Türkiye 14 Madencilik Kongresi / *14th Mining Congress of Turkey*, 1995 , ISBN 975-395-150-7

DEFORMATION OF ROCK AROUND A BOREHOLE SUBJECT TO INTERNAL PRESSURE BY AN EXPANSIVE CEMENT

M.A. Darwish
Prof. & Chairman, Mining Engineering Department, Faculty of Engineering, King Abdulaziz university, Jeddah Saudi Arabia.

M.Hanif
Assistant Prof., Mining Engineering Department, Faculty of Engineering, King Abdulaziz university, Jeddah Saudi Arabia.

ABSTRACT: Expansive cements are finding favour as demolition agents and for rock breakage in populated areas and dimension stone quarries . These are extensively used in Saudi Arabia for controlled rock fracture in urban areas as well as in dimension-stone quarries of granite and marble.

The deformation behaviour and fracture of granite when subjected to a slowly increasing expansive pressure exerted inside **a** borehole filled with an expansive cement is studied by the measurement of tangential strains at various points arround it. The effect of borehole diameter and burden is also investigated.

1. INTRODUCTION

In relatively old times, one of the methods of fracturing rocks was comprised of pouring quicklime into cracks / fissures in big boulders and enlarging them by the expansive property of hydration and finally breaking them with the help of wooden wedges (Kaisa, 1973). The use of expansive cements as a substitute for explosives is on the increase, specially in non-violent and pollution-free breakage of rocks in populated areas and in dimension stone quarries where exellent control on breaking rocks to required dimensions is achieved.

Onada Cement Company of Japan supplies four grades of expansive cement as Bristar 100, ISO, 200 and 300, suitable for use in maximum allowable temperature of 35° , 20° C, 15° C and 5° C, respectively. Lately Bristar 100S is supplied as being more suitable than Bristar 100 for the temperature conditions of Saudi Arabia (Onada).

Shiro Ishii 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 to 2000 to 3000 sq cm /gm specific surface area of grains.

Dowing and Labuz (1982) used thick-walled linders with strain gaugs affixed on external surfaces for determining the enternal pressure exerted by Bristar expansive cement. They calculated internal pressure using elastic solution of stresses and strains on thick walled cylinders (Tino shenko, & Godwin; 1951;Obert & Duval, 1967). Dowing and Labuz 1982 have indicated that the expansive pressure is not a function the borehole diameter.

Dar, Darwish and Hanif 1987 carried out research to determine the optimum burden to spacing ratio for the use of Bristar-100 expansive cement in marble quarries of Saudi Arabia. They conducted laboratory tests on a marble block using various combinations of burden and spacing with 14 mm diameter holes and correlated the laboratory results with those of the field trials in marble quarry with 34 mm diameter holes . They also used scaled thick-walled steel cylinders with strain gauges for determining pressure generated in the holes . In all the cases it was found that the pressure generated by Bristar-100 expansive cement, mixed with 30 % by weight of water generated a pressure of the order of 40 MPa after 52 hours of pouring. This pressure is far greater than die tensile strength of most rocks . They also found that the burden to spacing ratio of 0.8 gave the best results for the optimum use of Bristar-100

In order to extend the scope of the research to granite quarries, a rc'search project was undertaken by Darwish and Hanif 1990 . One of the objectives was to determine the strain-time **relationship at** various points around a borehole **filled with an** expansive cement and to study the **propagation** of cracks . Laboratory tests were carried **out** on **a** granite block from Widd quarry near Taif, measuring 1.0 **m** x 0.6 m x 0.6 m. One of the 1.0 **m** x 0.6 **m** faces was saw-cut and polished . **A 14** mm **diameter hole** was drilled to a depth of 260 mm at distance of 112 mm from two adjacent edges and a number of strain gauges were tangentially fixed at various distances and different angular positions . Bristar-100S expansive cement was mixed with appropriate proportion of water and poured in the borehole . Periodic readings of all the strain gauges were taken. In order to investigate the effect of burden the experiment was repeated at another point with burden increased to 220 mm.

TESTING OF WIDD GRANITE FOR MECHANICAL PROPERTIES

The expansive cement, when mixed with water and poured into a borehole, causes radial compressive and tangential tensile stresses in surrounding rock mass . Since the rocks are much weaker in tension than compression, the tensile strength is the most important property in determining whether or not a rock will break . Equally important are the elastic properties like poisson's ratio and young's modulus . Shear strength too becomes important in certain instances . It would also be interesting to determine the uniaxial compressive strength.

The Brazillian test, point load t est andFlexture (beam) test were made to indirectly determine the tensile strength of rock . The punch shear test was employed to determine the rock shear strength . The uniaxial compression test and stress-strain behaviour test were conducted on 35 mm diameter and 70 mm long specimens . The latter test was employed for the determination of Young's modulus and poisson's ratio.

The Brazilian test was conducted by applying a diameteral line load on discs cut from 35 mm diameter core.

The Point Load Test involves compression of a specimen between two hardened spherical points. It was originally developed by Brock and Franklin 1972 and has been extensively used for strength logging of diamond drill cores of rocks (Obert & Duval, 1967; Junikis, 1983;Bieniawski,1974).

In Flexture Test, 35 mm diameter cores of the rock were subjected to 3-point loading.

The Punch Shear Test was performed on 35 mm dia. discs and nominally 7 mm thick polished discs cut from the core. The punch diameter was 15 mm.

For Uniaxial Compression Test, cylindrical specimens of 35 mm diameter and 70 mm nominal length were prepared by cutting and grinding the ends smooth and parallel. In all the cases the specimens failed by radial tensile splitting suggesting a perfect brittle failure.

The Stress-Strain Behaviour Test was performed on three specimens having a diameter of 35 mm and nominal length 70 mm. Four strain gauges were glued to each specimen; two in the axial direction and two in the lateral direction. The strains were measured by the use of the digital strain indicator and a 10-channel switching and balancing unit. The stress-strain curve was practically linear. A summary of test results on Widd granite is presented in Table 1.

STRAIN MEASUREMENT AROUND A BOREHOLE SUBJECTED TO INTERNAL PRESSURE

One of the faces of 1.0 m x 60 cm block of granie from Widd Quarry near Taif was saw-cut and polished for the ease of installation of strain gauges in one plane.

TABLE l:Summary of test results performed on WEDD GRANITE:

TEST PARAMETER	RESULT
Brazilian Test for Tensile Strength (mean of 12)	6.70 MPa
Point-load Test for Tensile Strength Index (mean of 14)	7.71 MPa
Punch Shear test for Shear Strength (mean of 7)	23.78 MPa
Uniaxial Compression Test for Uniaxial Compressive Strength (mean of 7)	127.0 MPa
Young's Modulus at 50 % final stress (mean of 3)	50.2 GPa
Poisson's Ratio at 50 % final stress (mean of 3)	0.235

A 14 mm diameter and 260 mm deep hole was drilled normal to polished surface at distance of 112 mm from two adjacent sides. This distance was arrived at by experience with marble and application of the following scale relationship :

$$\frac{E_g\,(r_{og}^2 - r_{ig}^2)}{r_{ig}^2} = \frac{E_m\,(r_{om}^2 - r_{im}^2)}{r_{im}^2}$$

Where subscripts g and m refer to granite and marble.respectively and E, r_0 and q represent Young's modulus outside radius and inside radius of thick cylinder, regarding the radius of the bore-hole as ri and the smallest distance between the centre of the hole and the edge of the block (burden) as r_0.

Young's modulus of Widd granite was determined as 50.2 GPa compared with 34.8 GPa for marble block on which tests were performed by Dar et al 1990. The distance of 112 mm for the granite would be equivalent to 133 mm for marble.

Hanif 1974 developed the following Rock strength similarity Number NR based on the criterion of tensile strain due to compression:

$$N_R = \frac{F\ v}{L^2\ T_0}$$

where F is the force applied on a system, v is possion's Ratio, L is any linear dimension and To is the tensile strength.

Thus for the similarity of Widd granite and marble with their respective tensile strength of 6.70 MPa and 6.SS MPa and poisson's Ratio of 0.24 and 0.30 (Dar.etal 1988), using the following relationship, in which sub-script m stands for marble and g represents granite:

$$\frac{F_m \; v_m}{L_m^2 \; T_{cm}} = \frac{F_g \; v_g}{L_g^2 \; T_{cg}}$$

we obtain spacing value of 118 mm for granite as equivalent to 133 mm for marble. However, distance of 112 mm was used according to the first criterion.

Fourteen strain gauges were glued on positions indicated in the Fig. 1. The strain gauges were positioned with respect to 8 radial lines having an angular difference of 45° and to 4 sets of distances i.e 40 mm, 70 mm, 110 mm and 160 mm from the center of the borehole. Measurments of strain were made with a digital strain indicator having a least count of one micro strain. A half-wheatstone bridge circuit using a separate dummy gauge for each active gauge was employed. Prior to the commencement of the test, the gauges were connected to the strain meter and monitored for about a week in order to determine the creep behaviour of each pair of gauges connected to its specific channel.

The test was started by pouring Bristar-lOOs thoroughly mixed with 30 % by weight of water as recommended by the manufacturer. Fig. 2 shows creep corrected values of strain measured at selected points and at different times.

Experiment No. 2 (a):

Since the rock in experiment No. 1 was cracked before the hole diameter could be enlarged, the burden for the second test was nearly doubled to 220

A 14 mm diameter hole was drilled to a depth of 260 mm. A total of 12 strain gauges were installed according to the plan in Fig. 3. All strain gauges used for this experiment were wire type, which were found to be less susceptible to creep than the foil type gauges. Fig. 4 shows the results of strain gauges at selected positions, the radial distances from the center being 80 mm, 140 mm and 200mm.

Experiment No. 2 (b):

After 5 days, Bristar from the 14 mm borehole was drilled out and the hole was reamed to 20 mm diameter. Bristrar was again poured in the 20 mm borehole and periodic measurements of strains were made. The results of these measurements for selected strain gauges are shown in Fig. 5. This was continued for 172 hours. Fig. 6 shows the posiion of the two cracks resulting from the two experiments.

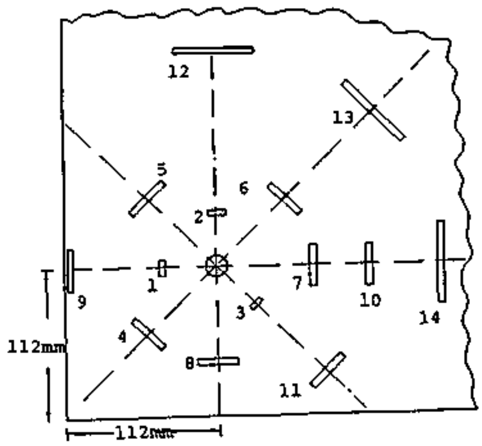

Fig. 1 : Positioning of strain gauges for Exp. 1

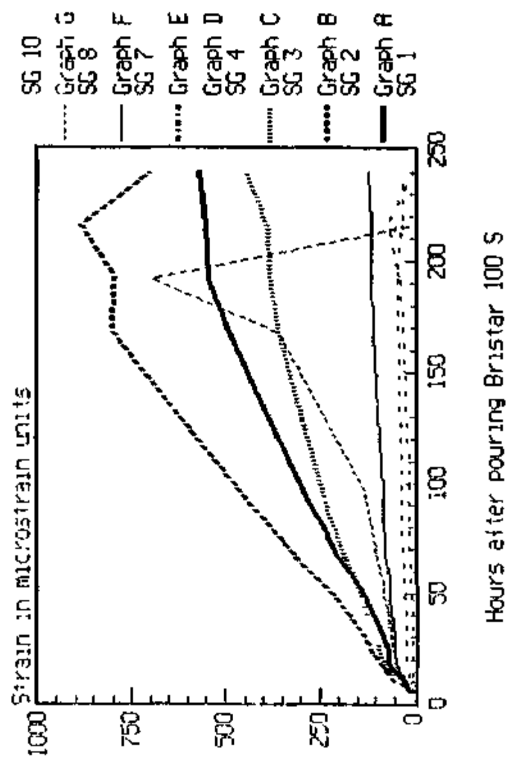

Fig. 2 : Time-strain relationship for some of the strain gauges for Exp. 1

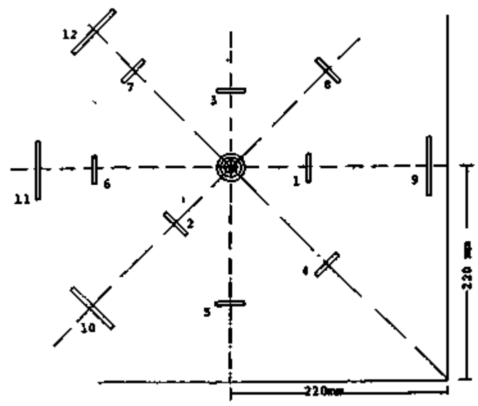

Fig. 3 : Positioning of strain gauges for Exp. 2

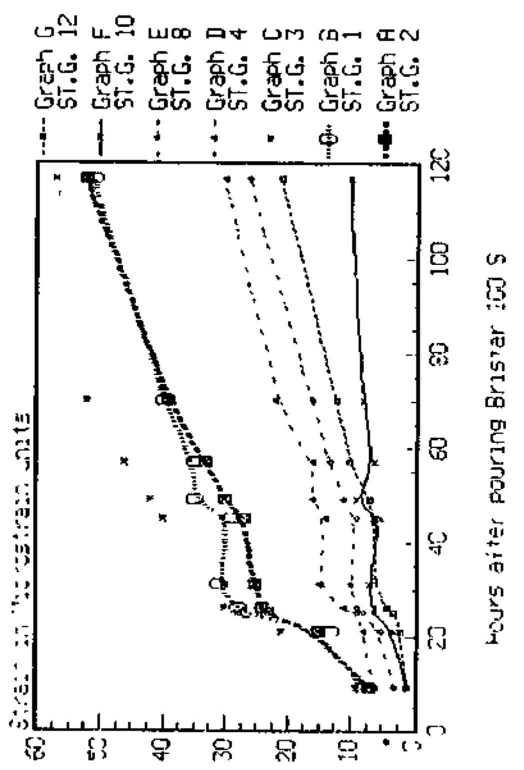

Fig. 4 : Time-strain relationship for some of the strain gauges for Exp. 2 (a)

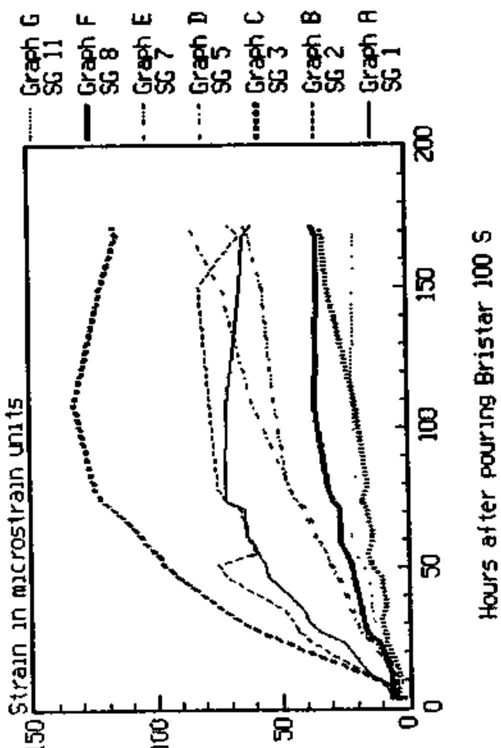

Fig. 5 : Time-strain relationship for some of the strain gauges for Exp. 2 (b)

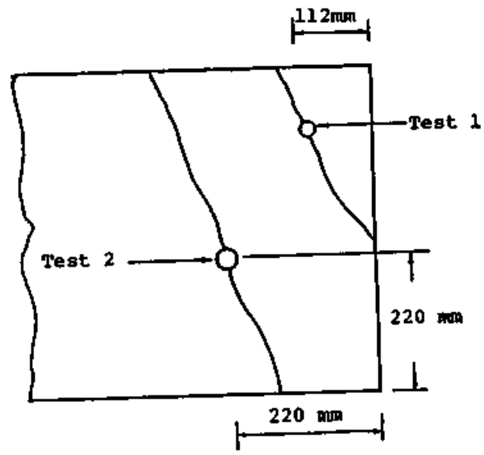

Fig. 6 : Position of cracks for Experiments 1 & 2

DISCUSSION OF RESULTS

1. The ratio of indirect tensile strength (Brazilian) for Widd granite to its uniaxial compressive strength was 1 :19. This seems to be typical of coarse crystalline rock like granite.

2. The axial stress versus axial strain curves for all the three tests were linear with only a slight reduction in slope close to the failure point suggesting that Young's modulus of elesticity would remain practically the same. The axial stress versus lateral strain curves were, howevar, not linear.

3. The important results yielded by Experiment No. 1 were as follows:

i) In general, the strain gauges close to the borehole registered greater strains than the ones farther off. The inverse square law generally holds.

ii) The rate of increase of strain (slope of strain vs time curves) was, in general, constant until 18 hours after pouring the expansive cement It then abruptly decreased but, later, gradually increased. The abrupt fall in rate of increase of strain may be explained by a probable outward slippage of the cement in the vicinity of the collar. The rate of increase of strain again picked at 30 hours and was almost constant until 96 hours, between the 96th hour and 168 th hour, all strain gauges registered increase. Strain gauge (SG) No. 2, then, registered decrease while SG 8 and 12 registered unusual increase and, then decreased down to zero as hairline crack was noticed. SG 4, 5, 10, and 14 registered significant decrease while SG 1,3,6,7 and 13 continued to increase.

It would be evident from these observations that an event affects all the strain gauges, albeit differently, which may be explained by readjustment of stresses at various points around the borehole. This is manifested by variation of the rate of change of strain at those points.

prior to an imminent failure, the slope of strain vs time curve continues to increase until the appearance of a crack. This phenomenon, however, occurs only at critical points; as demonstrated by the readings in SG 7 to a lesser extent in SG 2 and 11.

4. The results of experiment 2 (a) are plotted in Fig. 4.TTie abrupt variations in most of curves upto 57 hours may be due to the slippage of the cement close to the collar. In general the strains countinued to increase in all the strain gauges until the cement was drilled out after 117 hours. The level of strain in all the gauges was much lower than in Exp. 1. The mean of three strains at 80 mm from the centre was S3 micro-strains after 117 hours while the mean of readings of S gauges at 70 mm from the centre for Exp. 1 was 102 (computed) micro-strains over the same period of time. This may be explained by the increased burden which was doubled in Exp. 2.

5. Exp. 2. (b) with 20 mm borehole, indicated a consistent increase in strain recorded for all the gauges until 51 hours when SG 2 registered a fall but picked up again. After 78 hours, most of the strain-time curves levelled off, while one actually sloped downwards. The downward trend worsened at 108 hours suggesting that the failure might have actually taken place around 78 hours after pouring. No visible crack was, however noticed until 172 hours when the cement was drilled out and the hole was reamed to 25 mm diameter, for Exp. 2 (c). A comparison of the results of experiments 2 (a) and (b) would reveal that the rate of increase of strain was larger for the larger diameter.

6. For experement 2 (c) all the strain-time curves increased quit fast until 32 hours, when strains at the three innermost locations levelled off or actually decreased while the others continued to increase. A creak was noticed at 50 hours on one side of the hole. This suggested that failure had actually occured during experiment 2 (b). Where fall in strain gauge readings clearly suggests it. A conspicuous crack, however, did not appear then.

CONCLUSIONS

A. Conclusions related to rock testing:

1. The tensile to compressive strength ratio of Widd granite was 1 : 19 which is characteristic of coaresly crystalline granitic rocks.

2. The values of Young's modulus for Widd granite would be practically constant. The value of Poisson's ratio, however, was found to increase with an increase in stress.

B. Conclusions related to strains measurement around boreholes filled with the expansive cement:

1. Tangential strains closer to the hole were greater than the ones farther off from the holes. The trend generally followed the inverse square law.

2. Strains generally increased with time until failure.

3. A readjustment of strain rates at various points occurred at the time of deformational events such as the appearance of a crack.

4. Only one crack appeared in each one. This explains why the expansive cement method of rock breakage is so much better than the much faster blasting technique in controlled fracture, making it so

favoured for the dimension stone quarries.

ACKNOWLEDGMENTS;

The authers would like to thank the directorate of Scientific Research Administration, Faculty of Engineering, King Abdulaziz Unversity, Jeddah for

Sponsoring the research on which this paper is based.

REFERENCES

Bieniawski, Z.T., 1974. Estimating the strength of Rock Materials : /. *South African Inst. Min. and Metallurgy,* (March).

Brock, E. & Franklin, J. A. 1972. Point-load Strength Test *Int. J. Rock Mech. Min. Sei. vol 9* : 689-697.

Dar, I. H. Darwish, M. A. & Hanif, M. 1987. Optimum use of Bristar-100 Expansive Cement in Marble Quarries of Saudi Arabia . *Final Report, College of Engineering, King Abdulaziz University, Jeddah, K. S. A. , Research Project No.408/074.*

Darwish, M. A., Hanif, M. 1990 Optimum use of an Expansive Cement in Hard Dimension-stone Quarries of Saudi Arabia, *Final Report, College of Engineering, King Abdulaziz University Jeddah, K. S. A., Research Project No. 4101058.*

Dowding, C. H. and Labor, J. F. 1982 Fracturing of Rock with Expansive Cement : *American Society of Civil Engineers, Vol. 108, No. G.T. 10,* (October).

Hanif, M. 1974. Support and deformation of underground openings. *Ph. D. thesis, Department of Mining and Mineral Sciences, University of Leeds, U. K.*

Jumikis, Alfred R. , 1983. Rock Mechanics . Second Edition, *Gulf Publishing Co* : 312-325.

Kasia, Y. 1973. Recent Demolition Method. *Concrete Journal, Vol. II, No. 11* : 39-48.

Oben, L. & Duval, W. I. , 1967. Rock Mechanics and Design of Structures in Rock : *John Willy & Sons, Inc.* , New York : 495.

Onoda Cement Co. Bristar-Non-explosive Demolition Agent : *Technical Note Onoda Cement Co. Ltd.* , Tokyo, Japan.

Siro, Ishii, Study Of Demolition Method Using Non Explosive Demolition Agent : *R & D Laboratory of New Products, Onoda Cement Co.* , Tokyo, Japan.

Timoshenko, S. & Godwin, J. N. 1951. Theory Of Elasticity : *McGraw Hill Co.* New York : 78-81.