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Overpressure Comparison of Blasting in Air and Special-Made Hemispherical Structure*

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Abstract: The explosive welding process always accompanies with explosive vibration, shock waves, overpressure, hazardous gases and noises. A method of designing a hemispherical structure with 36 m in diameter, whose entrance and smoke extraction opening are 8 m in height and 8 m in diameter respectively, is proposed to decrease the influence of overpressure during the explosive welding process. In order to evaluate the rationality and efficiency of the special-made hemispherical structure, the overpressure comparative experiments of blasting are carried out in air and in the special-made hemispherical structure with a 1/6 scale factor. The experimental results prove that the hemispherical structure with a 1/6 scale factor reduces the overpressure efficiently, especially for the propagation distance longer than 20 m. Furthermore, the overpressure along the tangent direction (perpendicular to the entrance of the hemispherical structure) is lowered more than that along the radial direction (the entrance of the hemispherical structure) for the same propagation distance. Considering the characteristics of propagation and reflection of shock waves, the possible reasons for the overpressure decreasing of blasting in the hemispherical structure are also discussed.

Key words: shock waves; overpressure; explosion mechanics; explosive welding

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1 Introduction

Explosions often lead to the damage to property, and sometimes loss of human life. The two most important and indispensable factors of an explosion are overpressure and impulse[1]. Many researchers have focused on the overpressure research in theoretical and experimental aspects[2-13]. For instance, Sapozhnikov and his coworkers[6] studied the effects of overpressure and pulse repetition frequency on cavitation in shock wave lithotripsy. Ben-Dor *et al*.[7] investigated the propagation of shock waves in rigid porous materials by numerical method. Harvey and his coworkers[8] studied the dynamic calibration of shock overpressure transducers. Cui and Li[9] carried out the dynamic calibration research on the shock wave pressure measurement system. Explosive welding process produces hazards such as

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explosive vibration, shock waves, overpressure, hazardous gases and noises because of the applications of explosives[10]. In this paper, a special-made hemispherical structure was proposed to lower the destruction effects of shock waves and overpressure in *in-situ* explosive welding. In order to evaluate the rationality and efficiency of the special-made hemispherical structure, the overpressure comparative experiments have been carried out via the initiation of the special-made ammonium nitrate-fuel explosives in air and in the hemispherical structure, respectively. Combining with the characteristics of propagation and reflection of shock waves, the possible reasons for overpressure reduction are also discussed.

2 Experiments

2.1 Special-Made Hemispherical Structure

A special-made hemispherical structure with 36 m in diameter, whose smoke extraction opening is 8 m in diameter and entrance is 8 m in height, is introduced to reduce the overpressure in *in-situ* explosive welding. In order to validating the efficiency of the special-made hemispherical structure, the overpressure comparative experiments were carried out by initiating the special-made ammonium nitrate-fuel explosives in air and in the hemispherical structure with a 1/6 scale factor, respectively. The special-made hemispherical structure with 6 m in diameter is made of 16MnR steel plate having a thickness of 6 mm; the smoke extraction opening is 1.33 m in diameter, and the entrance is 1.5 m in height as shown in Fig. 1.

2.2 Theoretical Foundation

When a blasting occurs in air, spherically symmetric shock waves are formed generally. When the shock waves reach the ground surface, as shown in Fig. 2, the reflection and refraction of shock waves give rise to intrinsically nonlinear phenomena of Mach reflection and irregular refraction. In Mach reflection the reflected shock wave meets the incident shock wave at a triple point which is some distance from the ground and is joined to it by a third shock wave (usually curved) called the Mach shock or Mach stem[14-15]. The height of Mach stem is constantly changing for the spherical shock waves. Therefore, if the pressure sensors are arranged above the Mach stem during the overpressure measurement process, the peaks of incident wave and reflection wave can be obtained. On the contrary, the incident wave front can also be caught up and submerged by the reflection of the shock wave. The obtained peak of reflection wave by pressure sensors is normally twice of the peak of incident wave. The incident wave can not be obtained directly from the measurement results[16], so the used pressure sensors are fixed on the special-made frames about 1.3 m above ground surface to decrease the influence of reflection waves on the measurement results.

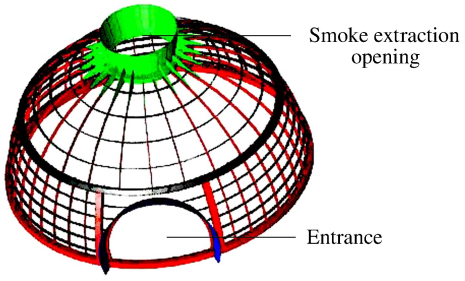


Fig. 1 Schematic of the hemispherical structure

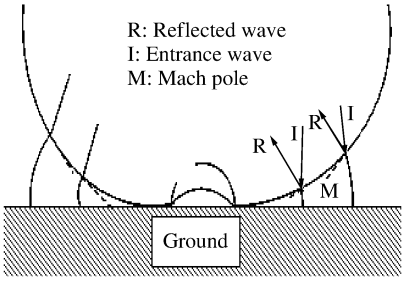
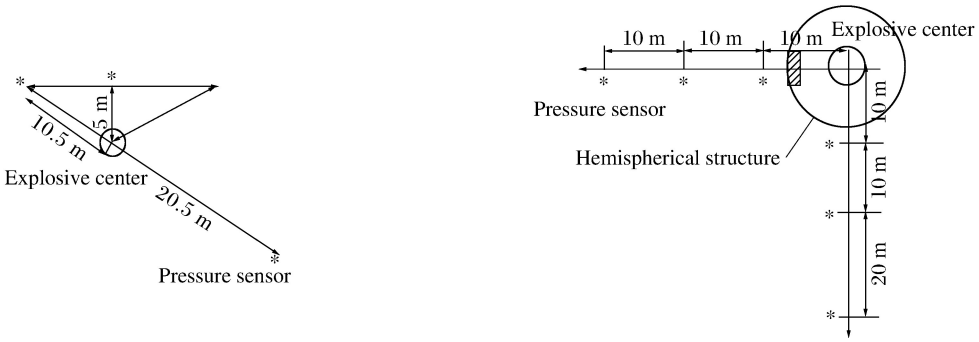


Fig. 2 Schematic of Mach reflection of shock wave

2.3 Experimental Procedure

In order to evaluate the overpressure reduction effect of the hemispherical structure, the overpressure comparative experiments were carried out via the initiation of the special-made powdered ammonium nitrate-fuel explosive charges in certain proportion in air and in the hemispherical structure, respectively. An electric No. 8 initiator and some plastic RDX (Hexogen) booster were used for each explosive charge. All of the pressure sensors were purchased from Baoji Transducer Research Institute. The blasting vibration recorders (IDTS3850) purchased from Chengdu VIDTS Dynamic Instrument Co. Ltd., were utilized to record the blasting waves. The schematic diagram of the overpressure measurement experiments and the located position of each pressure sensor are shown in Fig. 3. The used pressure sensors were fixed on the frames about 1.3 m above the ground surface to decrease the influence of reflection waves. All of the pressure sensors (CYG1101) were calibrated *in-situ* to acquire the test precision of measurement system.



(a) Blasting in air (b) Blasting in the hemispherical structure

Fig. 3 Schematic diagram of the overpressure measurement

3 Results and Discussion

3.1 Overpressure Analysis

The relationships between overpressure and propagation distance at different conditions (blasting in air or in the hemispherical structure with a 1/6 scale factor) are shown in Fig. 4. Compared with the blasting in air, it is obvious that the hemispherical structure considerably decreases the overpressure caused by explosion. For instance, under the same condition of initiating 4 kg explosive charge, the overpressure is lowered by 49% for a 10.5 m propagation distance (from 10 to 20.5 m) in air as seen in Fig. 4(a), while the overpressure is lowered by 66% only for a 10 m propagation distance (from 10 to 20 m) in the hemispherical structure with a 1/6 scale factor in Fig. 4(b). In addition, the similar reduction effect is also observed in Fig. 4(c).

The relationships between overpressure and explosive quantity at different conditions (blasting in air and in the special-made hemispherical structure with a 1/6 scale factor) are also shown in Fig. 5. It can be concluded that the overpressure propagation has more relationship with explosive quantity and propagation distance. When a blasting occurs in air, the overpressure increases with the increasing of explosive quantity at the same propagation distance away from the explosive center, and in addition, the overpressure is directly proportional to the explosive quantity with a small slope at the comparatively longer distance away from the explosive center. When a blasting occurs in the hemispherical structure with a 1/6 scale factor, the overpressure propagation process shows obvious differences along

the radial direction (the entrance of the hemispherical structure) and tangent direction (perpendicular to the opening) at the same propagation distance. As can be seen from Fig. 5(b), the overpressures shows various fluctuations in different degrees along the radial direction; while the overpressures are approximately proportional to explosive quantity with a gentle slope to some extent, that is, they increase with increased explosive quantity along the tangent direction. The remarkable effects of lowering the overpressure along the tangent direction can also be observed in Fig. 5(b).

The overpressure change trends along the radial direction for 5 kg explosive charges in the hemispherical structure with a 1/6 scale factor at different propagation distances are also shown in Fig. 6. Two main high overpressure peaks can be found in Fig. 6. Compared Fig. 6(a) with Fig. 6(b), we can observe that the overpressures decays with the increasing propagation distance (from 10 to 30 m), and the overpressure along the tangent direction is lowered more than that along the radial direction at the same propagation distance of 20 m. It seems that the effectiveness of the hemispherical structure depends on what direction the entrance of the structure is facing to a certain extent. Furthermore, the waveforms of the overpressure are also changed due to the existence of the "burr peaks" as shown in Fig. 6.

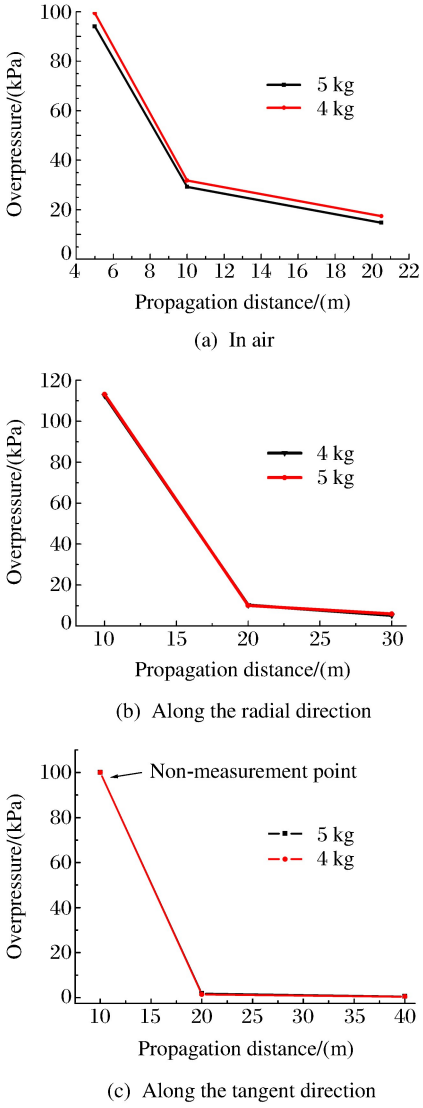


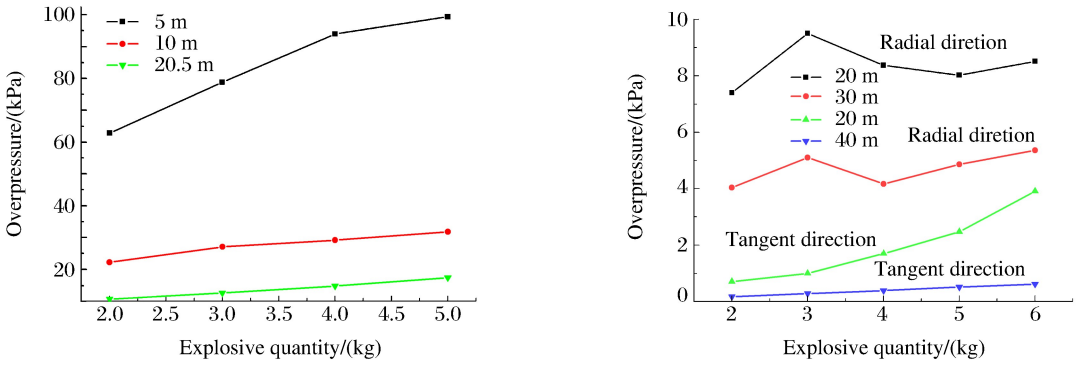
Fig. 4 Overpressure versus propagation distance

3.2 Reasons Analysis

It is well known that the spherical shock wavefront will be reflected because of the action of wall or ground, and it also will be diffused and changed during the propagation process. When a shock wave is propagating, tensile stress and oscillation are formed at the back of shock wave[17]. As for the propagation process of overpressure in the special-made hemispherical structure, the similar phenomena also exist.

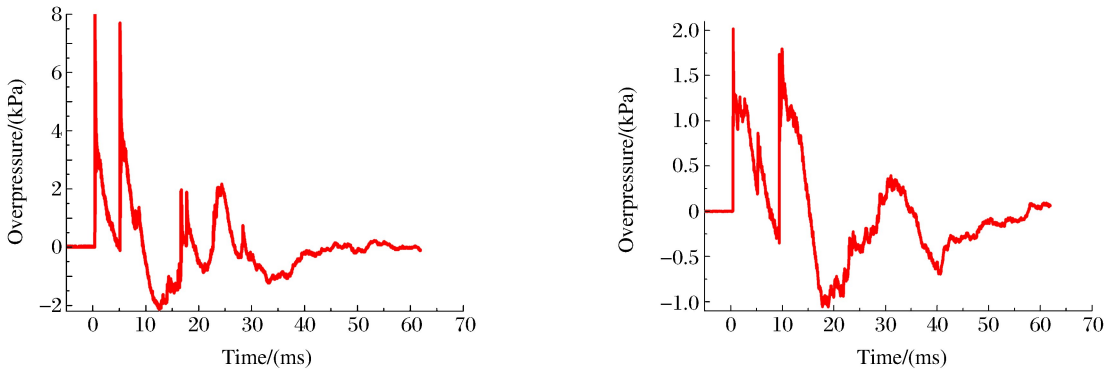
When the explosive charge is detonated in the special-made hemispherical structure with a 1/6 scale factor, the spherical shock waves are developed because of the outside expanding of explosion products. Then the formed shock waves severely compress the surrounding air at the beginning of blasting and change part of the mechanical energy into heat energy, and the vibration of the interface between explosion products and air at the equilibrium position consumes some energy. These cause the decreasing of energy on account of maintaining the movement of shock waves. Explosion can cause the distortion of ground, which also consumes energy. It is impossible that the energy of shock wave is totally reflected during the processes of ionization, breakdown and molecular combination of the gases

in the special-made hemispherical structure. Therefore, the overpressure is decreased.



(a) In air　　(b) In the hemispherical structure

Fig. 5　Overpressure versus explosive quantity



(a) Along the radial direction　　(b) Along the tangent direction

Fig. 6　Overpressure versus time

As can be seen from Fig. 6, the overpressure of blasting explosive charges along the tangent direction of the special-made hemispherical structure decreases greater than that along the radial direction at the same propagation distance, which may be associated with the following reasons. When shock waves transmit from air into the hemispherical structure, the intensity of shock waves is reduced considerably since the wave impedance of iron is much larger than that of air. While the shock waves propagate from the hemispherical structure into the air again, the intensity of shock waves is enhanced, which is lower than the intensity of original incident wave. It is obvious that the overpressure of blasting propagating directly in air is higher than the same overpressure propagating from air into steel plate and then into air again because of energy consuming. That is to say, the overpressure along the tangent direction is reduced more than that along the radial direction. On the other hand, when the shock waves are reflected by the inner wall of the special-made hemispherical structure, the reflected action is enhanced due to the unevenness of the inner wall. Therefore, the burr effects are reinforced as observed in Fig. 6(a) and Fig. 6(b). Movement and deformation of the special-made hemispherical structure produced as a result of internal explosive loading conversely influence the propagation of the shock waves and result in a periodic increase and decrease of the intensity of shock waves. Therefore, the isopiestic line becomes disorder with the propagation distance increasing due to the complex wave structures as shown in Fig. 6.

From the experimental results, we can conclude that the overpressure is reduced effectively using the special-made hemispherical structure, and furthermore, the effectiveness of the special-made hemi-

spherical structure depends strongly on what direction the structure entrance is facing. In order to evaluate the validity of the conclusion, it is still necessary to further study the flow field distribution of the radial direction for the special-made hemispherical structure and make the overpressure measurement slightly off the radial direction of the hemispherical structure.

4 Conclusions

The overpressure comparative experiments of blasting in air and in a special-made hemispherical structure with a 1/6 scale factor have been carried out in this paper. The measurement results prove that the hemispherical structure decreases the overpressure caused by explosion efficiently, especially for a considerable propagation distance away from the explosive center (more than 20 m), and the overpressure along the tangent direction (perpendicular to the opening of the special-made hemispherical structure) is lowered more than that along the radial direction (the opening of the special-made hemispherical structure) for the same propagation distance. The hemispherical structure greatly meets the requirements of reducing the overpressure of *in-situ* explosive welding. It is an effective way to build a special-made hemispherical structure to decrease the harmful effects of explosive welding.

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裸爆和特制半球形结构内爆超压对比实验研究

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摘要:爆炸焊接过程会产生爆炸地震、冲击波、有毒气体和噪音等有害效应。设计并制作一个直径为 36 m、入口和排烟口直径分别为 8 m 的半球形结构,用以降低爆炸焊接过程中产生的超压影响。为了研究实际超压降低效果,进行了裸爆和按 1/6 比例建立的半球形结构内爆炸的超压对比实验。实验结果表明:当超压的传播距离大于 20 m 时,这种半球形结构能有效降低爆炸焊接过程中产生的超压;对于相同的超压传播距离,切线方向(垂直于半球形结构入口方向)比径向方向(半球形结构入口方向)的超压降低效果好。结合冲击波的传播和反射特点,对超压降低的可能原因进行了分析。

关键词:冲击波;超压;爆炸机理;爆炸焊接

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