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The damage and failure mechanism of the concrete subjected to shaped charge loading

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ABSTRACT

In this paper, the experiments of the large-size shaped charge jet penetration in concrete target were carried out. Then, the concrete target was cut off to obtain the internal structure and measure the shape of the penetration hole. Moreover, the cube concrete samples with the sizes of 100 mm length in different location of the concrete target were incised, and the material compressive strength was test by the material testing machine. The test results show that the material strength of the concrete target is enhanced with the increase of the distance to the penetration hole. Therefore, the damage of concrete target can be rough evaluated according to the compressive strength of the concrete samples. Based on the test results, the damage factor was added in the dynamic constitutive, which can describe mechanical behavior of concrete subjected to intensive impact loading was proposed. In this model, the concrete is assumed to be homogenous and consecutive in macroscopically. The results of the model were compared with the experimental results and the results which not considering the damage factor. The comparing results show that the model can be used to describe the dynamic mechanical behavior of concrete.

1. Introduction

The research of shaped charge penetration in thick concrete target focused on the penetration hole diameter, the penetration depth, the shaped charge structure and the linear cover material which have high-performance penetration ability [1–3]. While the damage and failure of the concrete around the penetration hole was less involved. However, the damage behavior of the concrete around the penetration hole has important significance for studying the failure mechanism of the concrete.

Concrete material has been used in structural engineering for nearly one hundred years and is also an important type of material for safety engineering in the defense field [4–5]. Concrete fortifications used for military protection have larger thickness and higher reinforcement ratio than the concrete structures used in civil engineering [6–7], so it is extremely difficult to effectively destroy them. Shaped charge is an explosive charge shaped to penetrate solid target, such as thick concrete with high reinforcement ratio. The penetration performance of shaped charge depends on the liner, which has been well studied by scholars at home and abroad to improve the device's penetration capability. Shaped charge with conical or spherical liner is also one of the most widely used structures used in warheads [8].

The penetration of shaped charge has been well investigated. Murphy et al. studied shaped charge penetration of concrete target with experimental and numerical methods, and the influences of the liner material, cone angle, wall thickness and burst height were compared on the penetration effect [9–10]. Elshenawy T. studied the influences of the target strength and confinement, and obtained better predictions for the jet penetration depth [11]. Huerta conducted numerical simulation to study the structural design and

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optimization of single cone shaped charge and the results were verified by experiments [12]. Xiao designed double material composite of jet shaped charge structure to increase the crater diameter of shaped charge jet [13]. Resnyansky A proved an efficacy of the shaped charge jet assembly modifications and evaluated the performance improvement of the ultrahigh performance concrete against the plain concrete [14]. Ning et al. studied the jet formation and the effects of various parameters on penetration with experimental and numerical methods [15–16].

Current literatures survey show that previous studies on shaped charge penetration concrete basically considered the penetration depth and the penetration aperture. Since concrete has complex dynamic characteristics, there are few literatures studies focus on the damage mechanism of concrete target. However, the shaped charge penetration is difficult to completely destroy of concrete target for the thick concrete target. Generally, only the concrete near the penetration hole will be completely damaged, the other location of concrete will not be completely damaged. For destroy the thick concrete often need another explosion impact loading, this lead to the mechanism of the concrete surrounding the penetration hole need to be studied. Therefore, the damage and failure mechanism of the concrete subjected to shaped charge loading have important research significance for the secondary explosion impact loading on the concrete.

In this paper, based on the law of the shaped-charge forming of different type [9,15–16], a heavy-caliber shaped charge structure which could penetrate the thick concrete target was designed and the corresponding experiment was carried on. After the experiment the concrete target was cut to estimate the damage of the internal concrete by the concrete cutting section results. Then, the cube concrete specimens which height is 100 mm were obtained at different location of the concrete target and the concrete compressive strength tests which can rough evaluate the damage of concrete target were carried out by the material testing machine. Based on the test results, the concrete dynamic constitutive was proposed which can describe mechanical behavior of concrete subjected to intensive impact loading. In this model, the damage factor which can describe the damage degree of concrete was added and the concrete is assumed to be homogenous and consecutive in macroscopically. Comparing the results of the model with the experimental results and the results which not considering the damage factor show that the model can be used to describe the dynamic mechanical behavior of concrete.

2. The failure mechanism of the concrete

The detonation of explosive acts on the liner, which is then crushed or flipped before a high-velocity penetrator is formed, Fig. 1 shows the progress of the shaped-charge forming. The penetration of the high-velocity penetrator in the concrete target is a very complex physical process, in which the material of liner is solid at the beginning but then approximately becomes fluid under crushing, so the penetration process has the features of both rigid projectile penetration and high-speed fluid penetration [19–20].

2.1. The dynamic constitutive of concrete

The concrete targets experience high pressure which induces the micro-voids collide each other in the concrete and the irreversible plastic deformations would be occurred. The collapse of the micro-voids will cause the micro-crack damage in the concrete endlessly, which leads the concrete to fail. Thus, a dynamic constitutive of concrete was proposed to describe the mechanism of the concrete subjected to shaped charge loading. In this model, the behavior of the concrete is described by the decomposition of the strain into elastic part and plastic part on the premise of small deformation. By the decomposition of strain assumption:

$$\varepsilon_{ij} = \varepsilon_{ij}^{e} + \varepsilon_{ij}^{p} \tag{1}$$

where ε_{ij} were the total strain, $\varepsilon_{ij}{}^{e}$ were the elastic strain, $\varepsilon_{ij}{}^{p}$ were the plastic strain.

For the time derivative:

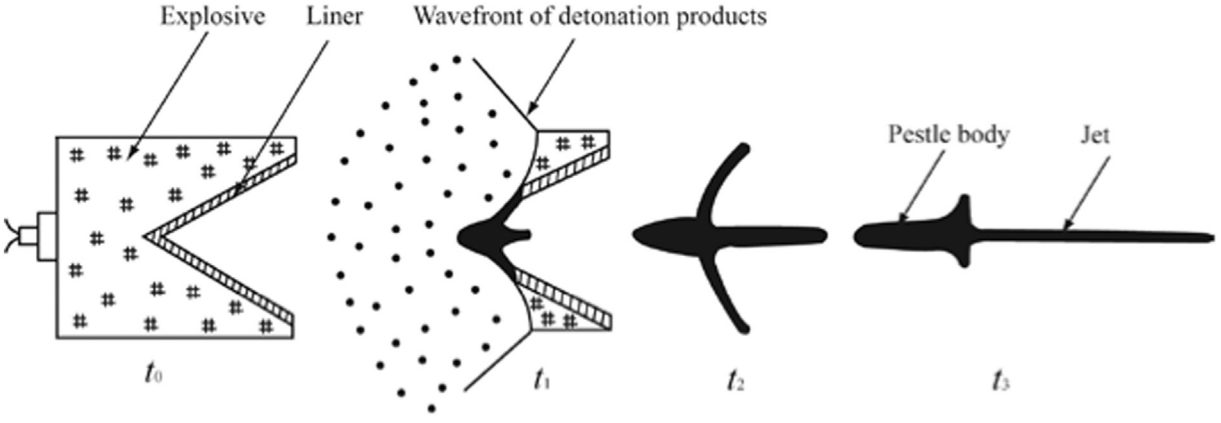

Fig. 1. Shaped-charge forming process.