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Technical Note

Engineering properties of a low-grade metamorphic limestone

Louis Ngai Yuen Wong *, Varun Maruvanchery, Nwe Nwe Oo

School of Civil and Environmental Engineering, Nanyang Technological University, Singapore 639798, Singapore

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ABSTRACT

A particular type of limestone in Singapore is studied in this paper. Seventeen uniaxial compressive strength (UCS) tests and seventeen Brazilian tensile strength (BTS) tests are conducted. From a comprehensive petrographical study, the generally high UCS and BTS values are found to be attributed to the respective mineralogy and texture, as a result of the prevalence of low-grade metamorphism. Altered grain boundaries resulted from pressure solution are observed. Wavy suture contacts between interlocking and interpenetrating grains are common. Signs of subsequent precipitation (cementation) processes are recognized, which reduce the primary porosity and enhance the packing of the rock. On the other hand, with the aid of a high speed video capturing technology during the loading tests, exceptional low strengths obtained in certain specimens can be accounted for. An analysis of the high speed videos reveals that the early crack initiation is often favored along calcite veins, mudstone stringers, fossil fragments and hair-line cracks etc., which appear to be local zones of weakness. We also attempt to correlate the presence of heterogeneities in the rocks with the specimen failure mode under uniaxial compression. In summary, the results presented in this technical note fill in an existing gap of the engineering geology literature of Singapore with respect to limestone. The novelty of our research approach, which integrates the microscopic study and the high speed video imaging technique, is demonstrated to account for the large strength variation of the study limestone.

1. Introduction

The variation in strength of limestone can be attributed to a number of different factors including textural characteristics like grain size, grain shape, internal structure of the grains, mineral composition, matrix content and heterogeneities present in the rock (Edet, 1992; Hawkes and Mellor, 1970; Rashed and Sediek, 1997; Tahir et al., 2011; Van de Steen et al., 2002).

Textural characteristics are a major factor in determining the mechanical behavior of limestones (Azzoni et al., 1996; Ersoy and Waller, 1995). A quantitative assessment of rock texture can be formulated with respect to parameters such as grain shape and size, interlocking index and index of grain size homogeneity, cemented material binding each grain (matrix), mineral composition and grain content. These parameters are collectively called texture coefficient (TC). Ozturk and Nasuf (2013) attempted to classify the rock material according to its TC values based on the binary and fuzzy domain. They found that rock strength is proportional to TC. Clifford (1991), Nicksiar and Martin (2013) related the strength of limestone with the clay, calcium carbonate and quartz content present in the matrix. The effects of porosity on limestone properties have been comprehensively addressed in many previous studies (Török and Vásárhelyi, 2010; Vásárhelyi, 2005), which concluded that the strength of limestone reduces with the increase in porosity.

Many researchers observed that heterogeneities in the form of micro-cracks, calcite veins, fossils and mud layer present in the rock can act as relatively weak zones promoting the crack growth during loading tests, hence reducing the rock strength (Moh'd Basem, 2009; Tahir et al., 2011; Van de Steen et al., 2002). Van de Steen et al. (2002), who studied the influence of internal structure on fracture paths in crinoidal limestone, observed that the calcite crystals present in the crinoidal limestone serve as fracture initiators and also act as a preferential fracture path.

Various types of limestone in different regions of the world have been studied experimentally with respect to their mechanical strength,

* Corresponding author.
E-mail address: lnywong@ntu.edu.sg (L.N.Y. Wong).

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Table 1
Relationship between uniaxial compressive strength (UCS) and Brazilian tensile strength (BTS) established for limestone in previous studies.

Relationship obtained	Type of relationship	Correlation coefficient	Local name of limestone	Description	References
UCS (MPa) = 12.195 BTS	Linear	Not given	Nkalagu, Yandev and Abini limestones	Hard, gray and shelly with olithic textures and frequently recrystallized	Clifford (1991)
			Ewekoro, Shagamu, Mfamosing, Etankpini and Ashaka limestones	Soft, pale gray or buff, and contain lenses of hard limestone and appreciable amounts of clay	
UCS (MPa) = 12.308 $BTS^{1.0725}$	Power	0.82	Limestone data from previous works (various sources)	Not provided	Altindag and Guney (2010)
UCS (MPa) = 7.86 BTS − 447.63	Linear	0.9241	Ocala limestone	Predominately calcium carbonate and is generally soft and porous	Farah (2011)
UCS (MPa) = 7.53 BTS	Linear	0.445	Cherat limestone	Yellowish brown, brownish gray and light to dark gray in color, coarsely crystalline, fossiliferous, and numerous calcite veins	Tahir et al. (2011)
			Kohat limestone	Creamy, yellowish, brown and pink in color, finely crystalline, highly fossiliferous	
UCS (MPa) = 10.61 BTS	Linear	0.54	Sogutalan/Bursa, Korkuteli/Antalya, Fethiye/Mugla, Bunyan/Kayseri Limestone, Yahyali/Kayseri Dolomitic limestone.	Not provided	Kahraman et al. (2012)
UCS (MPa) = 9.25 $BTS^{0.947}$	Power	0.9	Limestone	Not provided	Nazir et al. (2013)

particularly the uniaxial compressive strength (UCS) (Singh and Sun, 1990; Kasim and Shakoor, 1996; Guo, 1998; Van de Steen et al., 2002; Tan, 2006; Sabatakakis et al., 2008; Basem, 2009; Palchik, 2011; Ozturk and Nasuf, 2013). These studies reveal that the strength of limestone varies considerably from 10 MPa to about 250 MPa. According to ISRM (1981) rocks can be classified as very strong if their UCS is greater than 100 MPa, whereas weak-to-strong rocks refer to those rocks possessing UCS values between 5 MPa and 100 MPa.

The Brazilian tensile strength (BTS) of limestones also varies considerably, typically ranging from 3 MPa to 10 MPa (Vasarhelyi, 2005; Yagiz, 2009; Karakul and Ulusay, 2013). Probably due to the ease of conducting the Brazilian disc test as compared with the UCS test, there has always been a keen interest to establish a relationship between the BTS and the UCS. Relationships in both linear form and exponential form were suggested by various researchers (Clifford, 1991; Altindag and Guney, 2010; Farah, 2011; Tahir et al., 2011; Kahraman et al., 2012; Nazir et al., 2013). Refer to Table 1 for a summary. These relationships are however usually applicable only to a site-specific limestone. Establishing a general universal relationship between UCS and BTS for limestone is found impossible due to the large variation in strength values and lithology geographically.

The aim of the present research is to study the factors contributing to the strength variations of the Jurong limestone, which has not been comprehensively studied. In addition to the routine experimental uniaxial compressive strength test and the indirect tensile strength test, the present study also investigates the relationship between mineralogical composition/texture and rock strength. Both loading tests are performed with the aid of a high speed camera. Before each test, any unique heterogeneities observable on the specimens are carefully recorded. The deformation and cracking processes during the loading tests are carefully studied using high speed video technology, which can possibly help

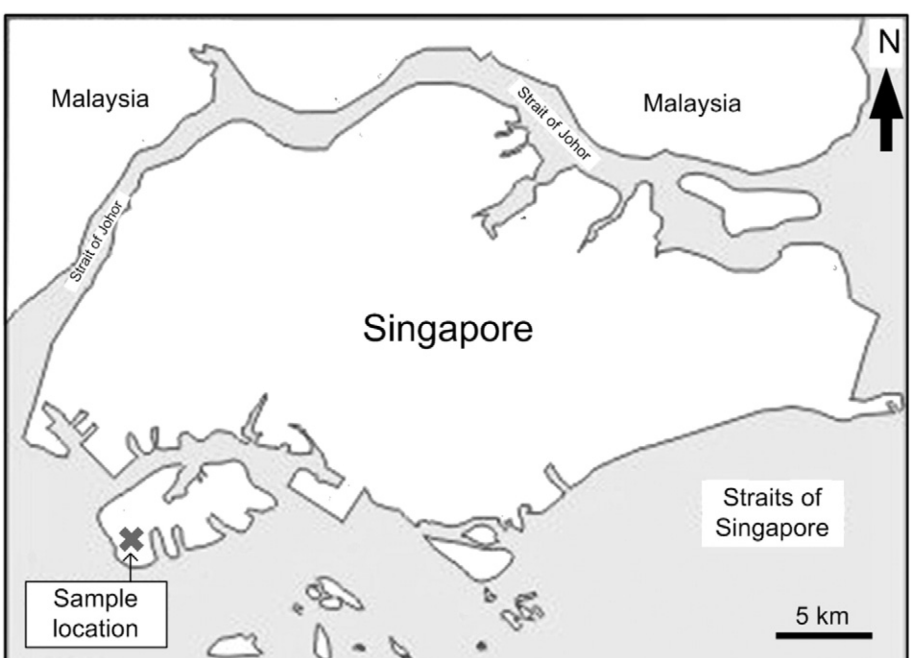

Fig. 1. Sampling location.