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Technical Note

Relationship Among Fatigue Strength, Mean Grain Size and Compressive Strength of a Rock

By

S. K. Singh

Department of Geology, University of Delhi, Delhi

Abstract

Fatigue tests carried on three sets of samples having different mean grain sizes revealed that fatigue strength is a function of mean grain size of the rock. Samples having smaller grain size show higher value of fatigue strength. Graywacke samples from Flagstaff formation having mean grain sizes of 1.79 mm, 1.35 mm and 0.93 mm showed fatigue strengths of 87%, 88.25% and 89.1% respectively. Since the mean uniaxial compressive strength also varied with varying grain size, i. e. higher mean strength value for samples having finer grain size; the fatigue strength of a rock also shows a converse relation with mean uniaxial compressive strength.

Introduction

Weakening of rocks under cyclic loading has been termed "rock fatigue". The maximum applied stress at which a rock can stand an infinite number of cycles without destruction is termed the "fatigue stress" (Vutukuri et al., 1978). The stress level at which the fatigue life is "*n*" number of cycles is "fatigue strength" and the number of cycles causing failure under given loading conditions is known as "fatigue life" of a rock (Mann, 1966).

One of the earliest studies, though inconclusive, was taken by Grover et al. (1950) on limestone. Later on, Burdin (1963) conclusively demonstrated that the influence of repeated loading on Berea Sandstone resulted in a decrease in its strength. The fatigue strength of Barre granite, Tennessee sandstone and Indiana limestone varied between 65% and 80% (Hardy and Chugh, 1970). Haimson and Kim (1971) demonstrated that fatigue strength of Tennessee marble lies at 75% of its dynamic compressive strength. Singh (1988) with experiments made on graywacke from Flagstaff formation demonstrated that a fatigue strength of 87% was common for these samples. Cain, Peng and Podnieks (1975) demonstrated that at high frequency cycles the fatigue limit was higher for the higher tensile rocks. However, studies are lacking as to how the fatigue strength of a rock varies with varying grain size. The present study deals with the relationship of fatigue strength with grain size of the rock.

The study area lies 250 km north of Sydney, N. S. W. It forms a part of Southern New England Fold Belt. Flagstaff-formation rocks of upper Carboniferous age outcrop in the area. The experiments were made on graywacke samples of the formation of varying mean grain sizes.

Methodology

At first, the mean uniaxial compressive strengths of the samples were determined. For this, 15 samples from each grain-size class were tested. Then the mean compressive strengths were calculated based on these data.

Fresh blocks from the rock mass were obtained, and several cores were obtained from one such block in order to assure identical sampling. All the cores were drilled normal to the bedding plane. All the samples used were 5.49 cm in diametre. The diameter-to-height ratio was kept between 1 : 2.5 to 1 : 2.7 as suggested by Mogi (1966). The testing machine works on the principle of controlling the strain rate. The distance between two platens can be reduced with constant speed. The sample placed between the platens reacts to this strain and the response is directly recorded on graph in form of stress-strain curve. A strain rate of 50 microns/minute was used

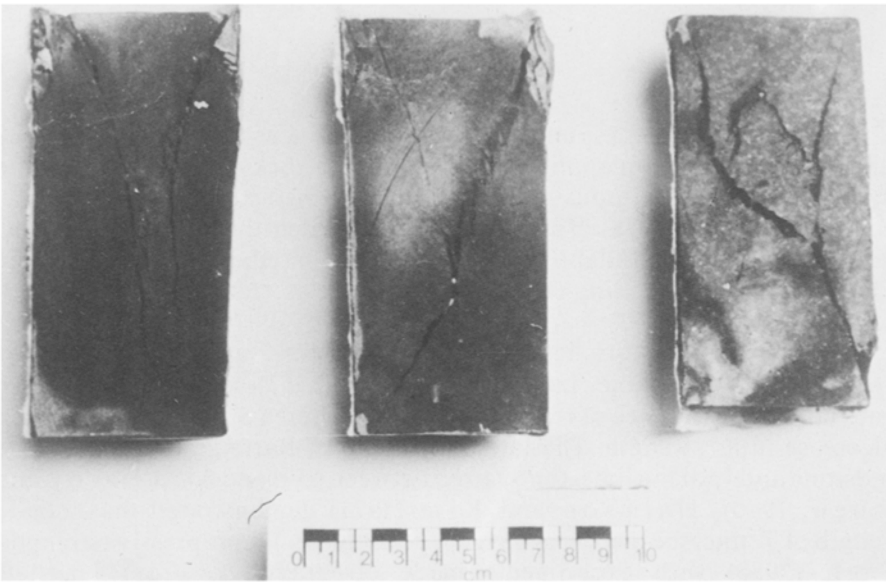

Fig. 1. Fatigue fracture developed in the samples

for all failure tests. For cyclic-load tests the frequency was kept at 60 cycles/minute. Fig. 1 shows some of the fracture patterns developed in the samples.

Mean Uniaxial Compresssive Strength

Fifteen samples from each grain-size class were tested. The uniaxial compressive strength of samples having mean grain size of 0.93 mm varied between 205 and 228 MPa. A mean compressive strength of 220 MPa with a standard deviation of 6.0 was determined for these samples. The uniaxial compressive strength of samples having mean grain size of 1.35 mm varied from 203 to 213 MPa. This gave a mean strength of 207 MPa with a standard deviation of 3.1. Similarly the uniaxial compressive strength of samples having a mean grain size of 1.79 mm varied between 179 and 191 MPa giving a mean strength of 185 MPa and standard deviation of 4.0. The data have been plotted in Fig. 2, which shows that the compressive strength of rock increases with decreasing grain size. This further supports the result obtained by Brace (1961).

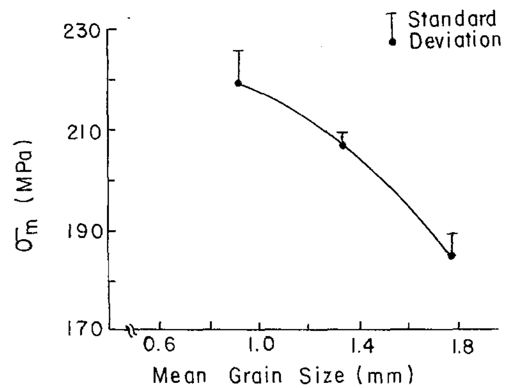

Fig. 2. Relationship between unconfined uniaxial compressive strength and mean grain size

Fatigue Strength

In order to establish fatigue stress, at a given mean stress level, the maximum applied stress and stress amplitude were varied. The maximum applied stress was reduced from 97% at 1% intervals until the sample did not fail up to 10,000 cycles. Three samples were tested at each stress level. At each stress level the number of cycles to failure was counted for each specimen. Same treatments were given to samples of each grain-size class. Fig. 3 shows the fatigue curve obtained for samples of each grain-size class. A fatigue strength of 87% was determined for samples having mean grain size of 1.79 mm. Similarly fatigue strengths of 88.25% and 89.1% were determined for samples having mean grain sizes of 1.35 and 0.93 mm respectively (Fig. 3).

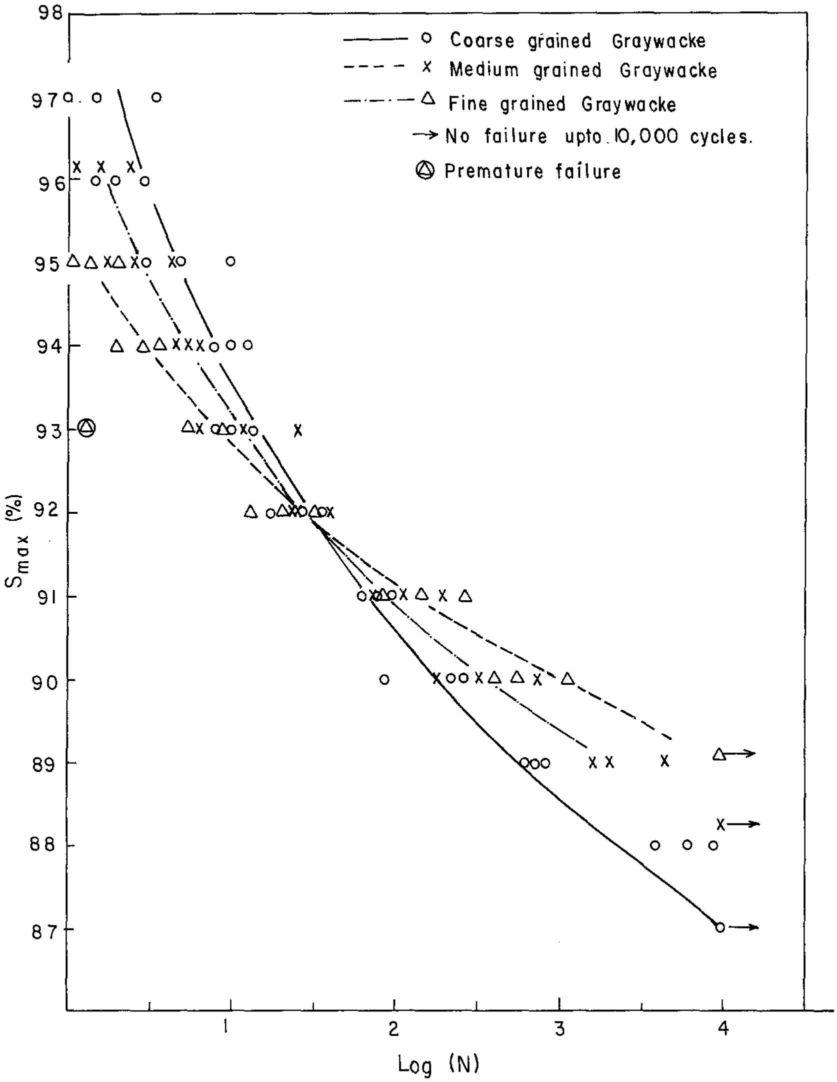

Fig. 3. Fatigue curve for samples having different mean grain size

Discussion

Fatigue experiments showed that all the samples show fatigue. The fatigue curves obtained for three different sets of samples were of the order of S = A-B log N (Fig. 3). Figure 4 shows a relationship between mean grain size and fatigue strength of a rock. The fatigue strength of a rock increases with decreasing grain size. Figure 5 shows that the fatigue strength is also a function of its mean uniaxial compressive strength. Samples having higher mean compressive strength have higher values of fatigue strength and vice versa.

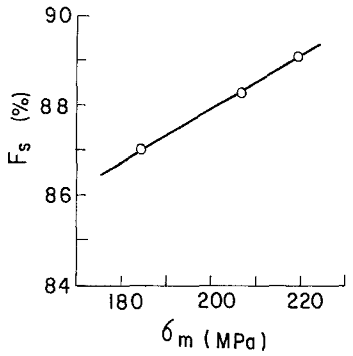

Fig. 4. Relationship between fatigue strength and mean grain size

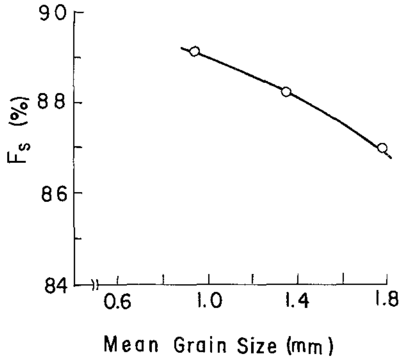

Fig. 5. Relationship between fatigue strength and uniaxial compressive strength

Summary and Conclusions

Three sets of samples having identical minerology and texture but with varying mean grain sizes showed different fatigue behaviour. It is established that fatigue strength of a rock is inversely related to the mean grain size. Samples having mean grain sizes of 1.79, 1.35 and 0.93 mm showed fatigue strengths of 87%, 88.25% and 89.1% respectively. It was further established that the uniaxial compressive strength of rocks is also inversely related to the mean grain size, as strengths of 185, 207 and 220 MPa were determined for the samples having mean grain sizes of 1.79, 1.35 and 0.93 mm respectively. This further indicated that the fatigue strength of a rock is conversely related to its mean uniaxial compressive strength.

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