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Mechanical properties and petrographic characteristics of Margala Hill limestone and Lockhart limestone of Rumli area, Islamabad Pakistan

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Abstract This study has been carried out to investigate the effect of petrographic characteristics on mechanical properties of Margala Hill limestone and Lockhart limestone of Rumli area, Islamabad, Pakistan. Mechanical properties, in terms of unconfined compressive strength (UCS), were computed by using point load test. Petrographic study reveals calcite and bioclasts as principal constituents of these limestones. These rocks have been classified as wackestones and mudstones. Mutual relationships of UCS with calcite, bioclasts and porosity of these rocks have been established which indicate that mechanical properties are directly linked with calcite contents and inversely related to porosity and bioclasts. Owing to comparatively higher porosity and bioclasts, Margala Hill limestone has relatively inferior mechanical properties than Lockhart limestone. Regression analysis was performed to find out some linear relationship between mechanical properties (UCS) with mineralogical characteristics and porosity of the Margala Hill limestone and Lockhart limestone. The study reveals significant positive correlation between UCS and calcite contents with higher values of regression coefficient ($R^2 = 0.91$ and $R^2 = 0.76$), and inverse relationship of UCS with bioclasts ($R^2 = 0.93$ and $R^2 = 0.77$) and porosity ($R^2 = 0.96$ and $R^2 = 0.79$) of the Margala Hill limestone and Lockhart limestone, respectively.

Keywords Petrographic characteristics · Margala Hill limestone · Lockhart limestone · Regression analysis

1 Introduction

Mechanical characteristics of crushed rocks are of prime importance for their utilization as aggregate source and dimension stones (Ngerebara and Youdeowei 2014). Unconfined Compressive Strength (UCS) is one of the most widely used tests to find out mechanical properties of rocks (Hawkes and Mellor 1970). Strength of rocks can be determined by using

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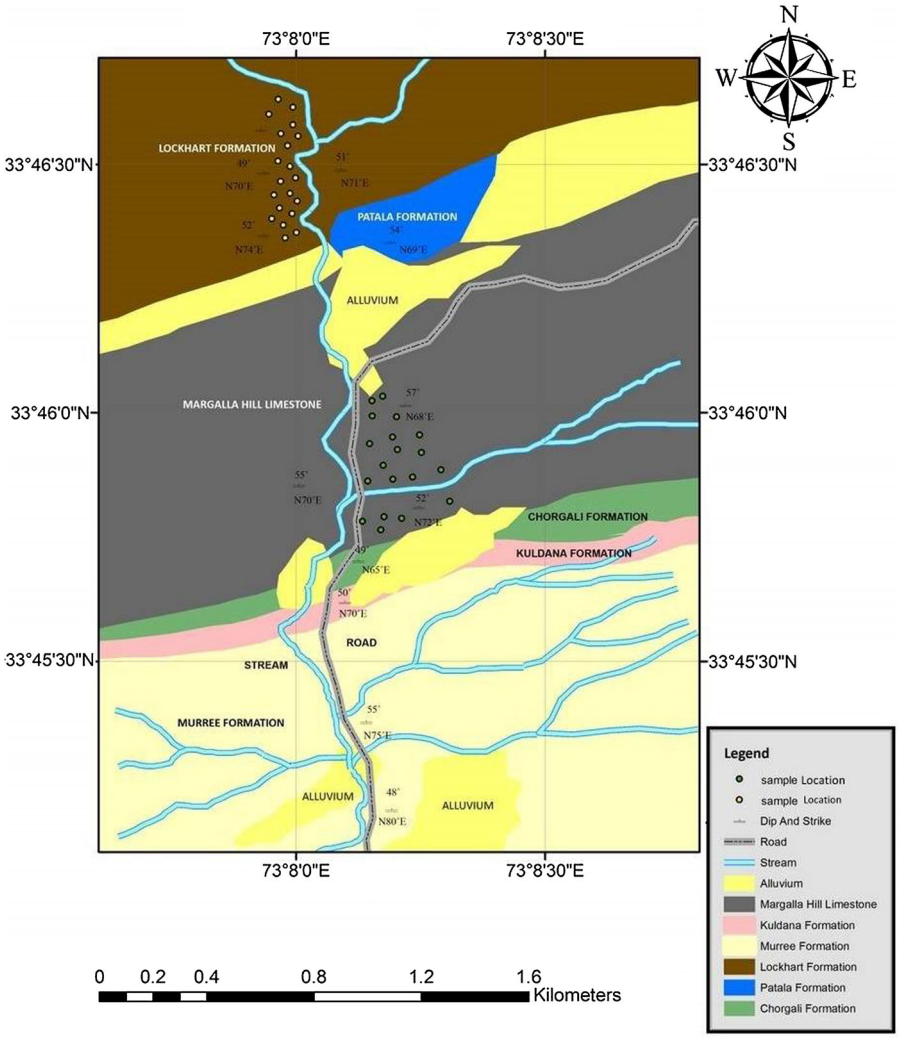

Fig. 1 Geological map of Rumli area showing location of samples

compression testing machine which involves time consuming and careful sample preparation technique. However, UCS of rocks can also be computed by using point load test (PLT). Various workers have developed relationships for the evaluation of UCS from PLT values. Sabatakakis et al. (2009) carried out UCS and PLT on sedimentary rocks (sandstone, marlstone and limestone) and established relations for each class:

$$\begin{aligned} I_s &< 2 \text{ MPa} \quad & UCS &= 13\ I_{s(50)} \\ I_s &= 2 - 5 \text{ MPa} \quad & UCS &= 24\ I_{s(50)} \\ I_s &> 5 \text{ MPa} \quad & UCS &= 28\ I_{s(50)} \end{aligned}$$

where I_s is point load strength index and $Is_{(50)}$ stands for point load test Index.

Table 1 Point load test (PLT) and unconfined compressive strength (UCS) values of Margala Hill limestone

Margala Hill limestone		
Sample No.	Point load test (PLT) values (MPa)	Unconfined compressive strength (UCS) (MPa)
MH-1	2.59	62.16
MH-2	1.89	24.57
MH-3	1.85	24.05
MH-4	1.82	23.66
MH-5	2.17	52.08
MH-6	1.97	25.61
MH-7	3.29	78.96
MH-8	3.63	87.12
MH-9	3.51	84.24
MH-10	3.33	79.92
MH-11	4.36	104.64
MH-12	3.14	75.36
MH-13	2.65	63.6
MH-14	2.82	67.68
MH-15	3.16	75.84
MH-16	3.16	75.84
MH-17	3.79	90.96
MH-18	4.44	106.56
MH-19	3.41	81.84
MH-20	3.99	95.76

Mechanical properties of intact rocks are greatly influenced by their petrographic characteristics. Influence of micro-structures and mineral composition of rocks on physical properties of crushed rock aggregate has been investigated by many workers (Ramsay et al. 1974; Hartley 1974; Lees and Kennedy 1975). UCS of rocks aggregate is indirectly related to their mineral constituents, bioclasts, cement and texture (Bell 1978; Dobereiner and De Freitas 1986; Shakoor and Bonelli 1991; Yates 1992; Ulusay et al. 1994; Bell and Lindsay 1999). Petrographic and aggregate characteristics of Margala Hill limestone and Lockhart limestone have been investigated by Gondal et al. (2007) however; UCS of these rocks has not been investigated by these authors. Physical properties of construction materials are directly related with UCS, mineralogical and textural characteristics of rocks. Therefore it is imperative to study these properties for the evaluation of soundness of these limestone aggregate sources. Consequently, UCS and petrographic studies of MH and LT of Rumali area, were carried out to determine aggregate potential of these limestones.

2 Lithological description

Margala Hill limestone (MH) and Lockhart limestone (LT) are exposed in Rumli area, Islamabad (Fig. 1). These rock units are basically composed of limestone with minor amounts of marl and shales. Margala Hill limestone is fine to medium, hard and medium to thick bedded lithological unit. It is grey on fresh surface and shows pale-grey color on weathered surface.

Table 2 Point load test (PLT) and unconfined compressive strength (UCS) values of Lockhart limestone

Lockhart limestone		
Sample No.	Point load test (PLT) values (MPa)	Unconfined compressive strength (UCS) (MPa)
LT-1	3.38	81.12
LT-2	2.66	63.84
LT-3	2.43	58.32
LT-4	2.24	53.76
LT-5	2.12	50.88
LT-6	1.90	24.70
LT-7	6.03	144.72
LT-8	5.06	121.44
LT-9	5.07	121.68
LT-10	4.19	100.56
LT-11	4.58	109.92
LT-12	3.72	89.28
LT-13	4.22	101.28
LT-14	5.78	138.72
LT-15	5.75	138.00
LT-16	3.59	86.16
LT-17	4.19	100.56
LT-18	4.57	109.68
LT-19	2.92	70.08
LT-20	3.35	80.40

The limestone is fossiliferous and contains calcite veins. The age of Margala Hill limestone is Paleocene (Shah 2009).

Lockhart limestone is light-grey to dark-grey on fresh surface and dirty-grey to light-grey on weathered surface. It is thick bedded, medium grained, hard and nodular limestone which gives fetid smell on fresh surface. Early Eocene age has been assigned to this rock unit (Shah 2009).

3 Research methodology

Total 40 block samples of MH and LT (20 samples of each limestone) were collected from their respective outcrops in Rumli area. Locations of these samples are given in Fig. 1. The MH and LT contain very small amounts of marl and shales but owing to predominant lithology. Samples were collected from limestone parts of these lithologic units. These samples were split into two parts. One part was used for PLT, while other portion was utilized to prepare thin sections for petrographic studies.

PLT were carried out on these limestone samples following the ISRM (1985) specifications. The ratio of distance between platens (D) and smallest rock specimen width (W) was kept in the range of 0.3 and 1. The distance between contact point and the nearest free face (L) was kept more than 0.5 D. The smallest rock specimen width (W) was calculated by averaging the width of both sides of the sample. These samples were put in the PLT machine.

Table 3 Rock classification, mineralogical composition and porosity of Margala Hill (MH) limestone

Margala Hill limestone							
Sample nos.	Rock name*	Calcite (%)	Bioclasts (%)	Hematite (%)	Limonite (%)	Pyrite (%)	Porosity (%)
MH-1	Wackstone	81.0	17.2	0.1	0.1	0.0	1.6
MH-2	Wackstone	76.2	21.6	0.1	0.1	0.0	2.0
MH-3	Wackstone	73.4	24.3	0.1	0.1	0.0	2.1
MH-4	Wackstone	73.2	24.5	0.1	0.1	0.0	2.1
MH-5	Wackstone	79.1	18.9	0.1	0.1	0.0	1.8
MH-6	Wackstone	78.2	19.6	0.1	0.1	0.0	2.0
MH-7	Mudstone	88.5	9.9	0.1	0.2	0.0	1.3
MH-8	Mudstone	89.3	8.9	0.2	0.4	0.1	1.1
MH-9	Mudstone	89.2	9.0	0.2	0.3	0.1	1.2
MH-10	Mudstone	88.8	9.5	0.2	0.2	0.1	1.2
MH-11	Mudstone	90.1	7.6	0.5	0.7	0.1	1.0
MH-12	Mudstone	88.3	10.0	0.1	0.2	0.0	1.4
MH-13	Wackstone	83.0	15.2	0.1	0.1	0.0	1.6
MH-14	Wackstone	83.9	14.4	0.1	0.2	0.0	1.4
MH-15	Mudstone	88.5	9.8	0.1	0.2	0.0	1.4
MH-16	Mudstone	88.3	10.0	0.1	0.2	0.0	1.4
MH-17	Mudstone	89.6	8.6	0.3	0.4	0.1	1.0
MH-18	Mudstone	90.3	6.2	1.2	1.2	0.1	1.0
MH-19	Mudstone	89.1	9.1	0.2	0.3	0.1	1.2
MH-20	Mudstone	89.6	8.4	0.3	0.6	0.1	1.0

* Dunham (1962) classification

Load was applied and steadily increased in order to achieve rock failure within 10–60 seconds. At the failure point the load value (P) was recorded from the gauge and the strength of the samples were calculate by using relation P/D^2. UCS was calculated by using the relation proposed by Sabatakakis et al. (2009) and results are presented in Tables 1 and 2.

For petrographic studies forty thin sections, of approximately 30 μm thickness, were prepared. These sections were stained by Alizarin Red and studied under Nikon Eclipse polarized microscope to determine mineral composition, bioclasts and textural characteristics of MH and LT. Mineralogical composition and rock classification of these limestones (Dunham 1962) is given in Tables 3 and 4.

4 Results and discussion

Petrography study of MH and LT revealed that these limestones are mudstones and wackestones (Dunham 1962) which are principally comprised of calcite and bioclasts (Figs. 2, 3a–f). Being major components calcite and bioclasts are going to affect mechanical properties of these limestones while the minor minerals have negligible influence on the strength of these rocks.

Mean calcite contents of MH and LT are 84.88 and 86.02 %, whereas bioclasts are 13.14 and 12.37 %, respectively. Hematite, limonite and pyrite are present is small amounts (less

Table 4 Rock classification, mineralogical composition and porosity of Lockhart (LT) limestone

Lockhart limestone							
Sample no.	Rock name*	Calcite (%)	Bioclasts (%)	Hematite (%)	Limonite (%)	Pyrite (%)	Porosity (%)
LT-1	Mudstone	88.9	9.9	0.1	0.1	0.0	1.0
LT-2	Wackstone	81.7	15.9	0.1	0.2	0.1	2.0
LT-3	Wackstone	80.1	17.7	0.1	0.1	0.0	2.0
LT-4	Wackstone	78.2	19.5	0.1	0.1	0.0	2.1
LT-5	Wackstone	69.7	27.7	0.1	0.1	0.1	2.3
LT-6	Wackstone	61.4	35.9	0.1	0.2	0.0	2.4
LT-7	Mudstone	93.4	5.4	0.5	0.3	0.1	0.3
LT-8	Wackstone	90.8	7.7	0.3	0.2	0.0	1.0
LT-9	Mudstone	91.1	7.4	0.4	0.3	0.0	0.8
LT-10	Wackstone	89.5	9.1	0.2	0.2	0.0	1.0
LT-11	Mudstone	90.1	8.4	0.3	0.2	0.0	1.0
LT-12	Mudstone	89.1	9.7	0.1	0.1	0.0	1.0
LT-13	Mudstone	89.5	9.1	0.2	0.1	0.1	1.0
LT-14	Wackstone	93.1	5.6	0.4	0.2	0.1	0.6
LT-15	Mudstone	92.7	6.0	0.4	0.2	0.0	0.7
LT-16	Mudstone	89.1	9.7	0.1	0.1	0.0	1.0
LT-17	Wackstone	89.5	9.1	0.2	0.2	0.0	1.0
LT-18	Mudstone	89.6	9.0	0.2	0.1	0.1	1.0
LT-19	Wackstone	84.1	14.6	0.1	0.1	0.1	1.0
LT-20	Mudstone	88.8	10.0	0.1	0.1	0.0	1.0

* Dunham (1962) classification

than 1 %). Calcite content varies in the range of 73.2–90.3 and 61.4–93.1 % along with bioclasts 6.2–24.5 and 5.6–35.9 % in MH and LH, respectively (Table 3 and 4). Whereas, UCS values of MH and LT vary from 23.66 to 106.56 MPa and 24.70 to 144.72 MPa, respectively. Highest UCS 106.56 MPa corresponds to maximum calcite percentage of 90.30 in MH-18 whereas, the lowest UCS value of 23.66 MPa have minimum calcite contents of 73.2 % in MH-4. Calcite contents in both limestones are comparable but bioclasts are relatively higher in MH as compared with LT which is revealed in the form of relatively inferior (69.02 MPa) mechanical properties (UCS) of the former than the later (92.26 MPa) as shown in Figs. 4 and 5a, b.

Although limestones have very little porosity but it does have negative impact on the mechanical properties (UCS) of these rocks. The porosity ranged from 1.0 to 2.1 % (mean 1.44 %) and 0.3 to 2.4 % (average 1.21 %) in MH and LT, respectively. Relatively higher porosity of the former may be related to its higher bioclasts contents. Comparatively higher porosity of the MH is main contributory factor imparting relatively lower strength (UCS) than LT. Limestone samples possessing lowest porosities have highest UCS values. In Margala Hill limestone sample MH-16 has lowest porosity (1.0 %) possessing highest UCS (106.56 MPa), whereas MH-4 with highest porosity (2.1 %) having lowest UCS (23.66 MPa). Similarly in Lockhart limestone LT-7 with lowest porosity (0.3 %) corresponds to highest UCS (144.72 MPa), while LT-6 has highest porosity (2.4 %) and lowest UCS (24.70 MPa) values (Figs. 5 and 6 a, b).

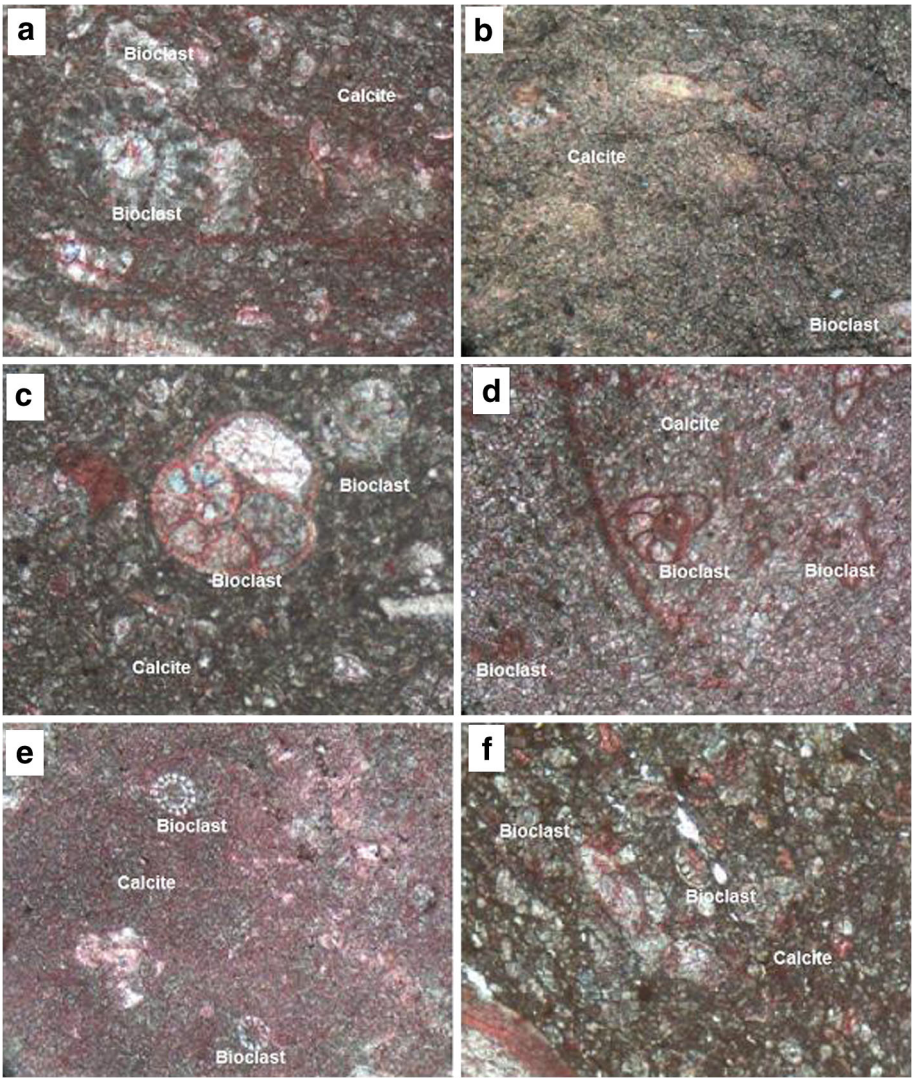

Fig. 2 Microphotographs (**a**–**f**) showing calcite and bioclasts in Margala Hill limestone

Linear equation for the best fit line and regression coefficient (R^2) value was determined by applying regression analysis of mechanical properties (UCS) with mineralogical characteristics and porosity of the MH and LT. Their mutual relationships indicate that strength of the rock increase with calcite content and decrease with the increase of bioclasts and porosity. A significant linear relationship between calcite contents and UCS of MH and LT has been witnessed (Fig. 7a, b respectively). These regression relations are:

$$\text{For MH} \quad \text{UCS} = 4.2596^{*}\text{clacite}(\%) - 292.53; \quad R^2 = 0.908$$
$$\text{For LT} \quad \text{UCS} = 3.4482^{*}\text{clacite}(\%) - 204.36; \quad R^2 = 0.764$$

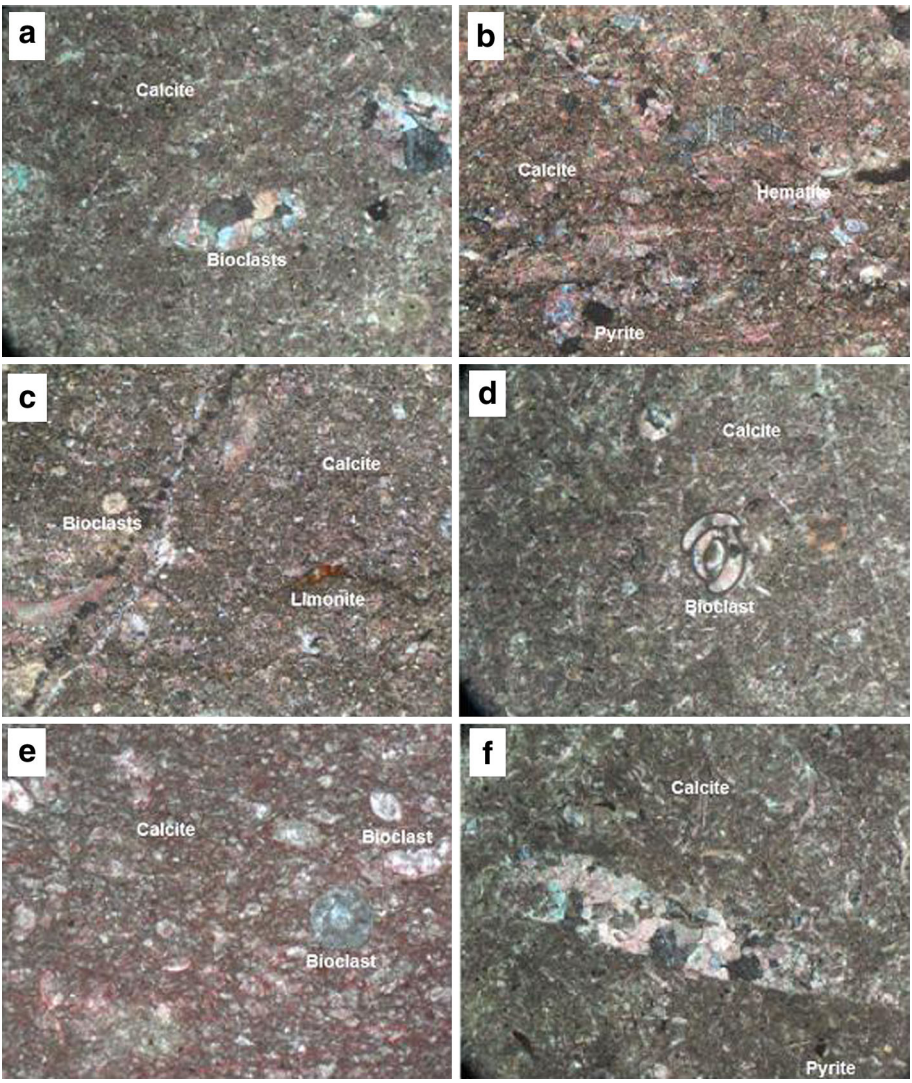

Fig. 3 Microphotographs (**a**–**f**) showing calcite, bioclasts, pyrite and limonite in Lockhart limestone

However, there is significant negative correlation between bioclasts and UCS values of MH ($R^2 = 0.93$) and LT ($R^2 = 0.77$) as shown in Fig. 8a, b repectively. These relations for Margala Hill limestone and Lockhart limestone are:

$$\begin{array}{lll} \text{For MH} & \text{UCS} = -4.3415^{*}\text{bioclast}\,(\%) + 126.05; & R^2 = 0.93 \\ \text{For LT} & \text{UCS} = -3.6596^{*}\text{bioclast}\,(\%) + 137.52; & R^2 = 0.77 \end{array}$$

Significant negative trends in MH ($R^2 = 0.96$) and LT ($R^2 = 0.79$) have been also noticed between porosity and UCS values as demonstrated in Fig. 9a, b respectively.

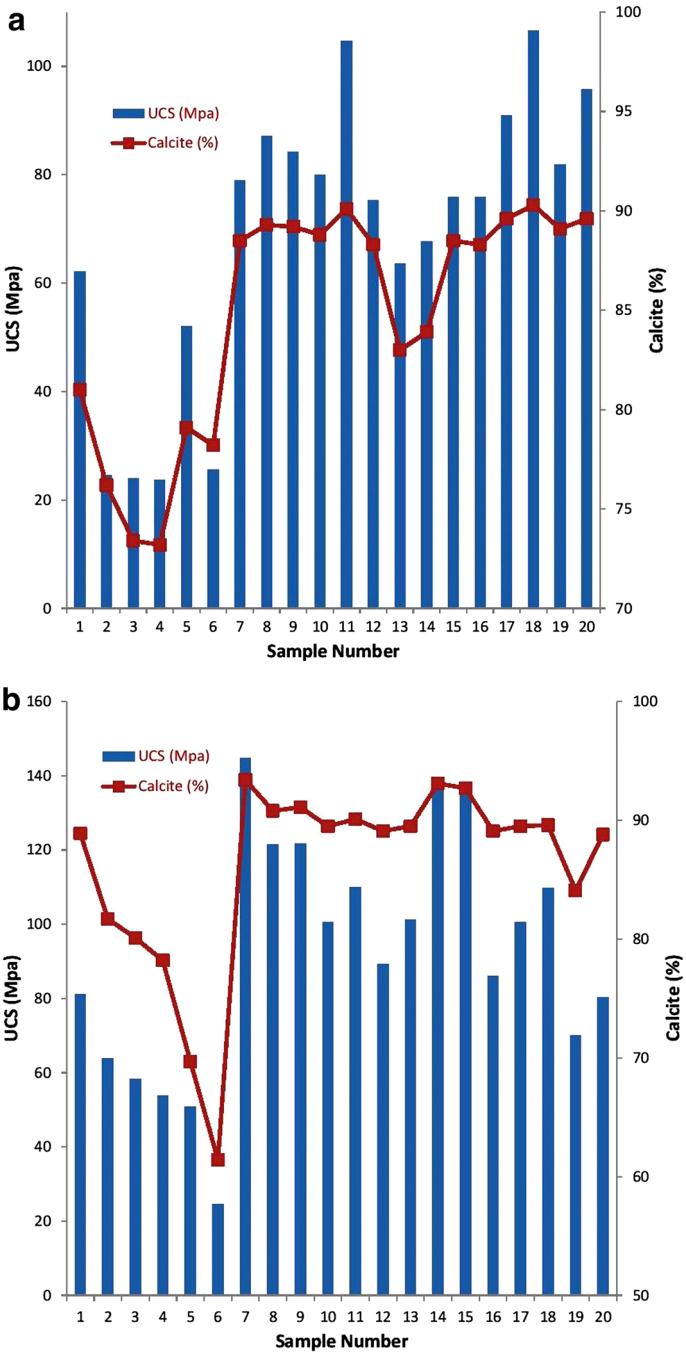

Fig. 4 Relationship of UCS with calcite in **a** Margala Hill limestone and **b** Lockhart limestone respectively. *Red line* represents calcite content and *blue bars* represents to UCS value in each sample. (Color figure online)

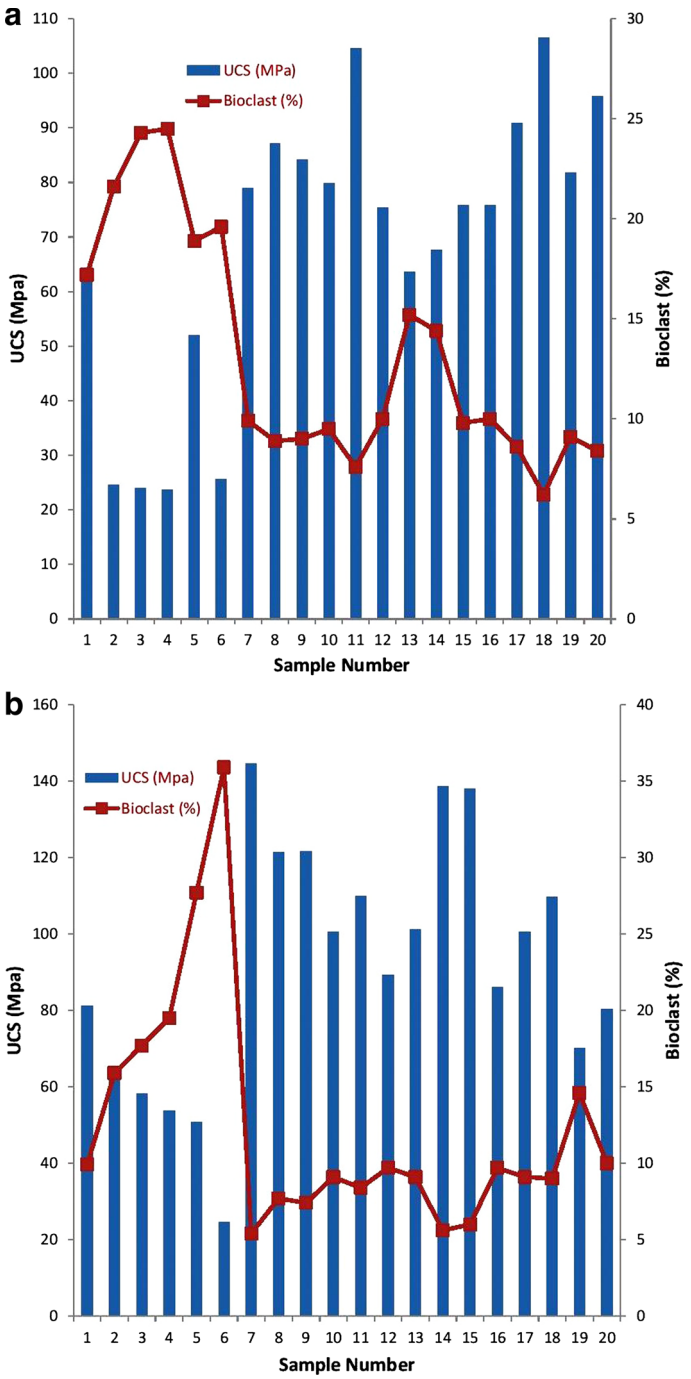

Fig. 5 Relationship of UCS with bioclasts in **a** Margala Hill limestone and **b** Lockhart limestone respectively. *Red line* represents bioclast content (in percentage) and *blue bars* represents to UCS value in each sample. (Color figure online)

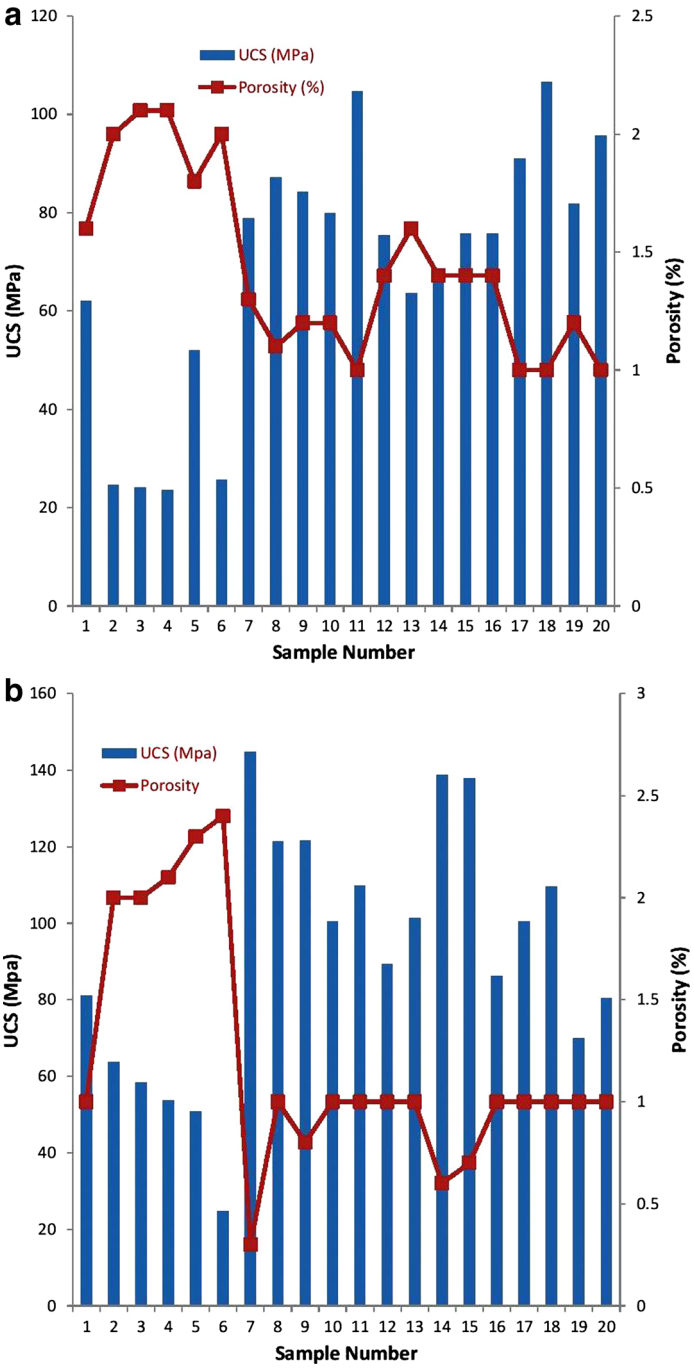

Fig. 6 Relationship of UCS with porosity in **a** Margala Hill limestone and **b** Lockhart limestone respectively. *Red line* represents porosity (in percentage) and *blue bars* represents to UCS value in each sample. (Color figure online)

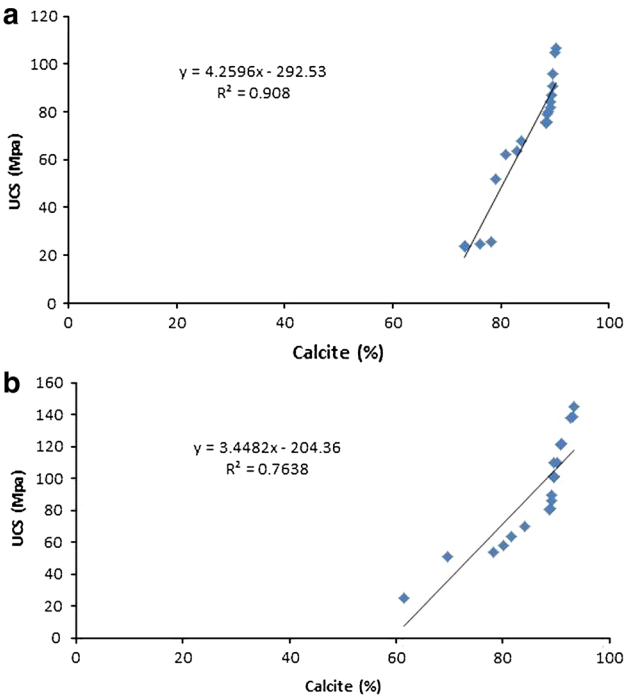

Fig. 7 Regression analysis of UCS versus calcite **a** in Margala Hill limestone and **b** Lockhart limestone

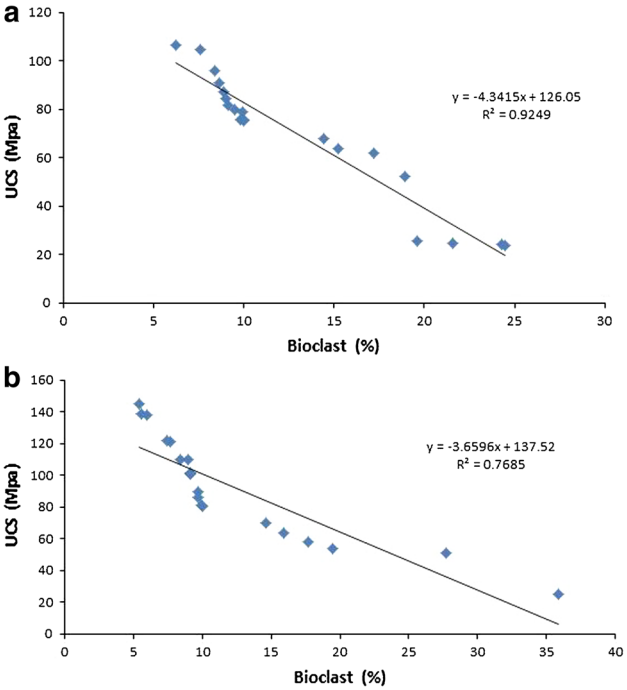

Fig. 8 Regression analysis of UCS versus bioclasts **a** in Margala Hill limestone and **b** Lockhart limestone respectively

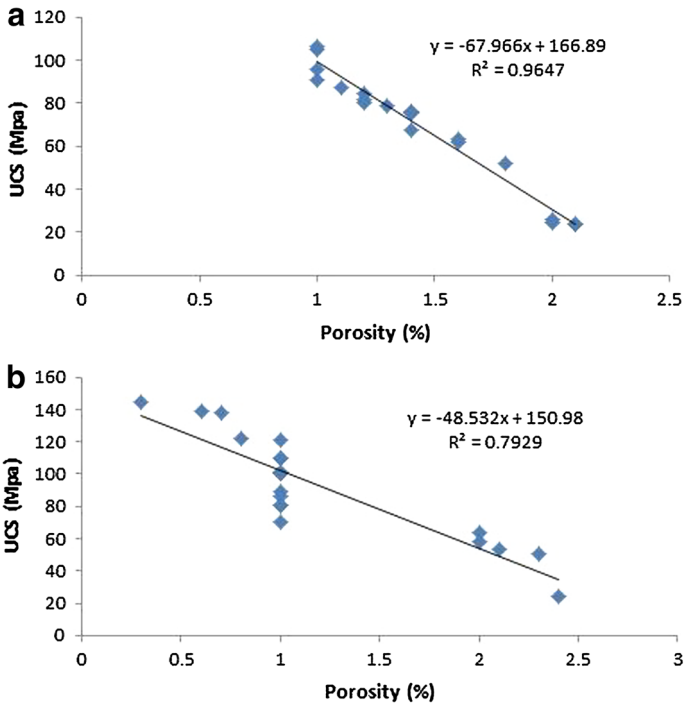

Fig. 9 Regression analysis of UCS versus porosity **a** in Margala Hill limestone and **b** Lockhart limestone respectively

The study indicates that although calcite contents have their impact on UCS but bioclasts and porosity are the major contributory factors which adversely affect the mechanical properties (UCS) of the MH and LT.

5 Conclusion

Mechanical properties, in terms of unconfined compressive strength (UCS), of Margala Hill limestone and Lockhart limestone were determined by using point load test (PLT). Petrographic study indicates that these rocks are wackestones and mudstones. Calcite and bioclasts are the main constituents of these limestones which significantly affect mechanical properties of these limestones. Having relatively higher bioclasts and porosity MH possess inferior mechanical properties (UCS) as compared with LT. Regression analyses indicate significant positive correlation between UCS and calcite contents, whereas significantly inverse relationship of bioclasts and porosity with UCS of the Margala Hill limestone and Lockhart limestone is revealed.

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