〔論　文〕

프라즈마장비의 發破工法 발파공법

Rock of Fragmentation with Plasma Blasting Method

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ABSTRACT: Rock fragmentation with plasma blasting technique has advantageous properties in contrast to the conventional blasting method in controlling of flyig rocks and ground vibrations when residents are complaining or surrounding structures stay in protection from blasting operations.

The experiences show in urban construction works that the plasma blasting is the most possible method to prevent damages and minimize adverse environmental impacts. The fragmentation energy level is evaluated by numerical simulation using PFC for various drill hole patterns and tested accordingly to get the feasibility. The energy output of plasma blasting system has been improved to a level of 1 MJ, which can break a 2-3㎥ granite boulder or 1.5m height bench face. Measurements are cvarried out to get the ground vibration level and propagation equation. So that the control of the blasting operations can be performed more precisely and safely.

1. INTRODUCTION

The conventional blasting technique, drill and blast method, has adverse environmental effects and in many cases where explosives of brisance is rather cumbersome or not possible to apply, when neighbouring structures stay in protection or residents are complaining for the possible damage and annoyance by blasting activities. To avoid such adverse effects the plasma blasting method is developed to utilize the advantageous properties. The plasma transformed from the electrolyte solution in a borehole reaches an energy of 280KJ by eletrickal input of 8.5KV and 200A and this rapidly released energy in the borchole developes a shock wave, which in turn producing a stress field that fractures the rock without producing excessive dust and fly rocks. The range of plasma strength varies with chemical additives. The increased energy delivery covers a wide scope of applications, from breaking a boulder to bcench cutting of grounds for buildings in urban area.

2. DETERMINATION OF PLASMA STRENGTH

Electrical energy stored in a capacitor bank is turned on by a high current gas

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piping switch this causes the are effect at drilled into the rock face. Under these conditions the electrolyte turns into a high temperature, high pressure plasma. The pressure must be high enough to fracture hard rock. Electrical energy input, an amount of and the oxidizer as additive surrounding the space between the electrodes and the rock determimes the energy output of the system in this case explosion energy can be interpreted analogically; it is initiated from the electrical source and chemical reation.

From the equation of chemical reaction by aluminum power as additive the oxygen balance reveals 0.89 gr and explosion energy is 22.3KJ for 1gr of alumiunm.

The Plasma system can supply 280KJ by electrical energy for 1.5 msec as shown in fig. I. So the system may deliver 0.95MJ additionally as a blasting energy when 30gr of aluminum completed its chemical reaction. This amount becomes 0.243 of relative weight stength of 243gr of ANFO. 201gr of GD or 320 gr of Emulite. The strength of an explosive can be explained with Langefors' empirical equation by the explosive energy, e, and the gas volume, V, as follows;

$$s = 5/6\ e + 1/6\ V \qquad (1)$$

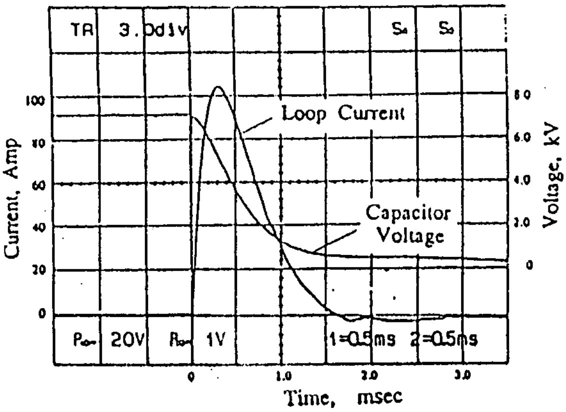

Fig. 1 The loop current and capacitor voltage history during a typical plasma discharge

Referring to this concept, the strength of the plasma system can be calculated as RWS 0.205,GD HiMite 5000 as RWS 1.19 respectively to RWS 1.0 of ANFO theoretically.

Table 1. Equivalent weights of explosives to the plasma strength (unit; gr)

Explosives	in RWS		in site test	final estimation
	theoretically	by equation		
Korean				
GD HiMite 6000	185	164	199 - 217	180
GD HiMite 5000	196	172	210 - 228	200
NewMite 4000	276	236	296 - 312	280
Finex 1	308	266	331 - 352	310
American				
ANFO	243	205	261 - 271	230
Gelatine Dynamite	209 - 222	205	224 - 271	210
Slurry (Ireseis)	279 - 295	205	300 - 331	280
Swesish				
Emulite	312	253	330 - 340	310

In the first developing stage of the plasma blasting technique the delivered energy did not include the chemical reaction. Tastes were carried out with 1㎥ concrete blocks by 0.28MJ of the electrical energy only. This amount was expected to have the power as much as 66 gr of gelatine dynamite(4.27MJ/kg). The specimen was caused three evident cracks which divided the upper half to equi-volume of 4 pieces and did not break the lower half. Simultaneously chemical explosive was applied to the same specimens which resulted in 1,2 or 3 cracks perpendicular each other. That system was equivalent to the same power of 46-67 gr of gelatine dynamite without tamping and when sand tamping was done to the power of 25-35 gr.

Adding aluminum power in the eletrolyte, the strength of plasma was so large engough to break hard rocks by chemical reaction that the scope of the application can be extended to the blasting operations for excavation works. One test for granite, of medium hard rock was completed to compare with Emulite. It was proved that the plasma blasting system has the power of 330gr of Emulite, which is a little more powerful than theoretically expected. The relative strength of the plasma is listed in Table 1 which can be applied in rock blasting design.

3. NUMERICAL SIMULATION OF PLASMA BENCH BLASTING

3. 1 Modeling technique

The fragmentation phenomenon for a rock bench model by plasma blasting is simulated using PFC^{2D}(Particle Flow Code), which is based on distinct element method. The Particle elements in PFC^{2D} are assumed to be rigid balls and the behavior at all contacts is characterized using a soft-contact approach, in which finite normal and shear stiffnesses are taken to present the measurable contact stiffness. The behavior of a solid can be simulated by bonding groups of balls togehter at their contact points using contact bond. The existance of a contact bond precludes sliding and limit the allowable magnitudes of normal tension and shear force acting at the contact. If either the nomal or shear limit is reached. Then the bond breaks and the contact cannot subsequently take tension.

The model of a rock bench is shown in Fig. 2. The interval between holes and the distance from free to the 1st row of holes are same as 60cm, and the hole diameter

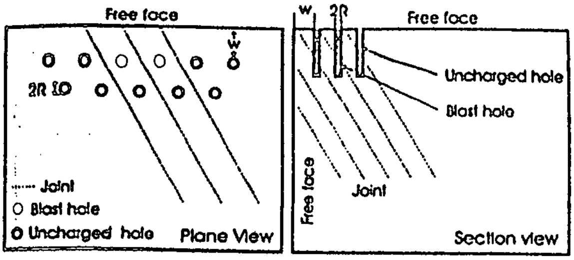

Fig. 2. The model of a rock bench blsting

is 10cm. The dottted lines are pre-existing joints.

It is known that the plasma reation induces shock wave only without gas production. So in this modeling, only the effect of shock wave is considered and the pressure by shock wave is imposed on the boundary particles of blasting hole. The history of borehole pressure with time by blasting is given as sine function of equation(2). Here, P_b is borehole pressure with time, P_o is the maximum borehole pressure, f is frequency, and t_o is the period of sine function.

$$P_b = P_o \cdot sin(2\pi ft),\ f = 1/t_o,\ 0 \leq t \leq t_o/2 \quad (2)$$

Referring to the discharge history of current and voltage during plasma reaction, lasting duration of the borehole pressure by plasma reaction is set as $t_{max}(= t_o/2) =$ 1.5msec.

3.2 *Fragmentation energy with blasting pattern*

For the plane view model of the rock bench, input borehole pressure, Po, and fragmentation pattern according to single hole blasting and synchronous aulti-hole blasting *and synchronous multi-hole blasting* are are analyzed. The optimum fragmentation pressure, namely, the minimum level of P_o which can produce crack formation to the bench face is obtained as about 692 Mpa in case of the single hole blasting. And it is obtained as 620 Mpa in cases of synchronous two-hole blasting and as 604 Mpa in case of synchronous four-hole blasting. It is shown from this result that the synchronous multi-hole blasting can produce similar fragmentation effect with 87-90% of the input energy compared with the single hole blasting

The effect of delay blasting on fragmentation with varying the delay interval between 1st and 2nd row of blasting hiles is sinmulated. Several energy terms can be calculated in PFC^{2D} analysis. Here, the ratios of the kinetic energy by particle movements and the strain energy stored at contacts to the body work by all applied forces are compared.

One priod of delay interval s-set as 1.5 msec which is the lasting duration of the borehole pressure by plasma reaction. According to this analysis, the delay interval between 1-2 period shows good fragmentation efficiently as shown in Table 2. This fregmentation medelling should be well related with field condition such as pre-existing joint patten.

Table 2. Fragmentation energy ratio with delay interval

Delay interval	ratio of knietic energy to body work	ratio of strain energy to body work
Synchronous	0.04	0.58
0.5 period	0.39	0.49
1.0 period	0.71	0.20
2.0 period	0.59	0.25
5.0 period	0.57	0.24

3.3 Effect of the pre-existing joint pattern on fragmentation

It is known that pre-existing joint patterns have effects on rock fragmentation by blasting. There cases of joint patterns are analyzed for bench blasting simulation.

In case of the joint pattern paralled to the bench face(Fig.3), the region between blasting hole and bench face is devided into several blocks with some opening of joint to distant region. On the other hand, there is little effect of pre-existing joints perpendicular to the bench face. The fragmentation pattern with inclined pre-existing joint is represented in shock wave propagates toward the joint plane by obtuse angle, new crack is not produced even though the energy is almost consumed in joint opening and released through joint. On the other hand, in the right side where shock wave propergates toward the joint plane by acute angle, some new cracks are produced acress the joint. The section view model with a pre-existing joint set inclined inward the rock bench as shown in Fig. 5 shows good fragmentation with new crack formation than the model with a pre-existing joint set inclined outward the rock bench as shown in Fig. 6

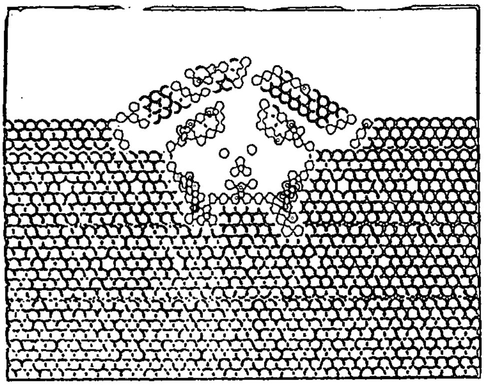

Fig. 3. Fragmentation pattern for the plane view model with a joint set parallel to bench face

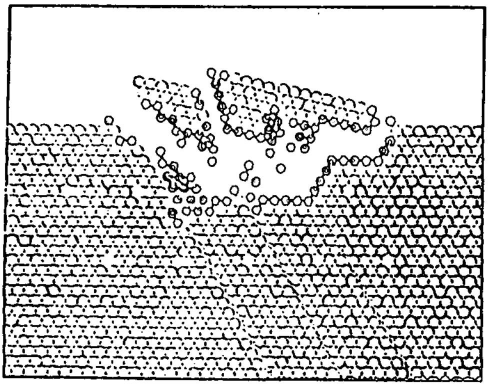

Fig 4. Fragmentation pattern for the plane view medel witha joint set inclined to bench face.

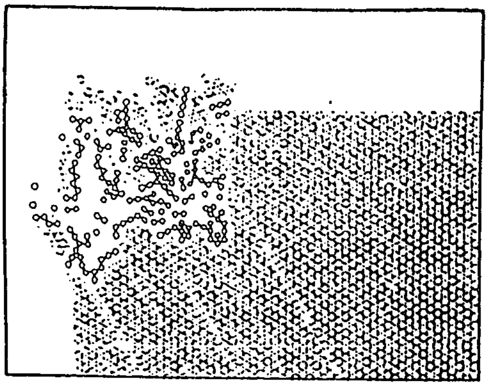

Fig.5. Fragmentation pattern for the section view model with a joint set inclined inward the rock bench.

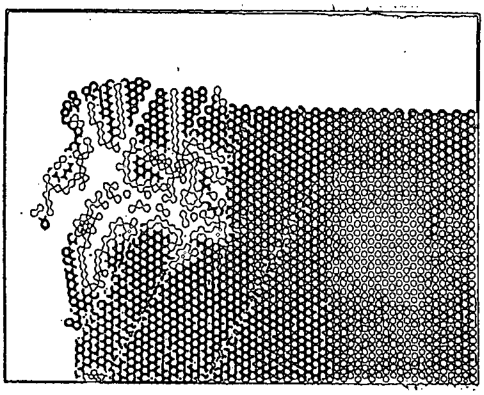

Fig.6. Fragmentation pattern of the sentiio view model with a joint set inclined outward the rock bench

The borehole pressure history and frequency characteristics of the shock wave by plasma reaction, which is related with damping effect, should be well evaluated as well as field rock conditions for numerical simulation of plasma blasting and its application to field.

4. CHARACTERISTICS OF GROUND VIBRATION, AIR PRESSURE AND FLY ROCK INDUCED BY PLASMA BLASTING

Blasting operations associated with the rock excavation work may have an environmental impact on nearby structures ao human beings. Use of explosives is sometimes re-stricted in for vibration and noise. The Plasma blasting system are devleoped as one of non-explosive residential area where the use of explosive demolition mothods to be applicable in the residential area where the use of explosives is restricted. Because the source characteristics of explosive blasting, it is also expected to generate different types of ground vibration, air pressure, and fly rock. Field measurements were performed to get understandings of environmental effects of plasma blasting system.

4.1 Measure of vibration to assess damage potential of structures

Peak particle velocity has been suggested as the descriptor to assess the damage potential of structures. Although peak particle velocity has been widly used, velocity itself is not sufficient to evaluate structural damage without considering tolerance of the structure. Structures respond differently to vibrations of differing frequency content. In recent years frequency content has become an increasingly important parameter in the measurement and analysis of the ground vibrations from blasting. The former U.S. Bureau of Mines and Office of surface Mining recommended safe blasting vibration criteria for residential structures, depending on the peak particle velocity varying with respect to the frequency (Siskind et al. 1980). The criteria incorporate an important element of response spectra technique in some respects. The German vibration standard, DIN 4150, also provides similar criteris for several types of structures.

4.2 Vibration level and propagation equation

The blast-induced ground vibration decreases in amplitude with increasing distance. The ground motion can be measured as displacement,, velocity or acceleration of a particle in the ground. The propagation characteriatics of the vibration is influenced by rock properties, geological discontinuities and design prameters. The most general from used for the prediction of ground vibrations from explosive blasting is given by

$$PPV = K \left(\frac{D}{W^b} \right)^n \qquad (3)$$

where PPV is the peak particle velocity in mm/sec, W is the charge weight per delay in kg, D is the distance from a blast source in m. The constants K, n and b are empirical and site specific. Analysis of measurement data shows that good correlation of results could be represented by square-root or cube-root scaling where the power b in D/W^b is 1/2 or 1/3, respectively (Nicholls et al. 1971 : Ryu & Lee 1979). Fig.7 shows the plots of each compotent of measured ground vibration induced by plasma system on log-log scale. Measurements were carried out at Kimpo granite quarry. X-axis is the scaled distance which scales the distance by cube root of voltage, kV. Solid line is the regression line representing the mean trend of peak particle velocity as a function of scaled distance. The propagation equations for each component are as follow :

$$PPV(L) = 162.0 \left(\frac{D}{KV^{1/3}} \right)^{-2.130} \qquad (4)$$

$$PPV(T) = 80.0 \left(\frac{D}{KV^{1/3}} \right)^{-1.887}$$

$$PPV(T) = 27.0 \left(\frac{D}{KV^{1/3}} \right)^{-1.437}$$

The correlation coefficient is 0.854 for longitudinal compenent, 0.826 for transverse 0.68 for vertical, respectively. It shows better correlation when distance is used in of scaled distance.

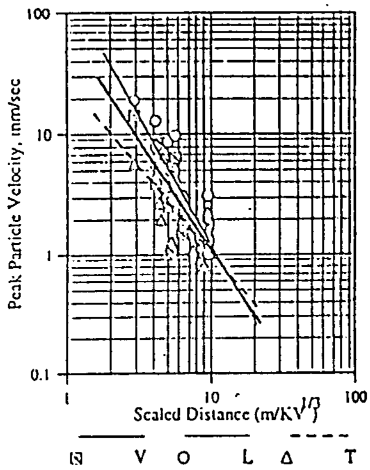

Fig. 7. Peak particle velocity vs. scaled distance

The propagation equations without scaling as follows :

$$PPV(L) = 802.5\ D^{-2.211}$$
$$PPV(L) = 338.5\ D^{-1.968}$$
$$PPV(V) = 89.8\ D^{-1.543}$$

The correlation coefficient is 0.865 longitudinal component, 0.841 for transverse 0.712 for vertical respectively. Fig. 8 shows results of plotting PPV with respect to distance from source.

In explosive blasting data used comparison, slurry explosive (KOVEX) is in granite and distance varies between 15cm from source. The propagation equa obtained from the data are as follows :

$$PPV(L) = 189.6\ D^{-1.152}$$
$$PPV(T) = 590.7\ D^{-1.463}$$
$$PPV(V) = 588.2\ D^{-1.510}$$

The correlation coefficient is 0.790 longitudinal component, 0.864 for transverse and 0.932 fir vertical, respectively. The attenuation index, n, appears to be about 2.0 for blasting, and about 1.5 for explosive blasting. That is, level of ground vibration induced by plasma blasting decrease more rapidly.

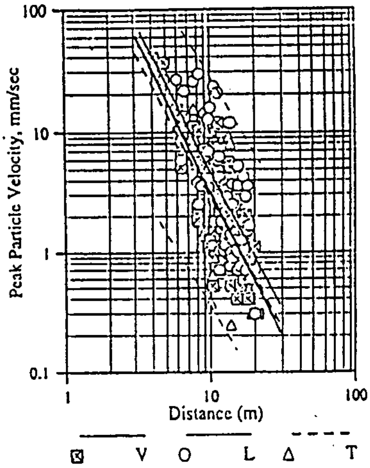

Fig. 8. Peak parrticle velocity vs. distance

4.3 Frequency, noise and fly rock

The distribution of principal frequency which is defined as that associated with peak amplitude of vibration level is ranging fron 30 to 110 Hz in plasma blasting while 20-70 Hz in explosive blasting. Although field conditions are not exactly same, current measurement data show the tendency of higher frequency in plasma blasting. Characteristics of generation of air pressure is not analysed due to lack of data.

Rock breaking works, however, were carreid out with satisfying the allowable limit described in the regulations. It was shown that sound level was reduced by 15 dB in A-weighting measurement by installing a fence.

The distance that fly rack is thrown by plasma blasting is very limited to surroundings of a source so as to allow nearby measurement. It is the typical differnece form that by the explosive blasting. Rock fragments may be propelled by build up gas pressure in explosive blasting. Uncoverd explosion sometimes yields unusual distant throw and causes hazards.

5. CONCLUSION

The plasma blasting technique opens a new field inrock breaking activities where adverse environmental impacts have to be considered. The plasma strength is improved with chemical additives that the rock fragmentation is feasible not only for boulders but also bench face. The numerical simulation shows the practicability of multi-hole and controlled blasting in jointed racks. Analysis of ground vibration. The peak level of ground vibration decreases rather rapidly and associates higher frequency which is more favourable considering the damage potential of structure.

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