CHEMICAL ENGINEERING TRANSACTIONS

VOL. 62, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216

DOI: 10.3303/CET1762009

Anti-Penetration Simulation for HDPE Honeycomb Protection Structure

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This paper adopts ANSYS / LS-DYNA to make a numerical simulation on the anti-penetration performance of High Density Polyethylene (HDPE) honeycomb protection structure. It is discovered by analyzing the projectile body's penetration trajectory that the projectile body deflects away at a certain angle after intruding into the protective structures. There is a certain vector displacement between where it ultimately stays and the invaded position. And beyond that, this paper probes into the impacts of HDPE film thickness and projectile initial velocity on the anti-penetration of honeycomb structures. The results reveal that the aggradation of the HDPE film in a certain range can effectively reduce the penetration depth of the projectile, however, if beyond a certain range, it is not obvious to play an effect on reducing the penetration depth of the projectile. The honeycomb structure has a better anti-penetration to the projectile in a certain initial velocity range. All in all, it has a brilliant prospect for future application.

1. Introduction

High Density Polymer (HDPE)(Wei, 2016), as a kind of burgeoning material with high tensile strength, good corrosion resistance and strong plasticity, has been widely used in every field, however, so less are there studies on the protective structure of HDPE as a lightweight material. Aiming at the application of HDPE in the protective works, domestic scholars Shi et al., (2014) adopted the more common polypropylene (PP) to build up a new composite strip honeycomb protection structure for which a bullet test and anti-penetration numerical simulation were conducted. The study shows that the polypropylene honeycomb cells can deflect the different projectile body penetrated and consume its energy to provide a well-protection for back structure of honeycomb cells with a high protection value. Luo et al., (2014) also used SPH Particle Flow Analysis to study the trajectory of the projectile invasion and the soil change inside the honeycomb cells.

The honeycomb protection studied in this paper is composed of HDPE with better ductility and higher tensile strength than polypropylene (PP), and in a wide range of sizes. Domestic and foreign scholars have long been delving into the performance of HDPE (Guo et al., 2015; Li et al., 2016; Ma and Zhang, 2008; Chen et al., 2017). Kwon and Jar (2008) have come to the constitutive relation of HDPE by several tests on fitting uniaxial tensile, which has a good adaptability to the HDPE uniaxial tensile simulation under large deformation. Beyond that, Khedri and Elyasi (2016) studied the fracture behavior of polymers subjected to impact and thermal by numerical simulation. Ming-ming Xu et al., (2008) conducted numerical simulation and theoretical analysis on projectile that penetrates the ultra-high-density polyethylene textile fabrics by LS-DYNA. The study reveals that the projectile penetration velocity is correlated with the textile fabrics thickness and penetration direction. Tang et al., (2016) used the synchrotron radiation cornule X-ray scatteration to observe HDPE plastic deformation against tension and hollowing behavior. At present, there are few studies on the structure selection and optimization of HDPE flexible honeycomb. In order to further study the energy change of the flexible honeycomb protective structure after being subjected to projectile penetration and the influence of HDPE film thickness and projectile initial velocity on the anti-penetration performance of the structure, this paper, based upon the above analysis, numerically simulates the HDPE honeycomb protection structure against penetration and invasion, and analyzes the application prospect of the protection structure with final verification.

Please cite this article as: Shou Chen, 2017, Anti-penetration simulation for hdpe honeycomb protection structure, Chemical Engineering Transactions, 62, 49-54 DOI:10.3303/CET1762009

2. Model and parameters

2.1 Projectile material model

The material model used for the projectile is PLASTIC_KINEMATIC, a plastic kinematics that applies to beams, shells and solid elements, especially to isotropic and plastic kinematics hardening models which requires a rate effect. Specific parameters in the model are shown in Table 1.

Table 1: Parameters for projectile material

Density (kg/m^3)	Elastic modulus (Pa)	Poisson ratio	Yield stress (Pa)	Failure strain
7830	1.17×10^{11}	0.22	1.79×10^{9}	0.8

2.2 HDPE film material model

The material model used for the HDPE film is PLASTICITY_POLYMER, a plastic polymer that is currently only available for shell elements. As an elastoplastic material model, it can define any stress-strain curve and any strain rate dependent parameter, including parameters about correlations such as failure strain and velocity, and the brittle response of polymer at high strain rates. The model also has a good adaptivity to the response to unparent distinction between elastic and plastic phases. Specific parameters for the material model are shown in Table 2.

Table 2: Parameters for HDPE material model

Density (kg/m^3)	Elastic modulus (Pa)	Poisson ratio
942	1.034×10^{9}	0.35

The constitutive model used for HDPE is Kwon with a relational expression as follows:

$$\sigma(\varepsilon)=\begin{cases}\dfrac{3}{2(1+\nu)}E\varepsilon & \varepsilon\le\varepsilon_y\\ d\{[a(\varepsilon+b)]^{(c-1)}-[a(\varepsilon+b)^{-c}]\}+e & \varepsilon_y<\varepsilon\le\varepsilon_n\\ \alpha k\varepsilon^{N} & \varepsilon_n<\varepsilon\le\varepsilon_t\\ K\exp(M\varepsilon^{\beta}) & \varepsilon>\varepsilon_t\end{cases} \tag{1}$$

It is a piecewise function and solve the problem on the calculation results of the numerical simulation doing not converge. Where σ is the equivalent stress; v is the Poisson ratio; E is the elastic modulus; ε is the equivalent strain; ε_y is the equivalent strain when the constitutive relation changes from a linear one to a non-linear one; ε_n is the equivalent strain when the "necking down" appears in the material; ε_t is the equivalent strain when the stress stiffening occurs in the material. The parameters are user-defined, and defined with reference to literature, as shown in Table 3.

Table 3: Parameters for Kwon constitutive equation

Parameter	Assignment
ε_y	0.015
d	-22.29
a	33.41
b	0.0149
c	0.001
e	15.5
ε_n	0.02
αk	35.517
N	0.077
ε_t	0.32
K	30.66
M	0.4953
β	1.8

2.3 Soil mass material model

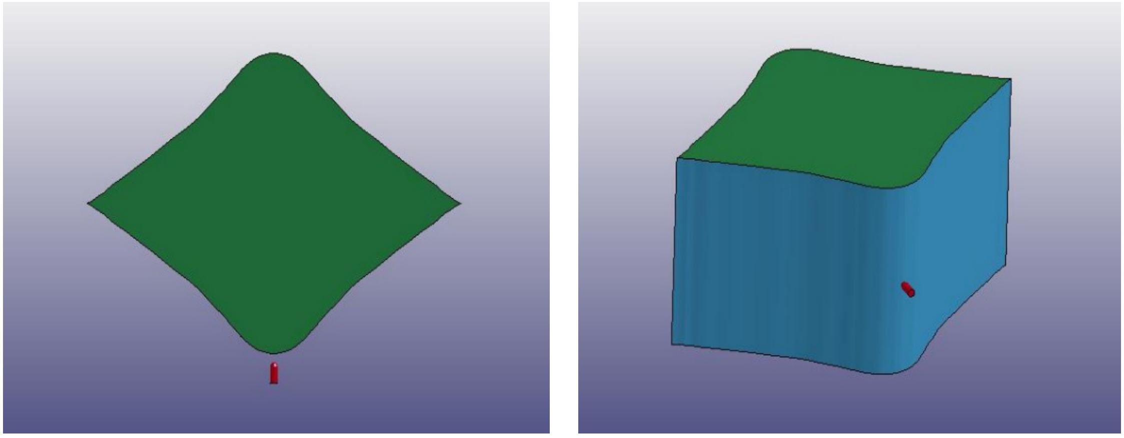
The soil material model SOIL_AND_FOAM_FAILURE can well simulate the wrapping and the geometrical border in soil mass periphery. When the pressure applied to the soil element reaches the failure value, the soil element will no longer be subjected to the tension. Specific parameters for the material model are shown in Table 4.

Table 4: Parameters for soil material model

Density (kg/m^3)	Shear modulus (Pa)	Bulk modulus (Pa)
1800	1.601×10^7	1.328×10^{13}

2.4 Finite element model and WC

Based on data available from field survey, each honeycomb cell is 97 cm long, 70.2 cm wide and 50 cm high. To simplify the calculation, a finite element model is set up by single cell, as shown in Figure 1. The meshs of the projectile body and the soil mass are divided by the solid element, and that of the HDPE film is done by the shell element. The CONTACT_EROSION defines the projectile penetration into HDPE film, projectile interaction with the soil surface. The CONTACT_AUTOMATIC_SURFACE_TO_SURFACE defines the interaction between the HDPE film and soil surface.



(a) Plan view *(b) Side view*

Figure 1: Finite element calculation model

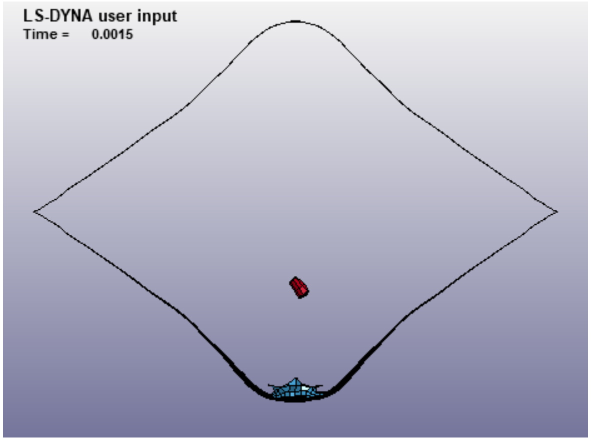
This paper focuses on the impact of HDPE film thickness and projectile initial velocity on the anti-penetration performance of the honeycomb structure. The main kinds of HDPE film thickness are 2 mm, 4 mm and 8mm, and the main kinds of projectile initial velocity are 300 m/s, 700 m/s and 1000 m/s, so a total of nine working conditions are designed, as shown in Table 5.

Table 5: Setting of WCs

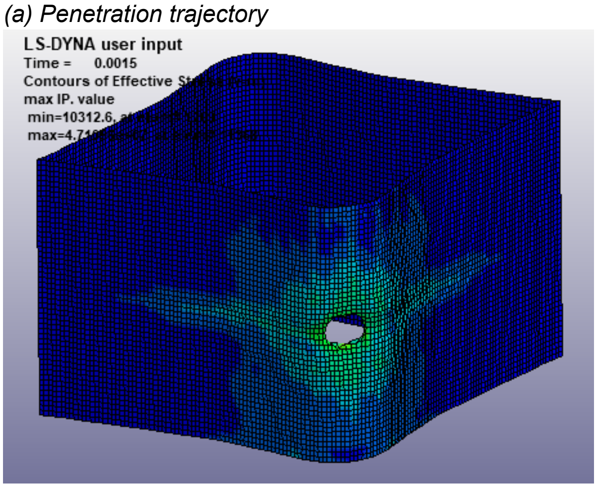
WC	HDPE film thickness (mm)	Projectile initial velocity (m/s)
1	2	300
2	2	700
3	2	1000
4	4	300
5	4	700
6	4	1000
7	8	300
8	8	700
9	8	1000

3. Results and Analysis

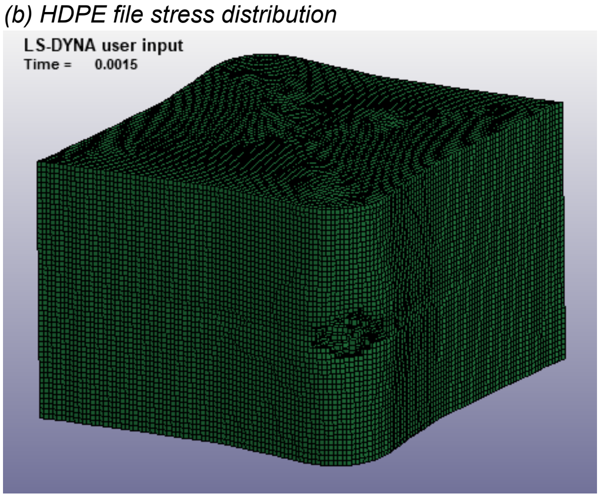
3.1 Projectile penetration



(a) Penetration trajectory



(b) HDPE file stress distribution



(c) Soil destruction

Figure 2: Schematic diagram of numerical simulation under WC 2

We make a study under the conditions of HDPE film thickness 2 mm, the initial velocity of the projectile 700 m/s, and WC 2. The numerical simulation of WC 2 is shown in Figure 2. As shown in Figure 2 (a), the projectile deflects away at a certain angle after invading into the protective structure. There is a certain vector displacement between where the projectile finally stays and the invaded position, and the projectile itself also rotates at a certain angle. It is found by observing warheads that there is an obvious plastic deformation under dual actions of HDPE film and soil mass. As can be seen from Figure 2 (b), there is a bullet hole in the HDPE film, whose diameter is roughly equal to that of the projectile and has a stress concentration. As shown in Figure 2 (c), after the projectile invades into the honeycomb structure, some of the soil mass is destroyed with a hollow cavity. Under the other sets of conditions, the above phenomenon appears again. Due to limited length, this paper will not describe it exhaustively.

3.2 Impact of HDPE film thickness on anti-penetration of honeycomb structure

We make a study under 3 sets of working conditions, i.e. the initial velocity of projectile, 300 m/s and HDPE film thicknesses 2 mm, 4 mm and 8 mm. The variations of projectile penetration depth under all WCs are shown in Figure 3. It can be seen that the changes of projectile penetration depth in three working conditions are basically consistent at the initial stage of penetration, but with deepening of the projectile penetration, they differ greatly. The general trend is that the penetration depth of the projectile is subjected to decrease with the increase of HDPE film thickness. The build-up of HDPE film thickness from 2mm to 4mm makes the projectile penetration depth significantly reduce, while from 4 mm to 8 mm, it does not change obviously. It is suggested that the build-up of HDPE film thickness within a certain range can effectively reduce the penetration depth of the projectile, but beyond a certain range, the effect is not obvious. Under the other sets of conditions, the above conclusion can be get again. Due to limited length, this paper will not describe it exhaustively. Therefore, there is an economic HDPE film thickness. In this test, HDPE film thickness of 4 mm is more economical and practical.

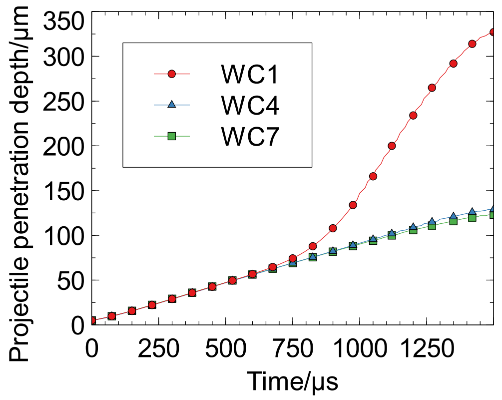


Figure 3: Variations of projectile penetration depth under WCs

3.3 Impact of projectile initial velocity on anti-penetration of honeycomb structure

We take three sets of WCs, i.e. the HDPE film thickness 4 mm, the initial velocity of the projectile, 300m/s, 700m/s and 1000m/s for study. The variations of projectile penetration depth under three WCs are shown in Figure 4. It can be seen that, with the increase of the initial velocity of the projectile, the penetration depth is also on the rise, but none of them penetrate through the honeycomb structure.

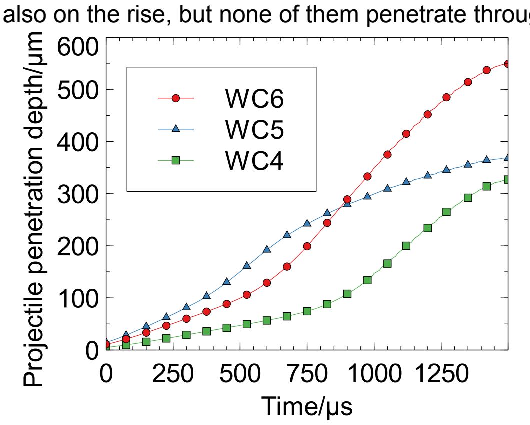


Figure 4: Variations of projectile penetration depth under three WCs

It is suggested that the honeycomb structure has good anti-penetration performance within the initial velocity range, and has certain application prospects. In the follow-up study, we continue to increase the initial velocity of the projectile to find the critical initial velocity at which the projectile can penetrate through the entire honeycomb structure in order to provide a guidance for the protection works.

4. Conclusion

(1) By analyzing and comparing the impact of different HDPE film thickness on the anti-penetration performance of honeycomb structure, it is deduced that the projectile penetration depth can be reduced within a certain range of HDPE film thickness, once it exceeds a certain range, the effect is not obvious. HDPE film thickness of 4 mm is more economical and practical.
(2) By analyzing and comparing the impact of different initial velocity of projectile on the anti-penetration performance of honeycomb structure, it is deduced that the honeycomb structure can present a better anti-penetration to the projectile within a certain initial velocity range and has a promising application prospect.

Acknowledgments

I would like to express my deepest gratitude to my tutor, Dr. Shi S.Q., for his support and guidance throughout the research. His continued support led me to the right way. I would also like to extend my appreciation to my senior: Dr. Chen Z.P. for his advice during my research. My sincere appreciation is extended to Dr. Sun J.H. for his invaluable support and advise on the physical properties evaluation. Special thanks to Li Z.Z., Zhao Y. and Yu D. for their assistance in the laboratory experiment. I would also like to extend my deepest gratitude to my family who were always with me during the project.

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