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## Effect of Stress Level on the Compressive Strength of the Rock Samples Subjected to Cyclic Loading

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# Effect of Stress Level on the Compressive Strength of the Rock Samples Subjected to Cyclic Loading

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**Abstract.** The effect of stress level on the compressive strength of rock samples is researched using Tephrite samples subjected to cyclic loading. Four sets of stress level (% 20, %30 %40 and % 50 of uniaxial compressive strength) were applied for cyclic loading tests on dry and saturated samples by 200 tons servo-hydraulic testing rig. The compressive strength of the rock by different stresses were determined under constant frequency and number of cycles at failure. The results of the cyclic loading tests indicate that stress level has significant influence on the uniaxial compressive strength. An increase in stress resulted in a decrease in compressive strength proportionality. In the case of the saturated samples, it was found that compressive strength reduced by approximately 25 per cent.

## 1. Introduction

Rock units and tunnels, dams, roads, bridges and underground structures created in rock masses are exposed to static and dynamic loads. Static loads are the weight of the rock mass on any rock unit or structure. Dynamic loads are defined as loads that change with time and are caused by earthquakes, drilling and blasting, loading, mechanical excavation and heavy traffic [3, 7, 11, 12]. The understanding of mechanical properties of rock under dynamic loads is more crucial than under the static load.

Different rock materials exhibit different behavior under dynamic loading conditions. Some becomes stronger and ductile, but some becomes weaker and more brittle [15, 19]. The cyclic loads cause weakening of rock mechanical properties. This has been called ‘rock fatigue’ [1, 5, 6, 18]. Limited numbers of past research on this topic have revealed. Firstly, Burdine [4] showed the weakening of the material under compressive cyclic loading. Hardy and Chugh [8] determined that fatigue strength is nearly % 65 and % 80 of uniaxial compressive strength under compression cyclic loading by using ramp amplitude model. Li et al. [13] investigated the effect of cyclic loading on the mechanical properties of the rock for dry, frozen and water-saturated conditions. While dry samples have higher strength than frozen samples, frozen samples have higher strength than saturated samples. The detailed literature research on fatigue behavior in rocks has already been presented by Bagde and Petros [2]. Thereafter, many studies are reported about the effects of the cyclic loading. Bagde and Petros [3] studied the effects of uniaxial cyclic compression tests on sandstone and conglomerate rock samples in different amplitudes and frequencies. These researchers reported that fatigue failure is influenced by the petrographic, physical and mechanical properties of these rocks. Liang et al. [14] studied the effect of cyclic load on samples of tenardite, glauberite and gypsies under uniaxial compressive strength and founded that the uniaxial compressive strengths of tenardite, glauberite and gypsies decreased by 34%, 19% and 35%, respectively. Khanlari and Momeni [10] investigated the

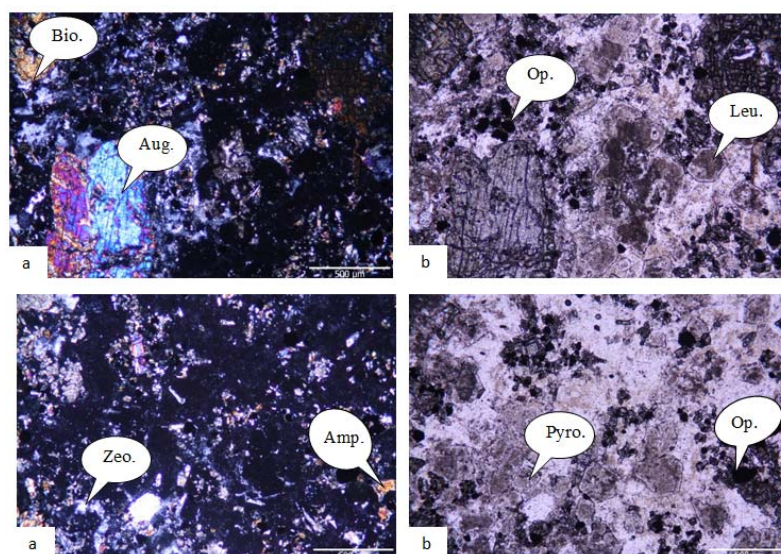


fatigue behavior of Monzogranite subjected to various loading levels (85%, 90% and 95% of the strength of the rock) at amplitude % 70 with 1 Hz cyclic loading frequency. They observed that different loading levels have effect on the fatigue behavior of the rock. For the first few cycles, it concluded that the rock displays elastic behavior and elasto-plastic behavior with increasing cycle numbers. As the result of studies, the yield stress level reduces, and the plastic behavior of the rock is dominant in each cycle with the increasing cycle numbers. Taheri et al. [20] showed peak strength variations of Hawkesbury sandstone under cyclic loading and detected that fatigue influenced the peak strength of the sandstone. It is reported that fatigue failure occurs during cyclic loading if the stress level in cyclic loading is equal or higher than 94 % of rock peak strength. All of these studies revealed that different materials showed different behaviors in cyclic conditions. There is some missing about the fatigue behavior of the dry and saturated rocks for low cyclic loads. The study was aimed to fill this gap. In this paper, different stresses that are one of the important variables of fatigue mechanism were performed in the experiments and the effect of the different stress levels on the cyclic loading of the rock samples for dry and saturated condition was investigated. Also, the compressive strength of the rock under cyclic compressive loading conditions is evaluated for Tephrite samples. This paper presents the preliminary results of an ongoing research. The number of the samples and the amount of data presented are relatively limited. However, the rock response under the cyclic loading may be seen explicitly, when especially combined with the literature work. After first paragraph, other paragraphs are indented as you can see in this paragraph. After Introduction, divide your article into clearly defined and numbered sections.

## 2. Experimental Set-up and Rock Properties

### 2.1. Rock Samples

Thin sections were prepared to analyze the mineralogical and petrographic properties of the rock. According to the results of analyses, this rock generally shows porphyritic, microlitic porphyritic and hyalo-microlitic porphyritic texture. It is observed that main components of most of these rocks are leucite, calcitic plagioclase, pyroxene (%20), amphibole (3-5%), biotite (3-5%) and opaque (2%) minerals. The secondary minerals are chlorite, calcite, zeolite and clay minerals. As a result of microscopic examination, this rock is located tephrite/basanite groups. Also, this rock is named as tephrite due to the olivine absence.



**Figure 1.** Microscopic view of the rock (Pyro: Pyroxene, Amp: Amphibole, Bio: Biotite, Ze: Zeolite, Leu: leucite, O: Opaque mineral, Aug: Augite)

Rock samples were cut to a length to diameter ratio of 2.5-3.0 with a diameter of NX core size, approximately 54 mm. The ends and sides of the specimens were prepared to ISRM [9] testing procedures. The physical and mechanical properties of the rock samples were determined (Table 1).

**Table 1.** Physical and mechanical properties of the rock samples

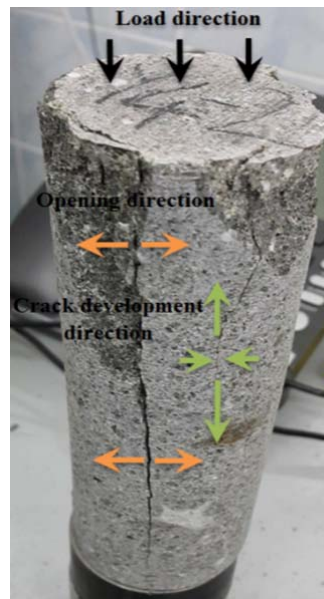
Material Properties	Trabzon Rocks
Density ( $\text{g/cm}^3$ )	2.59
Uniaxial Compressive Strength (MPa)	98.81
Tensile Strength (MPa)	6.42
Apparent Porosity (%)	3.74

## 2.2. Testing Methodology

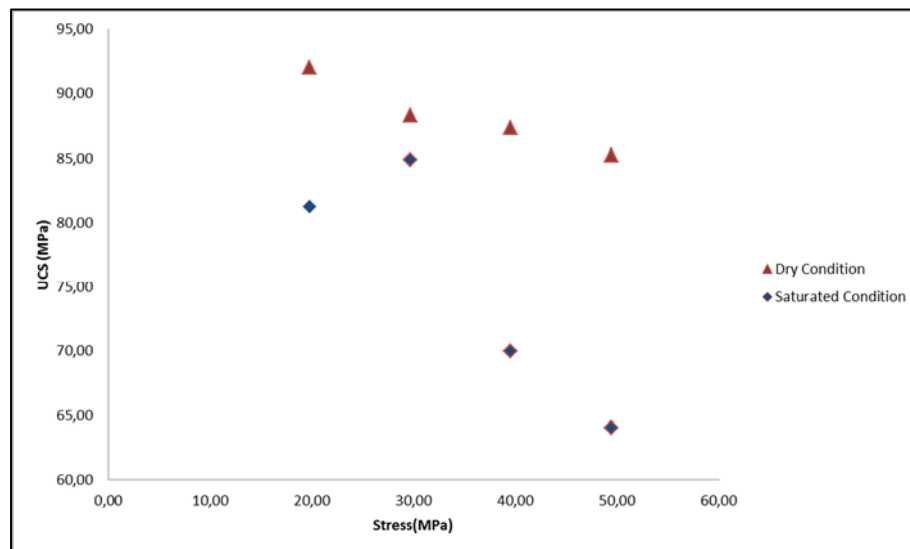
A series of uniaxial cyclic loading tests were performed on the core specimens using a servo-hydraulic Besmak Machine. Four different stress levels (% 20, %30, %40 and %50 of uniaxial compressive strength (UCS) are applied under constant frequency (0.5) and number of cycles (100). Each experiment was repeated three times, and their average was used as the result of the test. These experimental procedures were implemented for dry and saturated rocks. The saturated samples were heated, dried and cooled to room temperature and then saturated through free immersion. These samples were tested after 2 days of saturation in water. After cyclic loading until 100 cycles, UCS of these specimens is immediately determined again.

## 3. Results and discussions

Experiments were performed to determine the effect of the stress level on the strength of the rock. The strengths of the rock obtained after cyclic loads are evaluated by comparing with the static uniaxial compressive strength (98.8 MPa). After cyclic loading tests, the fractures occur, propagate and these fractures coalesce. These three steps have also been reported by many researchers [15, 16, 22]. The Tephrite specimen that failed under uniaxial compression cyclic loading is shown in Figure 2. The applied stress level has effect on the percentage decrease in uniaxial compressive strength [17]. In this study, the graph was plotted to investigate the effect of the applied stress level on the strength of the rock at fixed frequency (0.5 Hz) and number of cycles (100). It shows that the strength of the rock reduces with increasing the stress level and, relation between UCS of the rock and stress level is inversely proportional as shown in Figure 3. Momeni et al [16] stated that the deformation development in the rocks in the fatigue process started with the formation of capillary cracks in the rock mass. While the stress level continues, the cracks propagate, and this causes rock failure. Hence, the UCS of the rock decreases with increasing of the applied stress level. It was determined that the uniaxial compressive strength of the saturated rock samples decreased by 13 %. The decrease in fatigue strength (nearly %25 of UCS of the rock) in the case of saturation was also obvious and related to pore pressure effect and internal structural changes of the rock specimens as seen in the Figure 3. Similar observations were made by Burdine [4] and Tien et al. [21]. While stress level is at 20 MPa for saturated condition, there is an increase in uniaxial compressive strength due to machine behavior and the testing conditions.



**Figure 2.** Cracks features in specimen after failure



**Figure 3.** The graph versus UCS and load under cyclic loading

#### 4. Conclusions

The work presented here was performed to investigate the effects of stress level on strength of dry and saturated rock in uniaxial compression subjected to cyclic loading. The following conclusions were drawn from this research:

- The fatigue strength of the rock generally reduced by 10-15 % on average under cyclic loading compared to static strength of the rock. Also, it was determined that uniaxial compressive strength for saturated rock samples reduced by %13 of uniaxial compressive strength in terms of the water pressure in fissure. Also, fatigue strength decreased by % 25 of uniaxial compressive strength.
- The linear relation between stress level and strength of the rock are observed. The compressive strength decreases under constant cycle number and constant frequency, by an increase of the stress level.

- The fatigue mechanism is affected by mineralogical and petrographic properties and loading variables such as frequency, amplitude and loading cycles. Therefore, these parameters need to be considered to understand the fatigue mechanism of the rock. As a result, more studies should be conducted to understand the rock behavior under cyclic loading.

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### References

- [1] Attawel, P. B. and Farmer, I. W., 1973. Fatigue behavior of rock, *Int. J. Rock Mech. Min. Sci. Geomech. Abs.*, 10, 1–9
- [2] Bagde, M. N. and Petros V., 2005. Fatigue properties of intact sandstone samples subjected to dynamic cyclical loading, *Int. J. Rock Mech. Min. Sci.* 42, 237-250.
- [3] Bagde, M. N. and Petros V., 2009. Fatigue and dynamic energy behavior of rock subjected to cyclical loading, *Int. J. Rock Mech. Min. Sci.* 46, 200-209.
- [4] Burdine, N. T., 1963. Rock failure under dynamic failure conditions, *Soc. Petr Eng J.* 3, 1-8.
- [5] Eraslan, N., 2011. Static and Cyclic Laboratory Testing of Brisbane Rocks, PhD Thesis, School of Civil Engineering, The University of Queensland, Australia
- [6] Evans, A. G. and Fuller, E. R., 1974 Crack propagation in ceramic materials under cyclic loading conditions. *Metall Trans* 5:27–29
- [7] Haimson, B. C., 1978. Effect of cyclic loading on rock, In: *Dynamic geo-technical testing. ASTM STP 654, Am. Soc. Testing and Materials*, 228–245.
- [8] Hardy, H. R. and Chugh, Y. P., 1970. Failure of geological material under low cycle fatigue, *Proc 6.th Canadian Rock Mech. Symp*, 33–47, Montreal, Canada.
- [9] ISRM. Ulusay R. and Hudson J. A. (eds)., 2007. The complete ISRM suggested methods for rock characterization, testing and monitoring, 1974–2006. Suggested methods prepared by the commission on testing methods. Compilation arranged by the ISRM Turkish National Group. ISRM, Ankara, 87-88.
- [10] Khanlari, Gh. and Momeni, A. A., 2014. Assessment of fatigue behavior of Alvand Monzogranite Rocks, *Journal Geology Engineering*, Vol.8, No.1.
- [11] Ko TY (2005) Crack coalescence in rock-like material under cyclic loading. Master of Science in Civil and Environmental Engineering, Massachusetts Institute of Technology, United State.
- [12] Lee JU and Rhee CG (1992) A study on the fatigue failure behaviour of Cheon-Ho Mount limestone under cyclic loading. *Journal of Korean Nuclear Society*, 24(1), 98-109.
- [13] Li, N., Zhang, P., Chen, Y. ve Swoboda, G., 2003. Fatigue properties of a cracked, saturated and frozen sandstone samples under cyclic loading, *Int. J. Rock Mech. Min. Sci.* 40, 145–150.
- [14] Liang, W., Zhang C., Gao, H., Yang, X., Xu, S. and Zhao, Y., 2012. Experiments on mechanical properties of salt rocks under cyclic loading, *J Rock Mec. and Geo. Engng*, 4 (1), 54-61.
- [15] Liu, E. and He, S., 2012. Effects of cyclic dynamic loading on the mechanical properties of intact rock samples under confining pressure conditions. *Engineering Geology* 125, 81-91.
- [16] Momeni, A., Karakus, M., Khanlari, G. R. and Heidari M., 2015. Effects of cyclic loading on the mechanical properties of a granite, *Int. J. Rock Mech. Min. Sci.* 77, 89-96.
- [17] Ray, S. K., Sarkar M. and Singh, T. N., 1999. Effect of loading and strain rate on the mechanical behaviour of sandstone, *Int J Rock Mech. Min. Sci.* 36, 543–549.
- [18] Singh, S.K., 1989. Fatigue and strain hardening behaviour of greywacke from the flagstaff formation, NSW, *Engineering Geology*, 26, 171–179.
- [19] Stavrogin, A. N. and Tarasov, B. G., 2001. *Experimental physics and rock mechanics*, Balkem (Rotterdam), 356.

- [20] Taheri, A., Royle, A., Yang, Z. and Zhao Y., 2016. Study on variations of peak strength of a sandstone during cyclic loading, *Geomech. Geophy. Geo-energy Geo-resour.* 2, 1-10.
- [21] Tien, Y. M., Lee, D. H. And Juang, C. H., 1990. Strain, pore pressure and fatigue characteristics of sandstone under various load conditions. *Int J Rock Mech Min Sci Geomech Abstr*;27(4):283–9.
- [22] Xiao, J Q., Ding, D. X., Jiang, F. L. and Xu, G., 2010. Fatigue damage variable and evolution of rock subjected to cyclic loading, *Int. J. Rock. Mech. Min. Sci.*47, 461-468.