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Effective Use of Expansive Cement for the Deformation and Fracturing of Granite

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ABSTRACT

The fracturing of rocks in mines and quarries may be regarded as the first stage of comminution. The use of commercially available expansive materials in the dimension stone quarries is on the increase due to their effectiveness in controlled fracturing. However, these expansive cements are very costly and any means of economizing on their use is highly desirable.

An attempt is made to study the deformation behavior and fracture of granite by pouring expansive cement in a set of holes at variable spacing as against the usual practice of using holes at same spacing. It was found that the fracture through holes of variable spacing, starting from holes with smaller spacing, initiated sooner and propagated faster than through the line of holes with consistent spacing.

Keywords: Comminution, granite, fracturing, expansive-cement, quarrying

1. INTRODUCTION

Fracturing of rocks into blocks of definite sizes and shapes is essential for such industries as marble and granite quarries. The blocks or rock are cut so as to be easy to transport them to the factory. Large blocks from a dimension-stone quarry are processed to required dimensions by sawing, polishing and trimming.

There are several methods of producing blocks of required dimensions from a dimension-stone quarry; such as flame jet cutting, diamond wire cutting, wedging, and using expansive cement.

The use of expansive cements as a substitute for explosives is on the increase, especially in non-violent and pollution-free breakage of rocks in populated areas and in dimension stone quarries of granite and marble where excellent control on breaking rocks to the required dimensions is achieved.

Two Japanese companies, namely, Onada Cement Company and Sumitomo Cement Company are marketing expansive cement in Saudi Arabia. A local company, FOSAM has also started marketing expansive cement called Fosroc. Bristar, the most popular brand produced by Onada Cement Company, is supplied in four grades as Bristar-100, 150, 200 and 300 for use in maximum temperature of 35° C, 20° C, 15° C and 5° C, respectively. Lately, Bristar-100S is supplied as being more suitable than Bristar-100 for the prevailing temperature conditions of Saudi Arabia [1].

Onada Cement Company [1] conducted research on the properties of various grades of Bristar using long, thin-walled steel cylinders with strain gauges glued to their exterior for the determination of expansive pressure generated by the various grades of Bristar. They found that a stress level of 1300 t / m^2 to 3200 t / m^2 was achieved with the internal diameters of 10 mm and 50 mm, respectively. Shiro Ishi [2] reports that Bristar basically consists of lime, clay and gypsum which are mixed in a certain proportion and burnt in a rotary kiln at 1500° C. The resulting clinker is ground at 2000 to 3000 cm^2 / g specific surface area of grains.

Dawding and Labuz [3] used thick walled steel cylinders for determining the internal pressure exerted by Bristar expansive cement. They have indicated that the expansive pressure in a hole is not a function of the borehole diameter and, therefore, a simple scaled distance relationship of borehole spacing and diameter is appropriate for relating tests with different hole-diameters in the same material. They noted that temperature and thermal sensitivity could influence the spacing. They also performed tests on dolomite and found that a spacing of 8 times the hole- diameter was optimum.

Dar et al [4] conducted research to determine the burden to spacing ratio for the optimum use of Bristar-100 in the marble quarries of Saudi Arabia. They carried out laboratory studies on marble using various combinations of burden and spacing with 14 mm diameter holes and correlated the laboratory results with 34 mm diameter holes in a marble quarry. They found out that in both the cases, the optimum burden to

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*Corresponding author; e-mail: almagrabii@yahoo.com spacing ratio was 0.8. Tests on thick walled steel cylinders revealed that a pressure of 40 MPa, 52 hours after pouring expansive cement, with addition of 30% water by weight.

Darwish and Hanif [5] studied the optimum use of Bristar-100S in granite quarries of Saudi Arabia and strain-time relationship at various points around boreholes filled with expansive cement and investigated the mechanism of crack initiation and propagation in a block of granite. They found that the distribution of tangential strain around a hole filled with expansive cement followed the inverse square law. The strain was inversely proportional to the square of the distance from the hole.

Hanif and Fadol [6] attempted to economize on the amount of expansive cement by trying to mix other materials with the cement and leaving some of the holes empty. Mixtures with sand did not prove effective. However, leaving some of the holes empty yielded some interesting positive results. They also found that leaving two consecutive holes empty was counter-productive.

The objective of the study, hereby, reported was to test the possibility of facilitating the initiation and propagation of a crack through a line of holes at gradually increasing spacing from one side to the other.

2. MECHANICAL TESTS ON GRANITE

A block of granite from Ranya quarry in the Southern Province was obtained with the courtesy of the Red Sea Mining Company. It was 1.2m long x 1.0m wide x 0.8m high. The top surface of the block was made plane and smooth by cutting and honing. Additional small samples were also obtained for producing specimens for various mechanical tests.

The expansive cement in a borehole causes radial compressive and tangential tensile stresses in the surrounding rock mass. Rocks are much weaker in tension than in compression. Hence the tensile strength is the most important property in determining whether or not the rock around the hole filled with expansive cement will break. Equally important are the elastic properties like Young's modulus and Poisson's ratio. It may also be interesting to determine uni-axial compressive strength and shear strength.

The Brazilian test, point load test and flexure (beam) test were made to indirectly determine the tensile strength of granite. The punch shear test was applied to measure the shear strength. The uni-axial compression test was applied to 35 mm diameter and 70 mm long specimen. Axial and lateral strains were measured at successively increasing uniaxial compressive stress. Young's modulus and Poisson's ratio were determined from this stress vs strain relationship.

The Brazilian test was applied on 35 mm diameter discs subjected to diametric compression. If P is the applied load at failure, d, the diameter and L, the thickness of the disc, then, Brazilian tensile strength, $T_{B,}$ is given by:

$$T_B = 2P / (\pi d L) \qquad (1)$$

The SI units were used in all cases as may be seen in Table 1.

The point load test involved compression of a rock core between two hardened steel ball points. The test was originally developed by Brock and Frankline [7] for testing irregular lump specimen. However, it is extensively used in indirect determination of tensile strength of rock core samples [8,9]. The point load tensile strength index is given by:

$$T_{dp} = P / (d L) \qquad (2)$$

The beam test was applied by three point loading of cylindrical cores of 35 mm diameter. The punch shear test was applied to thin discs using hardened steel punch and anvil. The shear strength was given by:

$$S_o = P / (\pi d L) \qquad (3)$$

Where, d is the diameter of the punched hole and L is the thickness of the disc.

The results of various tests are given in Table 1.

Table 1. Results of mechanical tests on ranya granite [6].

S. No	TEST	DESCRIPTION	RESULT	REMARKS
1	Brazilian	Diametric compression of discs	10.60 MPa	Mean of 11
2	Point load test	Tensile strength Index	14.53 MPa	Mean of 17
3	Beam test	Modulus of rupture	30,45 MPa	Mean of 6
4	Uni-axial compression test	Uni-axial compressive strength	180.3 MPa	Mean of 6
5	Punch shear test	Shear strength	23.78 MPa	Mean of 6
6	Stress-strain test	Young's modulus @50% final stress. Poisson's ratio	50.20 GPa 0.235	Mean of 2

The tensile strength values determined by the Brazilian and point load tests were found to be fairly close. Either of them may be used for analysis. However, stress distribution over the fracture surface is more uniform for Brazilian test than for the point load test. The latter is more sensitive to the effect of specimen size on the value of strength. Therefore, it may be advisable to use the results of the Brazilian test. Also, the mechanics of failure in the case of Brazilian test and point load test i.e. induced tensile strain due to compression, resembles more closely with the problem of fracturing rock by expansive cement. The results of the beam test are not adopted for the purpose of this research.

The mean value of uni-axial compressive strength of 180.3 MPa was 17 times as much as the tensile strength (Brazilian) and 13 times the point load tensile strength index. According to Griffith's criterion, this ratio for brittle, homogenous isotropic materials should be 8. This ratio varies between 10 and 20 for most rocks. The Ranya granite was found to be very brittle.

2.1. EXPANSIVE PRESSURE GENERATED BY BRISTAR-100S

The expansive pressure generated by the expansive cement Bristar-100S was measured by a specially designed thick walled cylinder provided with strain gauges at its exterior [6]. The mild steel cylinder was 250 mm long with internal diameter of 45 mm and external diameter of 80 mm. It was constrained at both ends by studded 18 mm thick steel plates.

The strains measured by strain gauges on the circumference were used to calculate internal borehole pressure. The relationship of time in hours and internal borehole pressure in MPa is presented in Table 2. The Table is deduced from the actual time- pressure curve based on strain measurements taken at various times starting a few hours after pouring.

Table 2. Time vs borehole pressure generated by bristar-100S.

Time (Hours)	24	48	72	96	120	144
Pressure (MPa)	34	41	44	47	50	52

2.2. FRACTURING OF GRANITE BY EXPANSIVE CEMENT

In order to test whether there was any benefit of using holes with variable spacing, two experiments A and B were carried out with two lines of holes on the opposite sides of a Ranya granite block. Both had the same number of holes of the same diameter and depth; but one with uniform spacing and the other with gradually increasing, variable spacing.

2.3.EXPERIMENT A --- FIVE HOLES WITH UNIFORM SPACING

The Ranya granite block after earlier tests had two 90 cm long sides opposite to each other. On one side, five 14 mm diameter holes were drilled at center-to-center spacing of 15 cm to a depth of 40 cm. The burden was 14 cm. This may be called Experiment A., which is sketched in the upper part of Figure 1. The five uniformly spaced holes of experiment A, from left to right, are numbered, HA1, HA2, HA3, HA4 and HA5. Strain gauge SG1 was fixed between holes HA1 and the free face, SG2 fixed between HA4 & HA5 and SG3 was fixed between HA5 and the end.

2.4. EXPERIMENT B --- HOLES WITH VARIABLE SPACING

In this experiment, holes were drilled at variable spacing starting from the left hand side, hole HB1 was 9 cm from the free face, HB2 at 9 cm from HB 1, HB3 at 13 cm from HB2, HB4 at 18 cm from HB3. The spacing between HB4 and HB5 was 23 cm and that between HB5 and the free face was 18 cm. Since spacing was different for all the holes, 6 strain gauges were fixed in between the holes and between the end holes and the respective free faces. SG4 was between right free face & HB1, SG5 between HB1 & HB2, SG6 between HB2 & HB3, SG7 between HB3 & HB4, SG8 between HB4 & HB5 and finally, SG9 between HB5 & left free face.

3. DISCUSSION

The results of time versus strain relationship for all the strain gauges related to both the experiments are presented in Fig. 2 for ease of comparison. Strains in Fig.2 are plotted only up to 200 microstrains because the fracture occurs below that value. An attempt to plot values up to several thousands microstrains would not exhibit the difference between the behavior of various gauges in the vital initial stage. In all the cases, there was a relatively low rate of increase for the first few hours. The slope of the curves, then, increased for up to 24 hours. It, then, accelerated at a very high rate as the cracks started propagating.

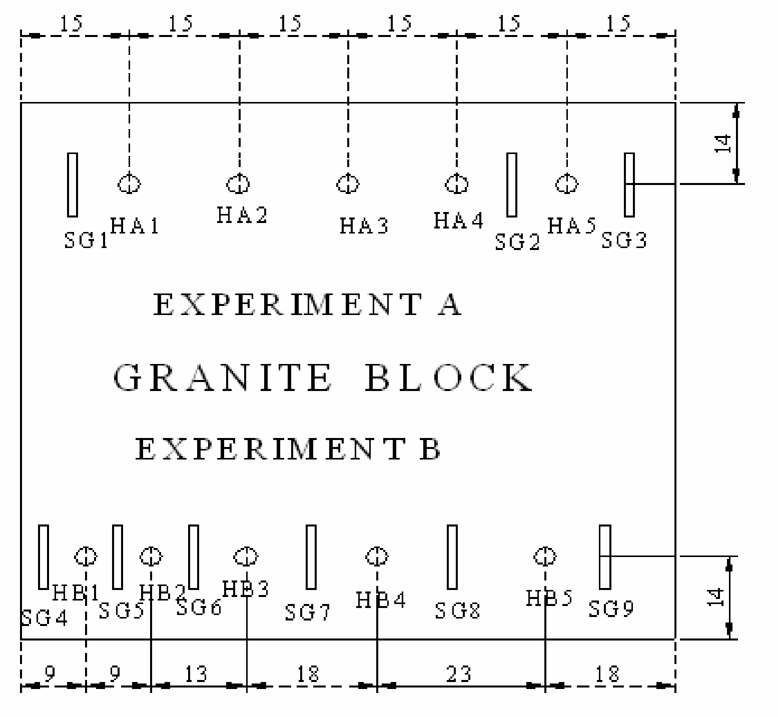

Figure 1. Positions of Holes and Strain Gauges on Granite Block (All dimensions are in centimeters)

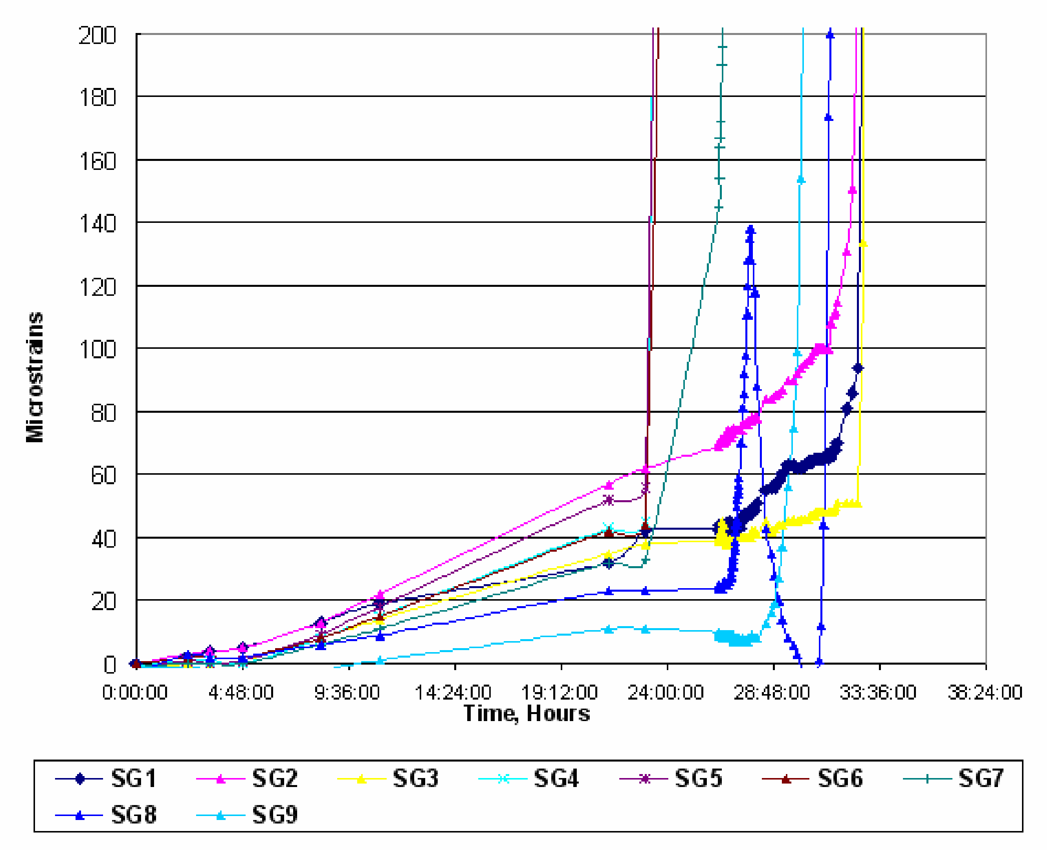

Figure 2. Strains vs time graphs for all strain gauges of both experiments.

For all the three strain gauges of Experiment A, with uniform spacing, there appears to be a transitional phase of about 6 hours in which there is a gradual increase of the slope prior to the very high rate. All the strain gauges showed a steady increase in the first stage beginning at about 4 hours after pouring. SG1 reading was in steady increase from 2 to 81 micro-strains in the first 32 hours. Then it started increasing at a high rate indicating the initiation of fracture of the rock. Almost same was the behavior of SG2 & SG3 in relation to Experiment A. The crack became visible at around 35 hours after pouring. The crack propagation was quite good because of the suitable spacing to burden ratio. But the time was relatively long in comparison to experiment B.

The SG4 of Experiment B registered the fastest rate of increase of strain. The steady rate of increase of strain continued until for about 23 hours as against 32 hours for Experiment A. At around 23 hours after pouring, the rate of increase of strain suddenly increased indicating the initiation of fracture. At 26 hours, the crack became visible. The next two strain gauges, SG5 & SG6 showed almost the same trend with a slight delay.

In SG7 the reading was increasing steadily until about 23 hours, when the slope of the curve started increasing at a high rate. The strain reached a value of 140 at about 26 hours when the rate of increase of strain further rose indicating the initiation of the crack which became visible at about 30 hours. The same happened in SG8. It increased up to 138 at 28 hours then it drastically dropped to slightly below zero at 30 hours. It, then, shoot up again indicating the initiation of the crack in its vicinity at 32 hours.

In SG9 the reading increased only slightly over the first 28 hours, then, it increased drastically until the crack appeared after a further interval of 30 minutes.

There was fluctuation in the case of SG7 and SG8. The first increase was probably because of a general increase in strain prior to initiation of the crack. The crack, when initiated, tended to bypass the strain gauges SG7 and SG8 beyond the hole, HB3. This resulted in drop of strain readings due to stress relaxation. Eventually, before the main crack developed and passed through SG7 and SG8, the readings in these strain gauges increased at high rate prior to the development and propagation of the main crack through all the holes. The cause of this tendency of the crack to try to move toward the free face may be because of the reduced burden to spacing ratio for the last two holes.

4. CONCLUSIONS

1) In comparison with a line holes at uniform spacing, the one with the same number of holes at gradually increasing spacing between consecutive holes causes the fracture to initiate much sooner and propagate at a faster rate, starting from the end where the spacing is the smallest.
2) If the burden to spacing ratio is reduced below a certain value, there is a tendency for the crack to deviate toward the free face.

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