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Application of a MEE-rock debris separation technique in deep hole bench blasting

M. Zhao[1], J. Zhang[2], Zh. Lei[3], Q. Kang[1]

[1]*Guizhou Xinlian Blasting Engineering Group Co. Ltd. Guiyang, Guizhou 550002, China*
[2]*Wuhan University of Technology, Wuhan, Hubei 430070, China*
[3]*Guizhou Institute of Technology, Guiyang, Guizhou, 550003, China*

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In order to solve the problem of water in boreholes which influences the blasting effect in open pit deep hole bench blasting, an isolator was designed for separating the mixed emulsion explosive (MEE) from rock debris, based on the principle of fluid dynamics. The finite element software ANSYS/LS-DYNA was applied to simulate the posture adjustment of the isolator in the process of falling. The result showed that the designed isolator could meet the purpose of separating MEE from rock debris. Simulation experiments in dry and wet borehole models with and without isolator were performed, and the results showed that the isolator can avoid the explosive misfire caused by mixing of MEE and rock debris, increase the utilization rate of MEE, improve the blasting effect, and meet the purpose of lowering the blasting cost.

Key words: Bench blasting, MEE-rock debris isolator, Numerical simulation, Blasting effect

INTRODUCTION

In open pit deep hole bench blasting, it is common that the borehole is filled with water. Since rock debris are with finer grain size and they are easy to form mixtures at the hole bottom when the slurry emulsion explosive is pumped in, the bottom part of the slurry emulsion explosive would get mixed with rock debris because of the effect of pumping and the weight of the explosive, which would lead to the loss of explosion power and cause the waste of explosives, directly influencing the blasting effect. Lots of studies on enhancing blasting effect and reducing blasting cost have been made home and abroad. Wang [1] studied the application of the emulsion explosives mixing and charging truck in water conservancy projects like the Three Gorges Dam, and stated the advantages and disadvantages of using MEE in boreholes full of water and its technology. Liu Lei *et al.* [2] found that under the water pressure of 0.2 Mpa, the detonation velocity of emulsion explosives sensitized by ordinary chemical could decrease by 74.81% and its shattering brisance could decrease by 49%, and when the pressure is up to 0.3 Mpa, most of the emulsion explosives would be half or all misfired. Adhikary *et al.* [3] studied the influence of water level, charging speed and borehole size on the charging effect of emulsion explosives in boreholes filled with water, and the results showed that when the depth of water was larger than the largest effective range of the jet flow, the explosives would fail to reach the bottom and a water column would be formed, so that the distance from the top of the charging tube to the bottom of the borehole should be reduced and the charging speed should be increased. Ye Haiwang *et al.* [4] studied the influence of the mixing situation of emulsion explosives, water and rock debris on the blasting effect through experiments and numerical simulations, analyzed the effect of different ways of charging on mixing, and put forward a control method increasing the charging speed and putting the charging tube to the borehole bottom. Pete *et al.* [5] made experiments on the critical diameter and the critical depth of several emulsion explosives, found the critical size of different explosives and discussed the main mechanism of efficacy loss by the geometric dimensions of emulsion explosives. Former studies have revealed the mixing process and action mechanism of explosives, water and rock debris during the charging process of site-mixed emulsion explosives, and found that the mixture would lead to negative effects like degradation of explosives, detonation performance or loss of efficacy, and suggested some techniques to control the negative effects. In order to prevent the efficacy loss caused by the mixing of site-mixed emulsion explosives and rock debris, this paper studied the ways of separating emulsion explosives from rock debris to increase explosive utilization rate.

DESIGN AND MANUFACTURE OF MEE-ROCK DEBRIS ISOLATOR

Based on the principle of fluid dynamics and the space characteristics of boreholes filled with water, the isolator was designed like a plate. Its density must be larger than that of water, so it can sink by its gravity in water and adjust to the level condition with its bottom down under the effect of the uplift and

*To whom all correspondence should be sent:
E-mail: 99113294@qq.com

resistance force of water or air till sinking to the borehole bottom, so as to achieve the goal of separation. Using this isolator in the charging process could effectively separate the explosives and rock debris at the borehole bottom and prevent explosive efficacy loss caused by the mixing at the middle and bottom parts of the borehole.

The isolator was used in a borehole 250 mm in diameter to check its separation effect. Its material was ordinary rubber with density of 1.4 g/cm^3 and thickness of 5 mm. Its structure and size are shown in Fig. 1.

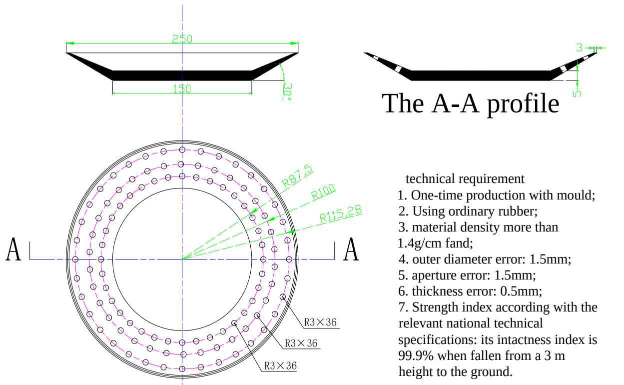

Fig. 1. Plate-shaped MEE-rock debris isolator

Calculation models and parameters

Based on the site experiments, the calculation models were constructed (see Fig. 2). The outside of the model is a steel tube, whose outside diameter is 250 mm. The upper part is filled with air, and the lower part is water. The isolator is in the air at its initial state. According to the site experiments, the isolator can quickly adjust its posture after being put in the water. Therefore, in order to reduce the calculation work, the length of the air column was considered as 1 m, the length of the water column was taken as 3 m, and the distance from the isolator to the water face was 0.3 m.

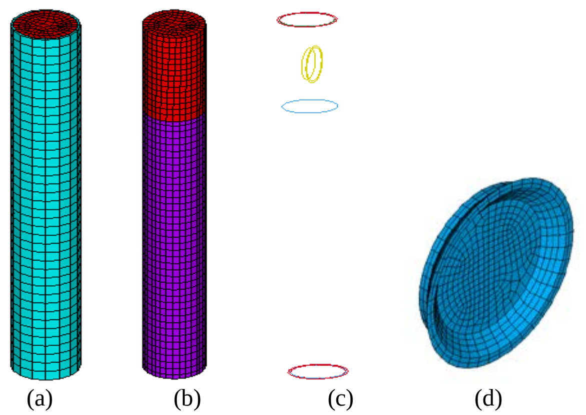

Fig. 2. Calculation models and finite element grids

Fig. 2 shows the calculation models of the numerical simulation of the adjusting process of the isolator and their finite element division, in which Fig. 2 (a) is the finite element grid of the whole calculation model, Fig. 2 (b) is the finite element grids of air (upper part) and water (lower part) in the tube, Fig. 2 (c) is the initial calculation state of the isolator, and Fig. 2 (d) is the finite element grid of the rubber plate at the bottom of the borehole.

The parameters of the materials are as follow: a flexible model is applied to simulate the outside steel tube, and the parameters of its material are shown in Table 1:

Table 1. Material parameters of the steel tube

Density /kg.m^{-3}	Elasticity modulus /GPa	Poisson's ratio
7810	190	0.25

Since air and water in the calculation model are fluid materials, their deformations are distinct under the disturbance of external force, so a state equation should be set during the calculation. In this part, Grűneisen state equation was used for air and water.

The material parameters of air are shown in Table 2:

Table 2. Material parameter of air

Density /kg.m^{-3}	Viscosity factor	C	γ_0
1.252	17.456E-6	343.7	1.4

The material parameters of water are shown in Table 3:

Table 3. Material parameters of water

Density /kg.m^{-3}	Viscosity factor	C	γ_0	S_1	S_2
1000	1.202E-3	1.647E-3	1.4	1.921	-0.096

The material parameters of the isolator are shown in Table 4:

Table 4. Material parameters of the isolator

Density /kg.m^{-3}	Elasticity modulus /MPa	Poisson 's ratio
1340	7.84	0.3

Simulation result of the process of the isolator falling into water

The process of the isolator falling into water was reproduced by numerical simulation. It theoretically reveals the feasibility of the isolator. Fig. 3 shows the isolator states at different times.

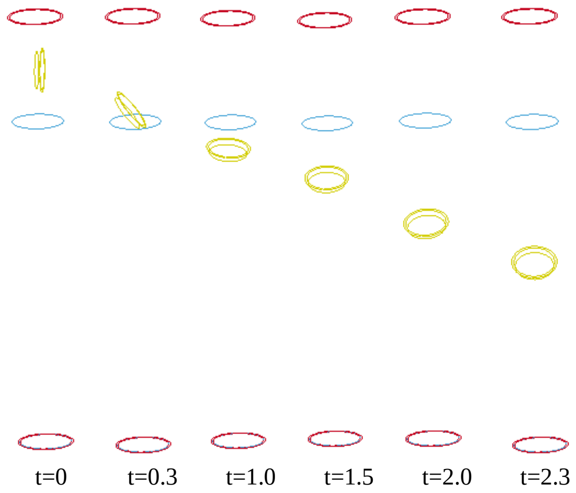

Fig. 3. Simulation results of the falling process of the isolator

Analysis of the simulation results

According to the numerical simulation, when the isolator meets water, it can quickly adjust its posture during the falling process, from vertical to the water level to face up, and there would be slight adjustment in the subsequent falling process, keeping face up. The numerical simulation reproduces the posture adjustment process of the site selection experiments, which shows that the designed MEE-rock debris isolator could adjust its posture automatically during falling, and it can keep face up when it meets water, so as to separate the emulsion explosives and rock debris.

SIMULATION EXPERIMENTS OF THE MIXING OF EMULSION EXPLOSIVES AND ROCK DEBRIS AND PERFORMANCE EXPERIMENT OF THE ISOLATOR

Since rock debris and water would be left in the borehole while drilling, emulsion explosives would get mixed with them, which would seriously influence the explosive's blasting performance, and lead to incomplete bursting of the explosives at the bench bottom and on top of the charge, causing boulders and bootlegs. In case of the appearance of these phenomena and for increasing the utilization factor of explosive energy, this section explores the mixing of MEE, rock debris and water in boreholes by simulation experiments, and experimentally studies the separation performance of the isolator.

Design of the simulation experiment set

The 1:1 model uses a steel tube with 260 mm inner diameter and 9 m length to simulate the borehole. For the convenience of observation, 7 observation windows, 40 cm long and 15 cm wide each, are opened in a line on the tube, and for the integrity of the "borehole", 2 layers of 3 mm thick high-strength transparent polyethylene sheets are wrapped outside the windows by iron wire. The steel tube is fixed on the ground with falseworks. Its structure is shown in Fig. 4.

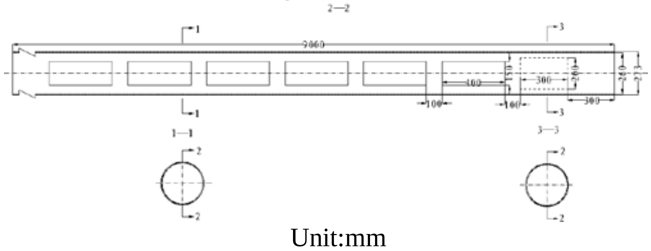

Fig. 4. 1:1borehole model structure

Fig. 5. On-site charging experiment set

Mixing mode experiments of the emulsion explosive and rock debris

Mixing mode experiments of the emulsion explosive and rock debris in the dry borehole

Put a certain amount of rock debris in the borehole model. Then pump the mixed emulsion explosive into it until continuous mixed emulsion explosive is seen. Plug the borehole model with rock debris. According to the on-site experiments, the mixture amount of the emulsion explosive and rock debris at the borehole bottom is quite large. The highest mixed column reaches 80 cm, and the shortest 18 cm. There is a certain amount of mixture of the emulsion explosive and the plugged rock debris on top of the charge. The length of the mixed column is 5 to 10 cm. Details are shown in Figs. 6 and 7.

Fig. 6. Typical mixture formed on top of the charge and at the bottom of the dry borehole model

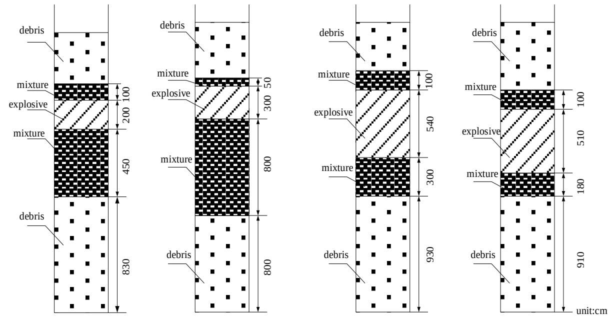

Fig. 7. Charging results in the dry borehole

Based on the experiments, the main reasons in the dry borehole that lead to the mixing of rock debris and the emulsion explosive are: (i) the stickiness of the on-site mixed emulsion explosive: the thinner the explosive, the more mixture there would be; and (ii) the distance between the pumping tube and the rock debris at the borehole bottom: the longer the distance, the more rock debris would be aroused up, and the larger amount of the mixture would be produced.

Mixting of the emulsion explosive and the plugged rock debris in the dry borehole is mainly caused by the impact of rock debris on the column charge while plugging.

Mixing mode experiments of the emulsion explosive and rock debris in the water borehole

Put a certain amount of rock debris in the borehole model, and then pour a certain amount of water into it. When the water gets clear, pump the mixed emulsion explosive in until continuous emulsion explosive is seen. Plug it with rock debris. According to the on-site experiments, the mixed amount of emulsion explosive, rock debris and water at the borehole bottom is quite large. The highest mixed column reaches 100 cm, and the shortest 12 cm. The gaps in the mixed column charge are filled with water in varying degrees (in an experiment, the emulsion explosive was not mixed with rock debris, but it was mixed with water). There is a certain mixture of the emulsion explosive with the plugged rock debris on top of the charge. The length of the mixed column is 9 to 15 cm. Details are shown in Figs. 8, 9 and 10.

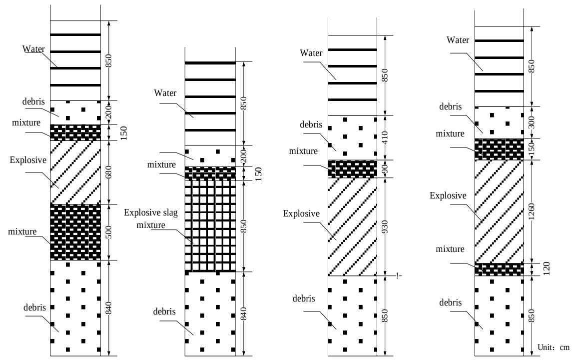

Fig. 8. Charging results in the water borehole

Fig. 9. Charging result of the water borehole model

Fig. 10. Typical mixtures in a borehole with water formed at the top and bottom

Based on the experiments, there would be a certain degree of mixing of the emulsion explosive, rock debris and water at the bottom of the water borehole.

When the distance between the charging tube and the borehole is shorter, most is the mixture of explosives and water, and less is the mixture of explosives and rock debris. When the distance is larger, the mixture is mainly made of explosives, rock debris and water, and the percentage of rock debris in the mixture is higher than that in the first circumstance.

When the pumping tube is plugged into the slurry at the borehole bottom while pumping, because of the disturbance of the pumping, there would be a turbulence flow. Since the slurry has a larger specific gravity than the explosive, the explosive, rock debris and water would quickly get mixed. In this circumstance, the mixing is most thorough, and part of the explosive fails to explode.

Table 5. Performance experiment result of the plate rubber isolator

Type	Experimental condition	Experimental time	Time of sinking to the bottom in the tilting posture	Time of sinking to the bottom in the level posture	Sinking speed, m/min
Plate rubber isolator	In the water-filled borehole	1000	0	100%	2～2.5
	In the dry borehole	1000	89	91.1%	-

Performance experiments of the isolator

The performance experiments of the isolator were conducted in a simulating experiment set. The posture adjustment performances, the sinking speeds of the plate-shaped rubber isolator and the bowl-shaped plastic isolator were simulated in both dry borehole and water-filled borehole. The design parameters were revised based on the experiments. Part of the experimental results of the finalized design of the plate rubber isolator are shown in Table 5

According to the experimental result above, the percentage of the plate rubber isolator sinking to the bottom in the level posture in the water borehole is 100%. Its posture adjusts slowly in the dry borehole, and it is easy to be crushed by the wall while sinking.

Separation experiments of the isolator

According to the experiments of different mixing modes of emulsion explosives and rock debris, with or without water or not, on the bottom of the borehole or on top of the charge, there would be a certain extent of mixing between mixed emulsion explosives, rock debris and water, especially at the borehole bottom, which would influence explosive's blasting performance at that part and causing explosive misfire. That would seriously influence rock fragmentation results at the borehole bottom, and produce boulders and serious bootlegs, slowing down the subsequent exploitation and loading speed. In order to reduce or avoid the above circumstances, isolators are arranged at the bottom of boreholes before pumping and on top of the charge after pumping to prevent mixing between MEEs, rock debris and water, making sure the explosive's utilization ratio. Related experiments are studied.

2.4.1. Mixed emulsion explosive charging experiments with isolators in dry boreholes

Put a certain amount of rock debris in the borehole model. Arrange an isolator before charging, and then pump the explosive until continuous mixed emulsion explosive is seen in the model. Arrange another isolator on top of the charge and plug the model with rock debris. The experiments show that, after the isolators are arranged in the model, there is nearly no mixing both at the bottom of the borehole and on top of the charge. Details are shown in Fig. 11.

Mixed emulsion explosive charging experiments with isolators in water boreholes

Put a certain amount of rock debris in the borehole model, and then pour a certain amount of water. When the water gets clean, arrange an isolator in the borehole, and then pump a certain amount of the mixed emulsion explosive in it. Arrange another isolator on top of the charge, and plug the borehole with rock debris. The experiments show that, after isolators are arranged in boreholes, there is nearly no mixing between the mixed emulsion explosive and rock debris both at the bottom of the borehole and on top of the charge, but there is a certain mixing between the mixed emulsion explosive and water at the bottom of the boreholes. Details are shown in Figs. 12 and 13.

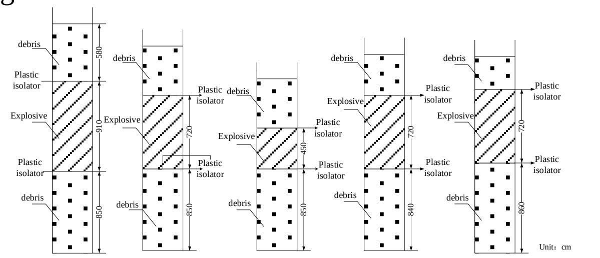

Fig. 11. Structures of charging experiments in dry borehole models

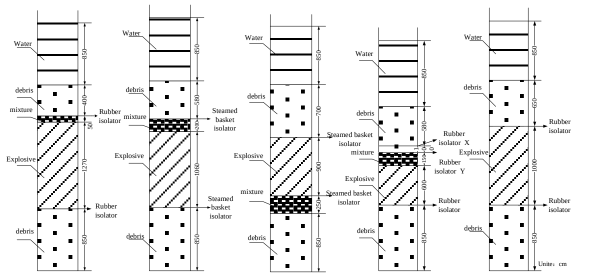

Fig. 12. Structures of charging experiments in water-filled borehole models

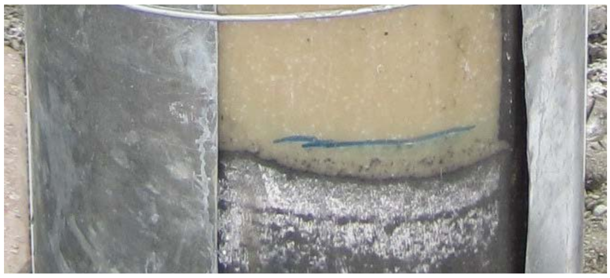

Fig. 13. Charging experiments of the mixed emulsion explosive in water-filled borehole models with isolators

All experiments showed that as long as the isolators are arranged, both in the dry borehole and in the water-filled borehole, there is barely mixing between the mixed emulsion explosive and rock debris, which testifies that the function of the isolator is notable.

However, there is still a certain mixing between the mixed emulsion explosive and water. The main reason is the distance between the pumping tube and the borehole bottom. The falling of the mixed emulsion explosive is slow in water. This would be easy to cause that some water is unable to seep up and stays in the boreholes, which would form a mixture of the MEE and water. The experiments also revealed that if the pumping tube is inserted to the borehole bottom and then pumps the mixed emulsion explosive, the charging result would be noticeably improved and the water at the borehole bottom could be basically squeezed out by the explosive.

CONCLUSION

The plate rubber isolator, designed on the basis of the principle of fluid dynamics, can automatically fall along the borehole under the its gravity, and adjust its posture under the effect of uplift and resistance force of water or air to the level condition with its bottom down before it reached the bottom, which would lead to the separation result.

The large-scale explicit dynamic finite element software, ANSYS/LS-DYNA, was applied to simulate the isolator posture adjustment during falling, and the result shows that the designed isolator could make a self-adjustment while falling, and could cover the water face when it meets water, which would achieve the separation result of the mixed emulsion explosive and rock debris.

The plate-shaped rubber isolator could effectively separate the mixed emulsion explosive and rock debris at the bottom of the borehole, avoiding mixing and the misfire. The isolator has many advantages. Its material is easy to get. Its production process is simple. It is easy to operate, of low cost, and takes little length of the borehole. There is no need to deliberately pay attention to the posture of the isolator.

The on-site mixing experiments showed that the amount of the mixture of MEE, rock debris and water at the borehole bottom is rather large. The highest mixed column reaches 100 cm, and the shortest 12 cm. The gaps in the mixed column charge are filled with water in varying degrees. There is a certain amount of mixture of the emulsion explosive with the plugged rock debris on top of the charge. The length of the mixed column is 9 to 15 cm.

The separation experiments of the isolator showed that the falling posture of the isolator is specific and stable. The percentage of the plate rubber isolator sinking to the bottom in the level posture in the water borehole is 100%. In the dry borehole, its posture adjusts slowly, falls with a quicker speed than the bowl-shaped plastic isolator does, and it is easy to be crushed by the wall while sinking.

The isolator could effectively separate the emulsion explosive from the rock debris at the borehole bottom or that for plugging, avoiding explosion waste caused by the mixing, thus increasing the utilization ratio of the mixed emulsion explosive. The isolator just takes up 5 mm of the borehole length. Comparing with other types of isolators, this one could improve the utilization ratio of the borehole, achieving the goal of lowering the blasting cost.

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