag{3}$$

where $k=\sqrt{\rho_{\mathrm{p}}/\rho_{\mathrm{t}}}$ and the subscript h represents the HTP.

For penetration by metallic jets, Eichelberger [3] considered the strengths of jet and target as constant initial pressures in the incompressible Bernoulli equation

$$p_{\mathrm{ic}}=\frac{1}{2}\rho_{\mathrm{p}}(V-U)^2+Y_{\mathrm{p}}=\frac{1}{2}\rho_{\mathrm{t}}U^2+R_{\mathrm{t}} \tag{4}$$

where Y_{p} is the dynamic yield strength of the jet, R_{t} is the penetration resistance of the target and p_{ic} is the pressure at the rod/target interface, i.e., the stagnation pressure. The subscript ic represents the incompressible model with strength. According to the above equation, we can get

$$U_{\mathrm{ic}}=\frac{1}{1-\rho_{\mathrm{t}}/\rho_{\mathrm{p}}}\left(V-\sqrt{\rho_{\mathrm{t}}V^2/\rho_{\mathrm{p}}-2(R_{\mathrm{t}}-Y_{\mathrm{p}})\left(\rho_{\mathrm{p}}-\rho_{\mathrm{t}}\right)/\rho_{\mathrm{p}}^2}\right) \tag{5}$$

$$PE_{\mathrm{ic}}=\frac{\sqrt{4(R_{\mathrm{t}}-Y_{\mathrm{p}})^2+\left[\rho_{\mathrm{t}}V^2+2(R_{\mathrm{t}}-Y_{\mathrm{p}})\right]\left[\rho_{\mathrm{p}}V^2-2(R_{\mathrm{t}}-Y_{\mathrm{p}})\right]}-2(R_{\mathrm{t}}-Y_{\mathrm{p}})}{\rho_{\mathrm{t}}V^2+2(R_{\mathrm{t}}-Y_{\mathrm{p}})} \tag{6}$$

However, in the case of hypervelocity penetration, the pressure at the rod/target interface is extremely high and the volumetric strain of rod or target is especially significant, so the incompressible assumption doesn't apply. Haugstad and Dullum [7] developed a complete compressible model firstly by adopting the compressible Bernoulli equation and treating the shockwave as the stationary wave. Then Flis and Chou [8] studied the effect of different EOS (equation of state).

Osipenko and Simonov [9] applied the linear Hugoniot relation between the shockwave velocity and the particle velocity into both the treatment of shockwave and the Mie-Grüneisen EOS, and thus the model is completely self-consistent. Flis [10,11] extended the compressible model to a quadratic dependence of shockwave velocity on particle velocity and considered the strengths of projectile and target. Flis [10,11] also performed CTH code (the Eulerian shock physics analysis package developed by Sandia National Laboratory) simulations to compare with the compressible model. The results predicted by the compressible model were in good agreement with the CTH simulations, showing the validity of the model. Federov and Bayanova [12] adopted the Murnaghan EOS to simplify the compressible model. Flis [13] simplify the compressible model by ignoring the shockwave and using the Hugoniot curve to approximate the EOS. The compressible models described above contain many complex equations and have to be solved by numerical method.

Song et al. [14,15] analyzed the effects of different factors in the compressible model, developed a simplified approximate model with an algebraic solution and analyzed the precision and applicable range of the approximate model. Unlike the complex models of other researchers, the simple solution of the approximate model can be easily used in the engineering problems without any numerical method.

In the simplified approximate compressible model of Song et al. [15], the Murnaghan EOS is used

$$p=p_0+A\left[\left(\frac{\rho}{\rho_0}\right)^n-1\right] \tag{7}$$

where p_0 is the initial pressure, ρ and ρ_0 are the density of compressed material and initial density, respectively. $n=4\lambda-1$, $A=\rho_0C_0^2/n$, λ is the slope of the linear relation between the shockwave velocity and the particle velocity and C_0 is the initial sound speed. The initial pressure p_0 is taken as Y_{p} for rod and R_{t} for target, respectively. The equation of pressure-equilibrium across the projectile/target interface is

$$\begin{aligned}p_{\mathrm{c}}&=Y_{\mathrm{p}}+A_{\mathrm{p}}\left\{\left[1+\frac{(n_{\mathrm{p}}-1)\rho_{0\mathrm{p}}(V-U)^2}{2n_{\mathrm{p}}A_{\mathrm{p}}}\right]^{\frac{n_{\mathrm{p}}}{n_{\mathrm{p}}-1}}-1\right\}\\&=R_t+A_t\left\{\left[1+\frac{(n_t-1)\rho_{0t}U^2}{2n_tA_t}\right]^{\frac{n_t}{n_t-1}}-1\right\}\end{aligned} \tag{8}$$

where p_{c} is the stagnation pressure in the approximate compressible model. The subscript c represents the approximate compressible model hereinafter. The solution of the above equation is assumed to be

$$U_{\mathrm{c}}=U_{\mathrm{ic}}+\mathit{\Delta}U \tag{9}$$

Please cite this article in press as: Song W-j, et al., The effects of compressibility and strength on penetration of long rod and jet, Defence Technology (2017), https://doi.org/10.1016/j.dt.2017.11.010

Download English Version:

https://daneshyari.com/en/article/7157612

Download Persian Version:

https://daneshyari.com/article/7157612

Daneshyari.com