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Abstract- High thermal effects on Point Load Index (P.L.I) of rocks tolerate in mind an essential issue for numerous geotechnical engineering purposes. Many engineering relevancies interact with it as Geothermal power reserve extraction, Fires would occur in tunnels, Underground Coal Gasification (UCG), and numerous ancient monuments that were made from these rocks and exposed to different thermal impacts. This research aims to carry out (P.L.I) experimental studies of intact rocks as Granite, Sandstone, Marble and, Limestone rocks. In this study, the rock samples are subjected to thermal effects (from room temperature degree 25 ºC to a high temperature up to 1100 ºC). The results are debated and introduced in terms of rising temperature degrees with different parameters. It has been known that the (P.L.I) of rocks decreased with the elevated temperature, particularly outside certain temperatures.

Keywords: Rock Strength, Thermal Effects, Point Load Index, Different Rocks

I. INTRODUCTION

The impact of thermal effect on rocks is a topic of growing importance in geotechnical engineering. This topic is relevance to several engineering applications such as hot dry rock (HDR), deep geological disposal of nuclear waste, (Granitic rocks such as granite and diorite are widely acceptable site for nuclear waste disposal and are also main rock types of HDR reservoir) (at temperatures which generally vary from 100 to 300 oC and will rise over the storage interval), geothermal energy resource extraction, solar heating of rock monuments and buildings, Fires in tunnels, mines and buildings and underground coal gasification (UCG). The process of Underground Coal Gasification (UCG) is based on in situ, sub-stoichiometric coal combustion for the production of a high-calorific synthesis gas, which can be applied for electricity generation. However, UCG can induce impacts such as high thermal effects on the surrounding rocks of the coal layer. Temperatures above 1,000 °C can be achieved in the UCG reactor and its close vicinity. The impact of high temperature on the physical and mechanical properties of rocks has been largely investigated using laboratory studies since the 1970s over the last several decades.

Numerous experiments in literature have shown that the temperature has a significant change in the rock strength parameters. Ferrero et al., 2001 tested 15 samples of two types of marble which were previously heated to temperatures up to 600 °C and later cooled. Koca et al. 2012 studied 9 samples of intact marble, under different temperatures observing the rock strength. These authors also tested five rock samples obtained from building elements previously exposed to fire (subjected to an estimated temperature of 500 °C). Ranjith et al., 2012 tested sandstones until 1000 °C obtaining different results than in other works, reaching 180% of the initial strength at 600 °C, then lowering until the maximum test temperature is reached. Xu et al., 2009 found that the granite UCS changes slightly from room temperature to 400 °C, but dramatically decreases with temperature from 400 °C upward. Shao et al., 2015 studied the fracturing behavior of Australian granite test specimens such as the crack propagation at high temperatures up to 800 °C using electron microscopy scanning (SEM) and unconfined strength test. The results reveal that the failure modes of granite specimens changed from brittle fracturing to ductile failure with increasing temperature.

Rock Samples (Granite, Sandstone, Limestone, and Marble)

In this research, granite material was collected from a quarry at Shellal village (central quarry) in Aswan city. It was the traditional northern frontier of the Nubian region during the period of both Egyptian and Roman Empire. During the period of ancient Egypt, it was a very important quarry area for granite production. Some of the monuments known to come from this site are The unfinished obelisk, The Cleopatra's Needle, The sarcophagus at the burial chambers of the Third Dynasty Pharaoh Djoser at Saqqara, Aswan granite is pink in color and medium-grained.
While Sandstone material was collected from a quarry at Madinaty city (It is located in a site between Cairo and Suez highway road). There are several monuments known made from sandstone rocks are Statues of an Egyptian pharaoh, a Wall with pharaonic painting, and a Pharaonic mural in the Egyptian museum at Cairo. Sandstone rock color is yellow and medium to coarse-grained.

Limestone rocks were collected from a quarry in the western north of Madinaty city (It is located in a site between Cairo and Suez highway road), eastern desert. There are several monuments known made from Limestone rocks are Egyptian pharaoh Lion head and the Nefertiti Head in the Egyptian museum at Cairo. Limestone rock color is white to yellow.

There are many quarries of different types of Marble rocks in Egypt. The sample was collected from a marble quarry in East of Asyout city. Many monuments known to come from this site are Pharaonic utensils in The Egyptian museum and many Statues of Egyptian pharaohs. The marble is white to yellow. It forms from limestone, which is subjected to the heat and pressure of metamorphism.

Drilled out of the adjacent part of a large block without any macroscopic cracks, the rock cores were prepared in cylinders with a diameter of 43 mm and a height of 50 mm for both Granite and Marble rocks, while with a diameter of 48 mm and a height of 50 mm for both sandstone and limestone rocks. To improve the accuracy of the experiments, each end faces of the rock samples were polished with an error of unevenness of less than 0.05 mm. The average dry density is 27.7 kN/m3 for granite rocks, 24.4 kN/m3 for Sandstone rocks, 21.0 kN/m3 for Limestone rocks, and 27.2 kN/m3 for Marble rocks. Fig. 1 shows the location of the different collected rocks.

Figure 1. Location of the Granite, Sandstone, Limestone, and Marble rock quarries

II. Materials Preparation

To eliminate the influences of natural water content on the experimental results, all the samples (Granite, Sandstone, Limestone, and Marble rocks) were first numbered and subjected to dry processing by putting the samples into a drying oven and baking them at 105 ^{0}C for 48 h to remove all moisture content as shown in Figures 2,3,4 and 5, respectively. Then, samples were placed in an electric high-temperature furnace. The designated high temperatures were 300 °C, 600 °C, 900 °C and 1100 °C respectively. In each case, the samples were heated at a certain rate (5 °C/min) at atmospheric pressure to prevent occurring heat shock in the rock samples in a furnace until a certain temperature is reached and kept within the desired high temperature for different interval times 3,6,12 and 24 hours. Subsequently, the furnace was turned off and varieties of point load tests were conducted on rock samples either under high-temperature treatment (after heated) or after the samples were naturally cooled to room temperature (after cooling) as summarized in Table 1.

Figure 2. Shape of the Cylindrical Samples of Aswan Granite rocks

Figure 3. Shape of the Cylindrical Samples of Sandstone rocks

Figure 4. Shape of the Cylindrical Samples of Limestone rocks

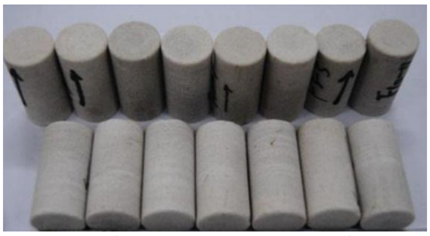

Figure 5. Shape of the Cylindrical Samples of Marble rocks

Table 1. Studied Cases of Thermal Effects

Cases of Thermal effects No.	Period of Temperature exposure (Hours)	Period of cooling before testing (Hours)
1	3	0
2	3	24
3	6	24
4	12	24
5	24	24

III. Experimental Equipment

The treated samples were conserved in a desiccator Point-load index test. The maximum loading capacity of the uniaxial compression testing system is 1000 kN. The point load test procedure helps to determine the diametrical point load strength index for the core specimen. The sample is placed between two specific cones and the load is applied until its failure as shown in Fig. 6. The point load strength index can be estimated using the following equation:

$$(PLI) = P/D^{2} \text{ (MPa)} \quad (1)$$

Where,

D= Equivalent core diameter in mm

P = the breaking failure load in N

Figure 6. Point Load Test System

IV. RESULTS AND DISCUSSION OF THE EXPERIMENTAL WORK

Figures 7, 8, 9, and 10 show the variation of (PLI) (MPa) with different heating for Granite, Sandstone, Limestone, and Marble rocks respectively for different and for heating periods, 3,6,12 and 24 hours after the samples were naturally cooled to room temperature (after cooling). While, in the case of heating period 3 hr., the variation of (PLI) (MPa) was conducted on rock samples both under high-temperature treatment (after heated) and after the samples were naturally cooled to room temperature (after cooling). Figure 11,12,13 and 14 show the mode of failure under the influence of heat after the PLI test for Granite, Sandstone, Limestone, and Marble rocks

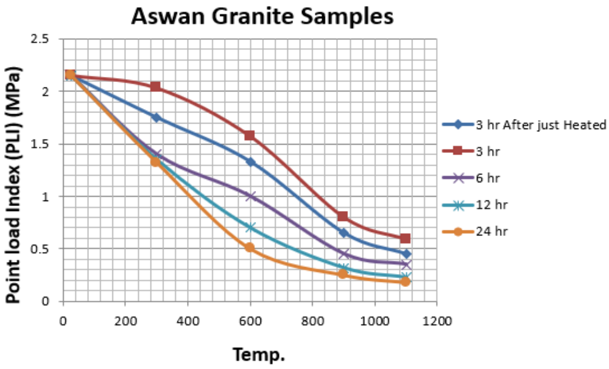

Figure 7 Variation of the (PLI) (MPa) of Aswan granite rock for different temperature degrees and heating periods

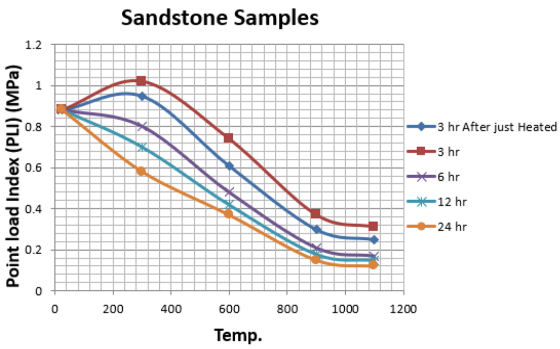

Figure 8 Variation of the (PLI) (MPa) of Sandstone rock for different temperature degrees and heating periods

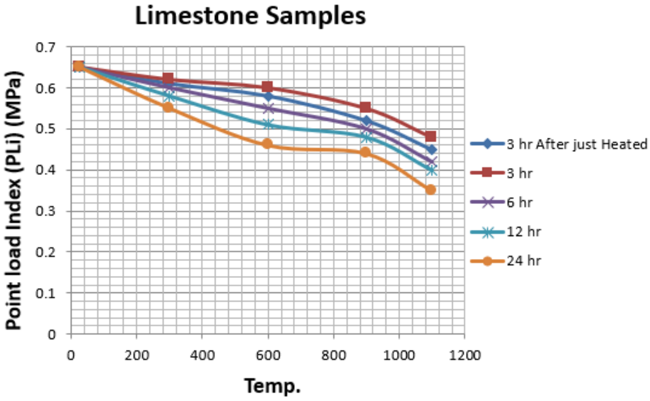

Figure 9 Variation of the (PLI) (MPa) of Limestone rock for different temperature degrees and heating periods

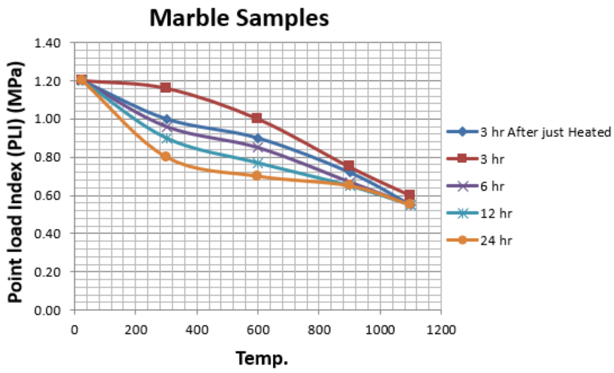

Figure 10 Variation of the (PLI) (MPa) of Marble rock for different temperature degrees and heating periods

A: 300 °C B: 600 °C C: 1100 °C

Fig. 11. Mode of failure under the influence of heat after the PLI test for Granite rocks

A: 300 °C B: 600 °C C: 1100 °C

Fig. 12. Mode of failure under the influence of heat after the PLI test for Sandstone rocks

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A: 300 °C B: 600 °C C: 1100 °C
Fig. 13. Mode of failure under the influence of heat after the PLI test for Limestone rocks

A: 300 °C B: 600 °C C: 1100 °C
Fig. 14. Mode of failure under the influence of heat after the PLI test for Marble rocks

The (PLI) (MPa) for Granite has a significant decreasing in strength upon heating up to 1100 °C by a range from 9% to 27% (compared with the initial value) for different heating periods

Sandstone rocks has a rising roughly to (300 °C) by 115 % then decreased sharply by range from 15% to 33% (compared with the initial value) for different heating periods

For Limestone rocks a decreasing tendency from the room temperature to a certain temperature of 1100 °C by a range from 46% to 65% (compared with the initial value) for different heating periods

The (PLI) (MPa) for Marble rocks has a slight decrease up to 300 °C treatment after that a significant decrease by approximately a range from 45% to 50% (compared with the initial value) for different heating periods.

Periods of thermal effect have great influence of (PLI) (MPa) for different rocks Granite, Sandstone, Limestone and Marble from the room temperature, and up a temperature of 1100 °C.

V. CONCLUSIONS

Based on the experimental investigations of the Point Load Index of Granite, Sandstone, Limestone and Marble rocks during and after excessive temperature treatment, the following conclusions would be drawn:

The (PLI) (MPa) for Granite has a decreasing tendency upon heating from the room temperature and up to 1100 °C by a range various between 9% and 27% (compared with the initial value) for different heating periods. Sandstone rock is increased roughly when heated up to (300 °C) and then is decreased sharply by a range between 15% and 33% (compared with the initial value) for different heating periods.

For Limestone rocks, there is a decreasing tendency of PLI when heated various between room temperature up to 1100 °C by a range various between 46% and 65% (compared with the initial value) for different heating periods. The Marble rocks have a slight decrease up to 300 °C followed by a significant decrease by approximately a range of 45% and 50% (compared with the initial value) for different heating periods.

Periods of thermal effect has a great influence of (PLI) (MPa) for Granite, Sandstone, Limestone and Marble rocks from the room temperature, and up temperature of 1100 °C.

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