Assessment of Sandstone, Western Desert of Iraq as Anti-Acidic and Alkalis Bench

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Abstract

The objectives of this study are to evaluate the sandstone (quartz arenite) as anti-acidic and alkalis tiles bench. Sandstones of Rutbah Formation are studied petrographically, mineralogically and geochemically. They are subjected to the many tests to assess their suitability as dimension stone and resistance. The physical and mechanical properties which include bulk density, water absorption, compressive strength, modulus of rupture and abrasion resistance are computed in addition to acidic and alkalis resistance testes. The results are successful and encouraging showing the possibility of manufacturing resistance bench. The Iraqi and American Standard for Testing Materials (ASTM) specifications are adopted for comparing the results.

Keywords: Western Desert of Iraq, sandstone, quartz arenite, anti-acidic and alkalis bench, ASTM, Iraqi specification.

الخلاصة

تهدف الدراسة الحالية الى تقييم الصخورالرملية (كوارتزارينايت) كبلاطات للبنجات المقاومة للحوامض والقواعد. درست الصخور الرملية بتروغرافيا, معدنيا وجيوكيميائيا و خضعت النماذج الى العديد من الاختبارات لتقييمها كصخور بعدية ومقاومة. تم دراسة الخواص الفيزيائية والميكانيكية والتي تتضمن الكثافة, امتصاص الماء,قوة الانضغاط, معيار الكسرومقاومة الاحتكاك بالاضافة الى اختبارات مقاومة الحوامض والقواعد. كانت النتائج ناجحة ومشجعة واظهرت امكانية تصنيع بنجات مقاومة وقد تم اعتماد المواصفات العراقية والعالمية لغرض مقارنة النتائج.

الكلمات المفتاحية: الصحراء الغربية العراقية، الصخور الرملية، الكوارتزأرينايت،بنجات مقاومة للحوامض والقواعد، المواصفات الامريكية القياسية لاختبار المواد، المواصفات العراقية.

1. Introduction

Sandstone is a dense and cohesive stone known for its remarkable durability. It does not alter in density or hardness over time like some types of rocks. Laboratory bench or countertop exposed to the influence of chemical substance, because of their uses in experiments. Accordingly, raw materials of these benches must be chosen when unaffected by these substance especially acids and alkalis. Sandstone as natural stones which are collected from 4 sites of Rutbh Formation are assessed by subjected to several tests to find their physical and mechanical properties as well as chemical properties.

2. Location of the study area

Sandstone samples were collected from Rutbah Formation outcrops in four sites. The first site is located about 25 km northwest Rutbah whereas the second site is located about 60 km north of Rutbah which is the main resource of hard sandstone. The third site is located about 7 km south east of Rutbah; the fourth site is located about 15 km southwest of Rutbah and forms the main resource of sandstone (Fig.1). The geographic coordinates are listed in Table 1.

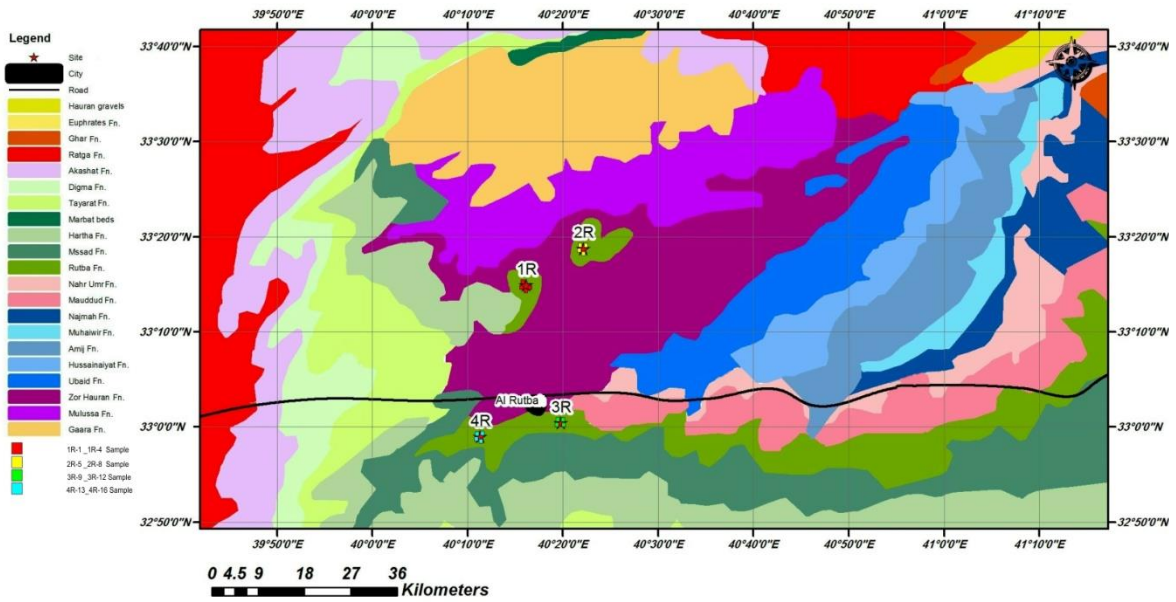

Fig. 1: Location map of the studied area (Sissakian, 2000).

Table 1: Coordinates of sampling sites Rutbah (R) Formation with simple descriptions.

Formation	Site no.	Sample no.	Location		Elev. (m)	Description
			Longitude E	Latitude N		
Rutbah	1R	1R-1 to 1R-4	40º 18′ 598″	33º 17′ 735″	628	Hard cemented sand stones with desert varnish (surface sample), white to pale grey in color.
	2R	2R-5 to 2R-8	40º 24′ 710″	33º 19′ 210″	679	Hard cemented sand stones with desert varnish (surface sample), dark red in color.
	3R	3R-9 to 3R-12	40º 19′ 920″	33º 0′ 906″	684	Hard cemented sandstones with desert varnish (surface sample), pale orange in color.
	4R	4R-13 to 4R-16	40º 11′ 690″	32º 58′ 970″	650	Hard cemented sandstones with desert varnish (surface sample), white in color.

3. Geological setting

Generally, the landscape of the Western Desert of Iraq is not complex, but is characterized by the varied forms; the study area is hilly to semi flat area.

Rutbah Formation was recognized in the Iraqi Western Desert for the first time by Foran and Keller (1937)in Bellen *et al.* (1959). It represents the third formation within the second sedimentary cycle of the Cretaceous Period.

It is exposed in Wadi Hauran, south of Rutbah town for about 20 Km, it extends in Wadi Hauran (northwards) till Rutbah town, then extends eastwards parallel to the underlying Cretaceous formations for about 85 Km, then extends northeast wards crossing Tlaiha vicinity, then Wadi Amij, then more northeastwards for about 36 km from Tlaiha, as dissected segments due to NW–SE trending faults. North of Rutbah town, it is exposed as isolated exposures like in Tal Al-Nasir. It is also exposed along the western rim of Ga`ara Depression (Sissakian and Mohammed, 2007). The type locality of Rutbah Formation is 4 km northwest of Rutbah town which consists of varies colored, white and ferruginous fine sands and sandstones, locally cemented to quartzites, with thickness 23m. (Bellen *et al.*, 1959).Al-Mubarak and Amin (1983) described Rutbah Formation NW of Kilo-160 vicinity as mainly ferruginous sandstone, partly quartzitic, yellowish grey with desert varnish, occasionally cemented by siliceous, calcareous and ferruginous materials, with thickness of 4–5 m increasing westwards. while Al-Azzawi and Dawood (1996) described it in NW of Kilo 160 vicinity as yellow and white sandstone, occasionally contains fine pebbles, overlain by white and grey sandstone, which includes sand balls (poikiloblastic texture), occasionally they change laterally to ortho-quartzite with clear desert varnish, overlain by white, violet, brown and red sandstone, which contains iron oxides, in the upper parts. Occasionally, thin horizons of claystone and sandy marl occur in the uppermost part, with thickness 9 m NW of Kilo-160 vicinity increases to 54 m east of Rutbah town.

Cenomanian is the age of Rutbah Formation according to Bellen, *et al.* (1959). The depositional environment of it is continental, exceptionally littoral marine (Buday, 1980). Rutbah Formation overlies the Mauddud Formation only in the extreme western parts of the exposure area. The contact is covered by thick Quaternary sediments (Al-Mubarak and Amin, 1983), and it overlies many formations. The contact is unconformable marked by the first appearance of sandstone horizon which occasionally contains iron oxides (Al-Azzawi and Dawood, 1996).

4. Materials and Methods

4.1 Field work

Sandstones are collected from four sites (1R, 2R, 3R and 4R). The site 1R is located about 25km northwestern Rutbah, near the Ubaila dam as shown in Figure 2. The site 2R is located of about 60 km north of Rutbah in Tal Al-Nisir (Figure 3). The site 3R is located about 7 km southeastern Rutbah, in area named locally the three hills (Figure 4). The site 4R lies about 15 km southwestern Rutbah, it represents a small area near the quarry of glass sand composing of a large blocks of sandstone (Figure 5).

Figure 2: Sandstone outcrop of Rutbah Formation in site 1R. Black color is desert varnish.

Figure 3: Sandstone of Rutbah Formation in Tal Al-Nisir, site 2R. Black color is desert varnish.

Figure 4: Sandstone outcrop of Rutbah Formation in site 3R. Black color is desert varnish.

Figure 5: Sandstone outcrop of Rutbah Formation in site 4R. Black color is desert varnish.

4.2 Laboratory work

The laboratory work includes many steps as follows:

a- Preparing sandstone thin sections for microscopic study.

b- Identifying the mineralogical composition by using X-ray diffraction technique.

c- Chemical analysis for major oxides by the following methods:
- SiO_2 and L.O.I are analyzed using gravimetric method.
- Fe_2O_3, CaO, MgO and MnO are analyzed using titration.
- Na_2O and K_2O are analyzed using the flame photometric method.
- Al_2O_3 and TiO_2 are analyzed using the colorimetric method.

d- Physical and mechanical properties of sandstone samples are found which include bulk density, porosity, water absorption, compressive strength, modulus of rupture and abrasion resistance.

e- Durability test by using different acids and alkalis after cutting and polishing the sandstone samples.

5. Results and Discussion

5.1 Petrography of sandstone

Monocrystalline quartz is a predominant mineral, and consists more than 95% of the total mineralogical composition (Figure 6). In all sites, a small amount of opaque heavy minerals in addition to the tourmaline, zircon and rutile are observed as accessory minerals (Figure 7).

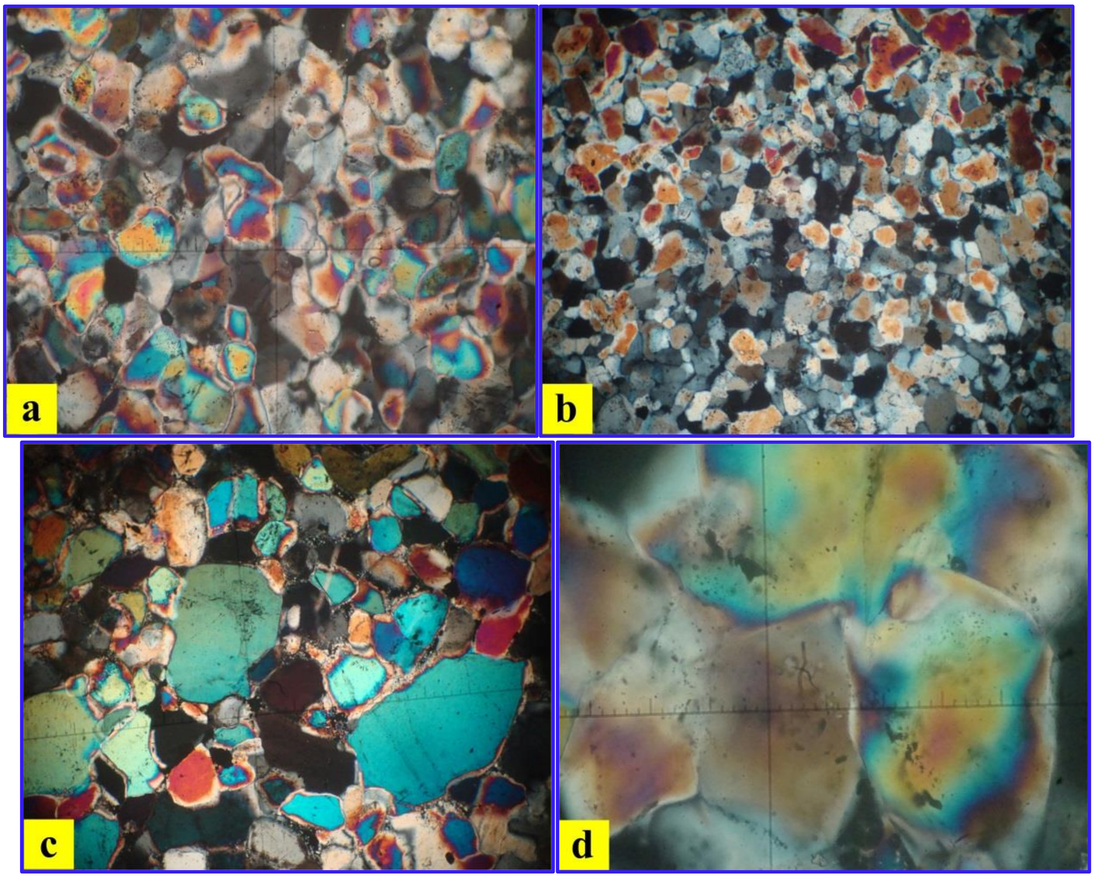

Figure 6: Photomicrograph of monocrystalline quartz as a predominant mineral in Rutbah Formation, a: Site 1R (sample no.1R-1), XPL, 10X; b: Site 2R (sample no. 2R-5), XPL, 4X; c: Site 3R (sample no. 3R-9), XPL, 10X; d: Site 4R (sample no. 4R-13), XPL, 25X.

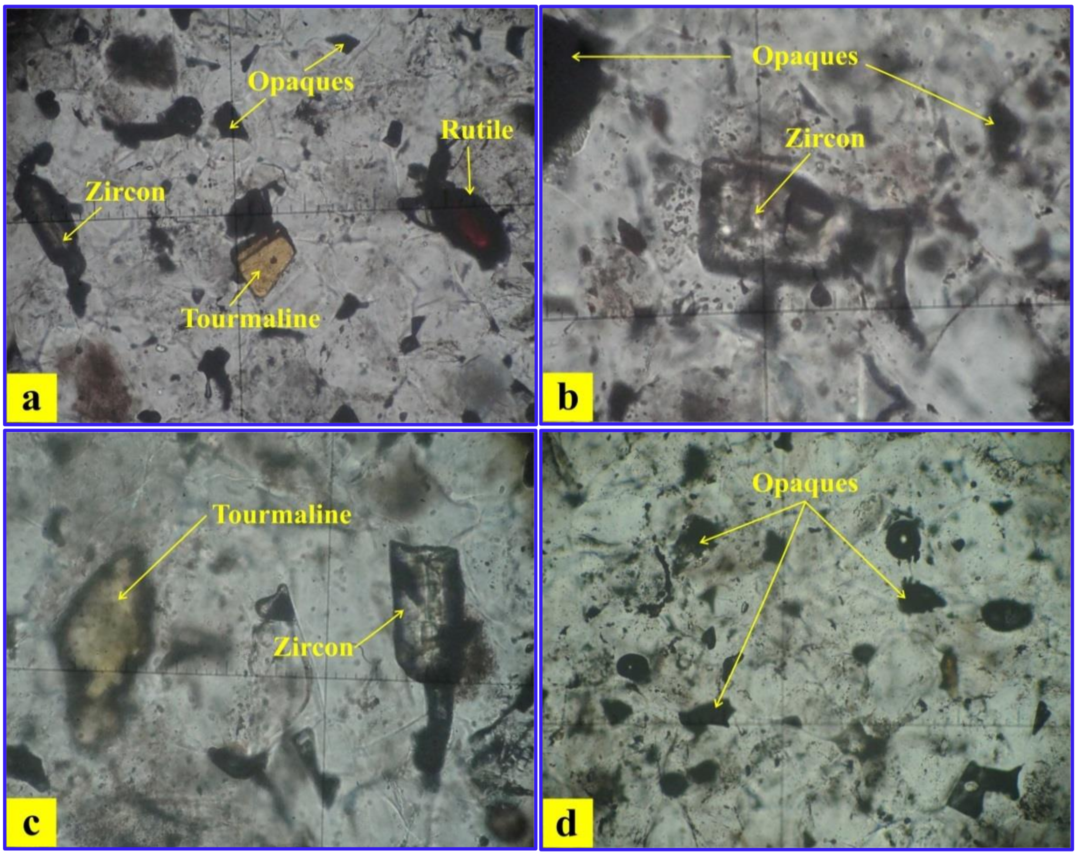

Figure 7: Photomicrograph of heavy minerals in Rutbah Formation; a: Site 1R, (sample no.1R-1), PPL, 25X; b: Site 2R (sample no.2R-5), PPL, 25X; c: Site 3R (sample no. 3R-9), PPL, 25X; d: Site 4R (sample no. 4R-13), PPL, 25X.

The samples collected from site 1R and site 4R are described as predominantly fine-grained sandstone characterized by well-sorting sub-angular to sub-rounded (Figure 8), while they are fine to medium grained sandstone, poorly sorted, sub-angular to sub-rounded in site 3R samples (Figure 9).

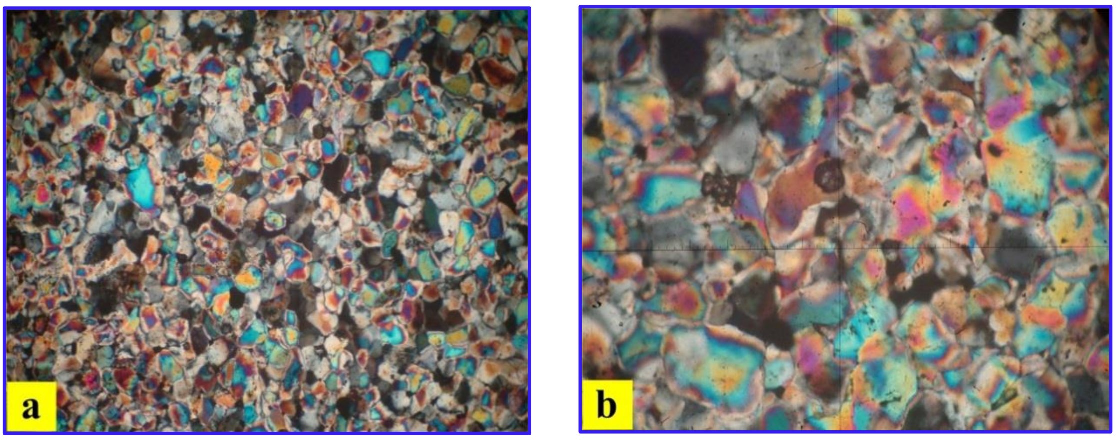

Figure 8: Photomicrograph of well sorted of fine-grained sandstone; a: Site 1R (sample no.1R-3), XPL, 4X; b: Site 4R (sample no. 4R-15), XPL, 10X.

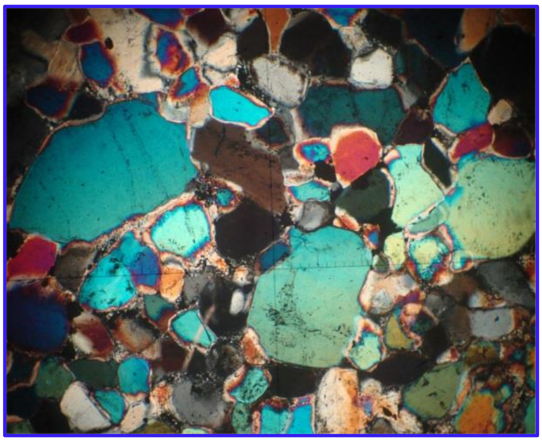

Figure 9: Photomicrograph of fine to medium grained, poor sorted sandstone of Rutbah Formation; site 3R (sample no. 3R-12), XPL, 10X.

The collected sandstone samples of site 2R consist predominantly of very fine grained quartz, sub-rounded to sub-angular grain shape and are well sorted (Figure 10).

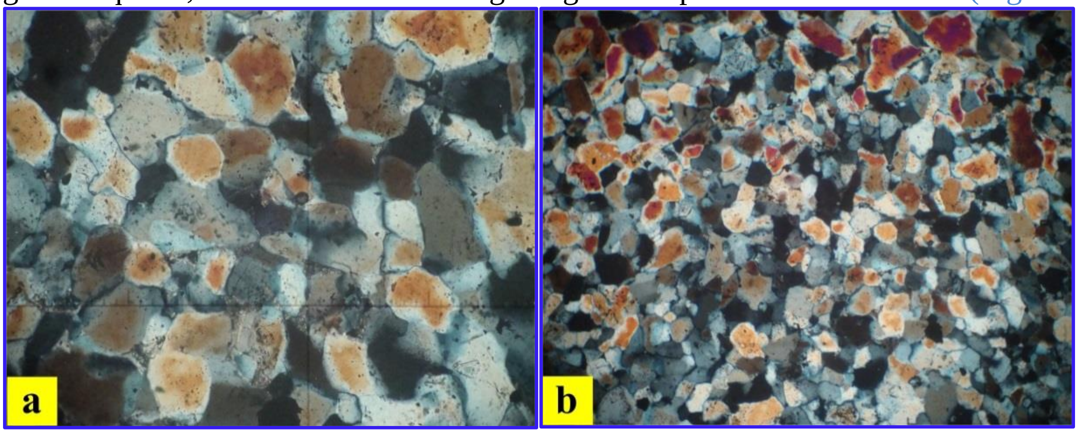

Figure 10: Photomicrograph of well sorted very fine grained sandstone; a: Site 2R (sample no. 2R-7), XPL, 10X; b: Site 2R (sample no. 2R-7), XPL, 4X.

Diagenetic processes affect properties of sandstone used in building and industrial purposes. Diagenesis in Rutbah Formation is represented by cementation and compaction.

The durability of sandstone is highly variable and depends mostly on the nature of rock matrix or cement (Winkler, 1994). In general, all samples that have been collected from the Rutbah Formation were completely cemented. Two types of cement are distinguished based on the petrographic study of thin sections. The detailed description of these types of cement is explained below:

1. Silica cement

Silica cement (quartz cement) is the main cement type in all the studied sites of Rutbah Formation. It is observed as a secondary overgrowth of a clear ring around the quartz grain and may be as microcrystalline quartz (Figure 11). Microcrystalline quartz may be deposited at the primary stages of diagenetic processes and with long time will be a more stable form of overgrowth (Dapples, 1967).

Quartz is a very useful mineral in maintaining the stability of the chemical composition of the rock. The stability of the rock, especially that of mono-mineralic stone provides stable physical and chemical characteristics. This property is useful in the industrial and petrotechnological evaluation.

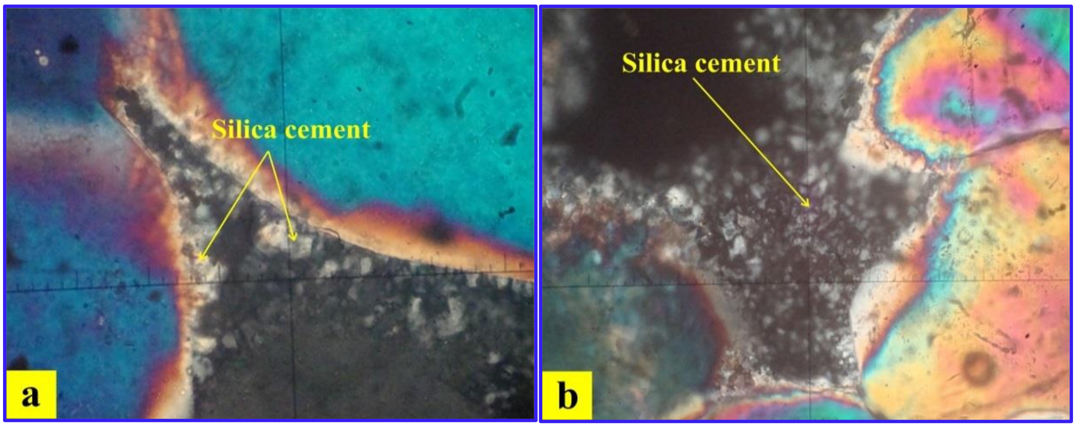

Figure 11: Photomicrograph of silica cement in sandstone of Rutbah Formation; a: Site 1R (sample no. 1R-4), XPL, 40X; b: Site 4R (sample no. 4R-16), XPL, 40X.

2. Iron oxide cement

Iron oxide is observed in two forms; opaque mineral grains and cement materials. Iron oxide cement is distinguished in site 2R and site 3R coating quartz grains. It sometime also fills the pore space among the quartz grains (Figure 12).

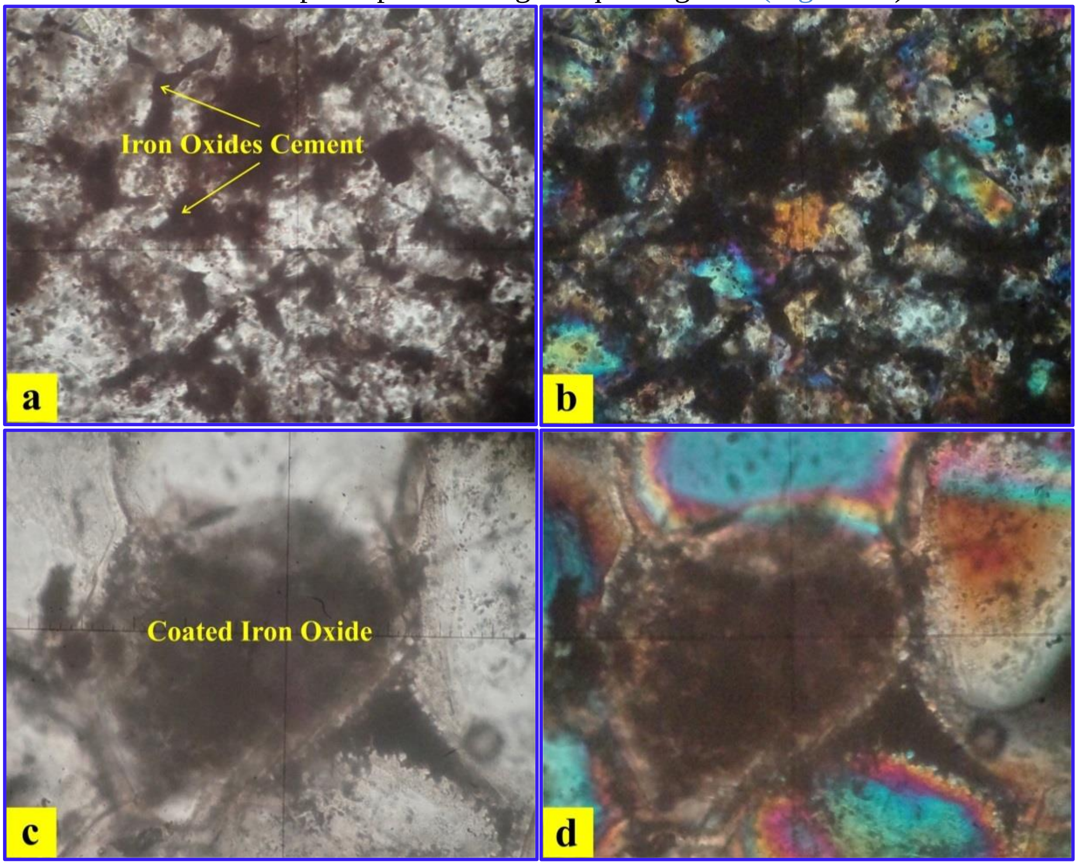

Figure 12: Photomicrograph of iron oxide cement in sandstone of Rutbah Formation; a and b: Site 2R (sample no. 2R-8), PPL, XPL, 10X; c and d: Site 3R (sample no.3R-11), PPL, XPL, 10X.

Compaction can be determined as one of the operation that leads to the lithification. Intense compaction is distinguished in some samples in the Rutbah Formation. Straight and concavo-convex contacts between quartz grains are clearly observed (Figures 13).

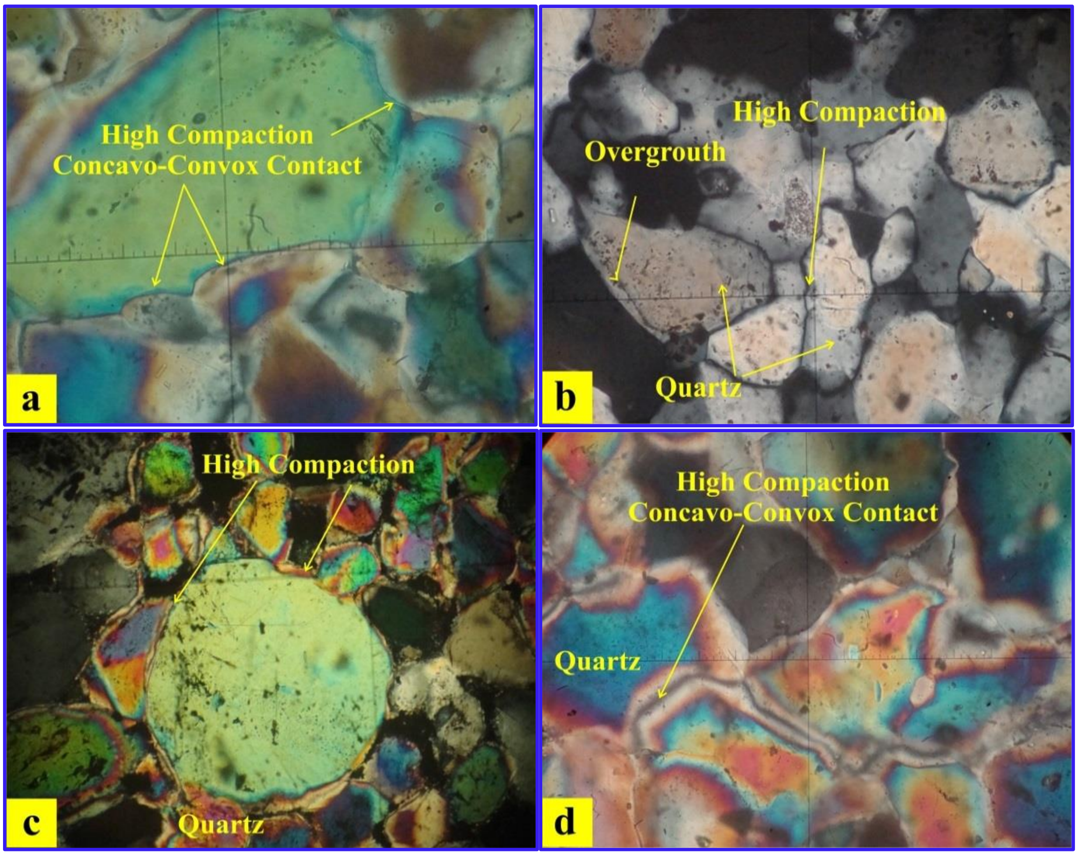

Figure 13: Photomicrograph of high compaction; a: Site 1R (sample no.1R-4), XPL, 40X; b: Site 2R (sample no. 2R-7), XPL, 40X; c: Site 3R (sample no. 3R-11), XPL, 10X; d: Site 4R (sample no. 4R-16), XPL, 40X.

5.2 Mineralogy of sandstone

The XRD results are presented in Figs.14, 15, 16 and 17. Quartz is commonly dominant in all sites.

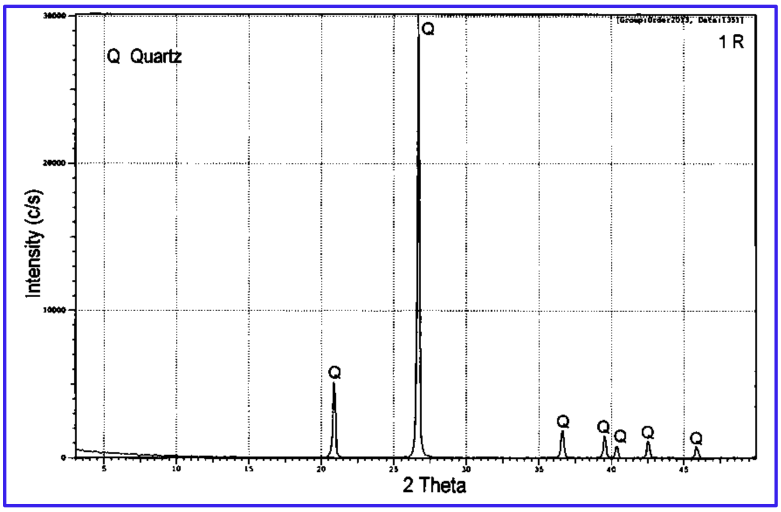

Figure 14: X- ray diffractogram of sandstone (Rutbah Formation), site 1R (sample no.1R-1).

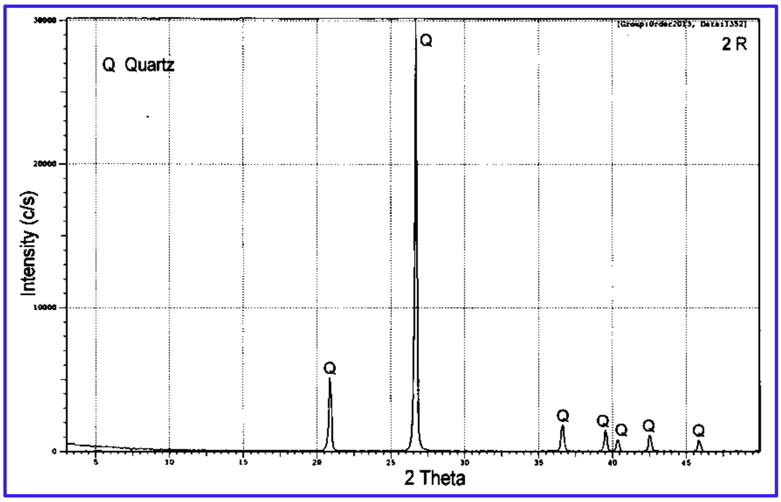

Figure 15: X- ray diffractogram of sandstone (Rutbah Formation), site 2R (sample no.2R-5).

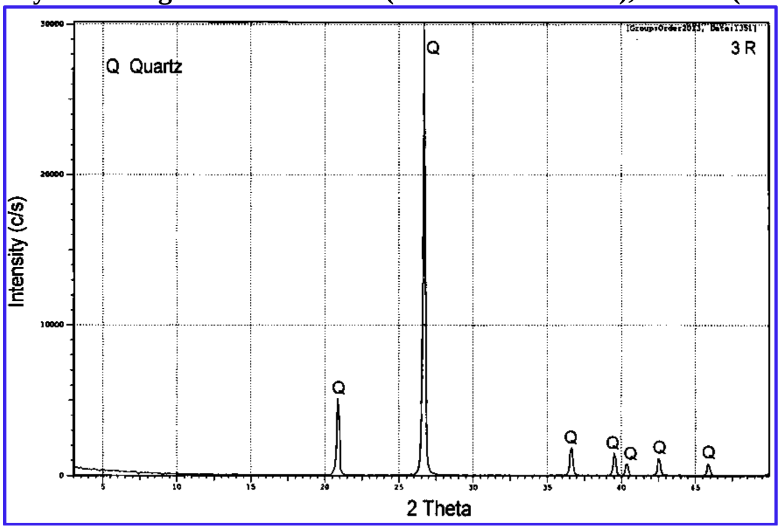

Figure 16: X- ray diffractogram of sandstone (Rutbah Formation), site 3R, (sample no.3R-9).

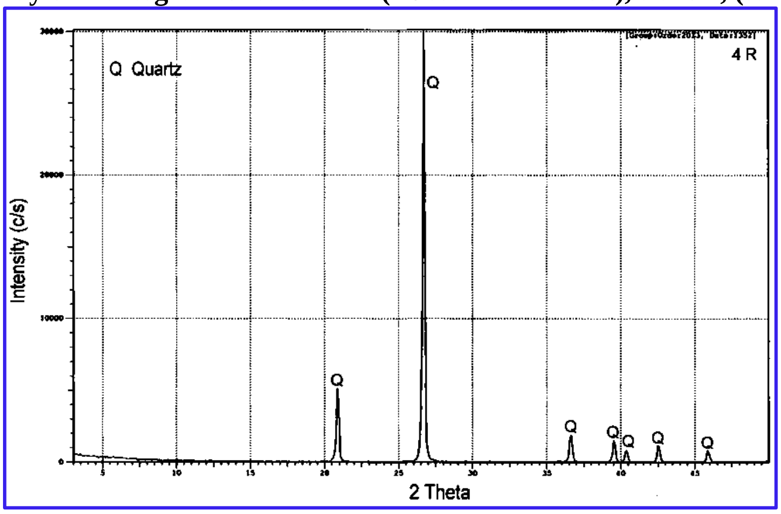

Figure 17: X- ray diffractogram of sandstone (Rutbah Formation), site 4R, (sample no.4R-13).

According to these results of the petrographic and mineralogical study, Rutbah Formation is classified as quartz arenite according to Pettijohn *et al.* (1972).

5.3 Geochemistry of sandstone

Sandstone samples are chemically analyzed for major oxides (SiO_2, Al_2O_3, CaO, MgO, Fe_2O_3, Na_2O, K_2O, TiO_2, MnO and L.O.I). The chemical results are listed in Table 2. Geochemical results of the major oxides are statistically treated by correlation coefficient to show the chemical behavior and characteristics of the studied samples of Rutbah Formation (Table 3). The critical value of correlation coefficient (r) for 16 samples at confidence level 0.05 or (95%) is 0.47 with two degree of freedom (Murdoch and Barnes, 1985).

Table 2: Chemical analysis results of sandstone of Rutbah Formation samples.

Site no.	Sample no.	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	Na_2O	K_2O	TiO_2	MnO	L.O.I	Total
		%										
1 R	R-1	99.40	0.09	0.13	0.02	0.06	0.02	0.02	0.10	0.01	0.13	99.98
	R-2	99.27	0.12	0.14	0.01	0.07	0.03	0.01	0.20	0.02	0.10	99.97
	R-3	99.60	0.02	0.10	0.01	0.10	0.01	0.01	0.01	0.02	0.09	99.97
	R-4	99.50	0.10	0.06	0.01	0.09	0.02	0.03	0.05	0.03	0.08	99.97
	Range	99.27-99.60	0.02-0.12	0.06-0.14	0.01-0.02	0.06-0.10	0.01-0.03	0.01-0.03	0.01-0.20	0.01-0.03	0.08-0.13	
	Average	99.44	0.08	0.11	0.01	0.08	0.02	0.02	0.09	0.02	0.10	
2 R	R-5	98.14	0.32	0.18	0.03	0.74	0.02	0.02	0.3	0.01	0.22	99.98
	R-6	98.17	0.37	0.22	0.02	0.70	0.01	0.03	0.2	0.05	0.20	99.97
	R-7	98.10	0.24	0.12	0.07	0.80	0.02	0.02	0.3	0.05	0.25	99.97
	R-8	98.20	0.16	0.10	0.09	0.78	0.03	0.02	0.3	0.05	0.22	99.95
	Range	98.10-98.20	0.16-0.37	0.10-0.22	0.02-0.09	0.70-0.80	0.01-0.03	0.02-0.03	0.2-0.3	0.01-0.05	0.20-0.25	
	Average	98.15	0.27	0.15	0.05	0.75	0.02	0.02	0.27	0.04	0.22	
3 R	R-9	98.50	0.04	0.25	0.03	0.77	0.02	0.02	0.2	0.05	0.10	99.98
	R-10	98.20	0.17	0.22	0.07	0.68	0.03	0.05	0.3	0.1	0.12	99.94
	R-11	98.70	0.12	0.14	0.04	0.59	0.02	0.03	0.2	0.05	0.09	99.98
	R-12	98.90	0.09	0.16	0.02	0.52	0.01	0.01	0.1	0.05	0.10	99.96
	Range	98.20-98.90	0.04-0.17	0.14-0.25	0.02-0.07	0.52-0.77	0.01-0.03	0.01-0.05	0.1-0.3	0.05-0.10	0.09-0.12	
	Average	98.57	0.10	0.19	0.04	0.64	0.02	0.03	0.2	0.06	0.102	
4 R	R-13	99.46	0.02	0.11	0.01	0.18	0.02	0.02	0.02	0.01	0.10	99.95
	R-14	99.40	0.03	0.13	0.02	0.20	0.01	0.01	0.03	0.02	0.13	99.98
	R-15	99.11	0.09	0.22	0.03	0.10	0.01	0.03	0.20	0.01	0.18	99.98
	R-16	99.20	0.12	0.21	0.02	0.12	0.02	0.02	0.10	0.02	0.15	99.98
	Range	99.11-99.46	0.02-0.12	0.11-0.22	0.01-0.03	0.10-0.20	0.01-0.02	0.01-0.03	0.02-0.20	0.01-0.02	0.10-0.18	
	Average	99.29	0.06	0.17	0.02	0.15	0.02	0.02	0.08	0.01	0.14	

Table 3: Correlation coefficient of major oxides of the Rutbah Formation samples. Degree of freedom=2 (the pair oxides), r=0.47. n=16.

	SiO_2	Al_2O_3	CaO	MgO	Fe_2O_3	Na_2O	K_2O	TiO_2	MnO	L.O.I
SiO_2	1.00									
Al_2O_3	-0.76	1.00								
CaO	-0.43	0.28	1.00							
MgO	-0.74	0.33	0.06	1.00						
Fe_2O_3	-0.95	0.59	0.33	0.69	1.00					
Na_2O	-0.29	0.10	-0.10	0.50	0.22	1.00				
K_2O	-0.41	0.33	0.35	0.41	0.29	0.30	1.00			
TiO_2	-0.89	0.67	0.39	0.77	0.75	0.51	0.43	1.00		
MnO	-0.63	0.26	0.28	0.64	0.67	0.34	0.59	0.51	1.00	
L.O.I	-0.67	0.72	0.17	0.57	0.51	0.04	0.08	0.65	0.02	1.00

Silica content in the site 1R ranges from 99.27% to 99.60 % with an average of 99.44%; while in the site 2R varies between 98.10% and 98.20% with an average of 98.15%. In the site 3R (SiO_2) ranges between 98.20% and 98.90 % with an average of 98.57%, and in the site 4R it ranges between 99.11% and 99.46% with an average of 99.29% (Table 2). The high content of silica reflects the predominance of quartz mineral in all studied sites which was confirmed also by petrographic study. The strong negative correlations between the SiO_2 and each of Al_2O_3, Fe_2O_3, MgO, TiO_2, MnO and L.O.1 (Table 3) indicates silica exists as independent mineral (quartz) and has not correlated with other oxides.

Alumina, content in the site 1R ranges from 0.02% to 0.12 % with an average of 0.08%; while in the site 2R varies between 0.16% and 0.37% with an average of 0.27%. In the site 3R (Al_2O_3), it ranges between 0.04% and 0.17 % with an average of 0.10%, while in the site 4R, it ranges between 0.02% and 0.12% with an average of 0.06% (Table 2).

Iron oxide content in the site 1R ranges from 0.06% to 0.10 % with an average of 0.08%; while in the site 2R varies between 0.70% and 0.80% with an average of 0.75%. In the site 3R, Fe_2O_3 ranges between 0.52% and 0.77 % with an average of 0.64%, while in the site 4R, it ranges between 0.10% and 0.20% with an average of 0.15% (Table 2).

Titania content in the site 1R ranges from 0.01% to 0.20 % with an average of 0.09%; while in the site 2R varies between 0.20% and 0.30% with an average of 0.27%. In the site 3R, TiO_2 ranges between 0.10% and 0.30 % with an average of 0.20%, while in the site 4R; it ranges between 0.02% and 0.2% with an average of 0.08% (Table 2).

MnO content in the 1R site ranges from 0.01% to 0.03 % with an average of 0.02%; while in the 2R site varies between 0.01% and 0.05% with an average of 0.04%. In the 3R site (MnO) ranges between 0.05% and 0.10 % with an average of 0.06%, while in the 4R site, it ranges between 0.01% and 0.02% with an average of 0.01% (Table 2). The strong negative correlation between Al_2O_3 and SiO_2 confirms the maturity of sandstone (Table 3). Fe_2O_3 and TiO_2 have positive correlation that is may be due to illmenite content, or indicate the presence of hematite and rutile. They have similarity with Al_2O_3 in geochemical behavior as resistant oxides (Goldschmidt, 1954) therefore a strong correlation has been recorded (Table 3). MnO appears to be as trace associated iron. The positive correlation between them supports this suggestion (Table 3).

CaO content in the site 1R ranges from 0.06% to 0.14 % with an average of 0.11%; while in the site 2R varies between 0.10% and 0.22% with an average of 0.15%. In the site 3R, CaO ranges between 0.14% and 0.25 % with an average of 0.19%, while in the site 4R; it ranges between 0.11% and 0.22% with an average of 0.17% (Table 2).

MgO content in the site 1R ranges from 0.01% to 0.02 % with an average of 0.01%; while in the site 2R, it varies between 0.02% and 0.09% with an average of 0.05%. In the site 3R, MgO ranges between 0.02% and 0.07% with an average of 0.04%, while in the site 4R, it ranges between 0.01% and 0.03% with an average of 0.02% (Table 2).

The averages of L.O.I in the sites 1R to 4R are 0.1, 0.22, 0.10 and 0.14% respectively (Table 2).

Correlations confirmed that there is no evidence of carbonate minerals such as calcite or dolomite as the petrographic study proved (Table 3), and these oxides may be included as major or trace elements within heavy minerals.

Na_2O and K_2O are of minor quantity in the sandstones. The averages of Na_2O in all studied sites have similar value of 0.02% (Table 2). The average of K_2O in the sites 1R, 2R and 4R is 0.02%; in the site 3R it is 0.03% (Table 2).

These oxides may be a remnant of feldspar (albite and orthoclase) that has altered to clay minerals by chemical weathering (Table 3), particularly, the origin of Rutbah Formation is granitic rock of Arabian Shield (Awadh, 2010).

5.4 Petrotechnology of sandstone

Sandstone as natural stones are subject to several tests to show its suitability as laboratory tiles bench. For this purposes, physical and mechanical properties as well as chemical properties of them are studied as follows:

5.4.1 Physical and mechanical properties

The physical and mechanical properties are important to evaluate since they affect the application. Physical and mechanical properties (bulk density, porosity, water absorption, compressive strength, modulus of rupture and abrasion resistance) are measured and used for assessing the sandstone petrotechnology using the standard method described by the Iraqi Standard (IQS) reference guide to standard test methods of natural building stone number (65/1989) which are similar to ASTM test method for the natural dimension stone.

5.4.1.1 Bulk density

The bulk density values of sandstone samples of Rutbah Formation are computed to be 2450 kg /m^3 for site 1R and 2520 kg/m^3 for site 2R, while 2500 kg/m^3 for site 3R and 2477 kg/m^3 for site 4R. (Table4). These values are compared with the American Standard for Testing Materials (ASTM C616-03) (Table 5). Accordingly, sandstone samples of Rutbah Formation are classified as quartzite sandstone for all studied sites.

5.4.1.2 Porosity

Sandstone samples have porosity of 0.582 % in site 2R and 0.805 % of site 1R while 0.619 % for site 3R and 0.728 % of site 4R (Table 4).

Cementation and compaction as digenesis processes were the most important process to reduce the pore space volume. The physico-mechanical properties are essential when assessing their suitability for use as dimension stone, as well as their durability. In case of clastic rocks (e.g. Sandstones) the main parameter is porosity itself (Sousa et al., 2005). Porosity as one of the physical properties of rocks that can control the other parameter such as bulk density which was inversely proportional with porosity (Table 4).

5.4.1.3 Water absorption

The values of water absorption of sandstone samples are 1.746 %, 1.158 %, 1.222 %, 1.447 % for sites 1R, 2R, 3R and 4R respectively (Table 4). According to ASTM C616-03 (Table 5), the water absorption values for all sites are assessed as permissible and permit to use the sandstone as dimensional stone.

The water absorption values are indicators of the permeability which reflect the effective porosity that can take water or gases which decreases the durability with time. The low water absorption values of Rutbah Formation samples may indicate that sandstone samples are free of gaps and pores and are good as dimensional stone.

5.4.1.4 Compressive strength

The compressive strength values of sandstone samples are 128.52 MPa for site 1R, 131.35 MPa for site 2R while 130.76 MPa for site 3R and 129.37 Mpa for site 4R (Table 4). These values are acceptable and allow using sandstone as dimensional stone according to ASTM C616-03 (Table 5).

The high value of compressive strength may reflect the diagenetic processes especially with sandstone as natural stone which is in general porous stone with high compaction and many contact grains and the type of cement can predict the strength value. Low strength makes natural stone highly vulnerable to breakage during handling and fabrication. The high compressive strength value may be due to high bulk density.

Table 4: Physical and mechanical properties of sandstone in Rutbah Formation.

Properties	Site 1R	Site 2R	Site 3R	Site 4R
Bulk Density (kg/m^3)	2450	2520	2500	2477
Porosity (%)	0.805	0.582	0.619	0.728
Water Absorption (%)	1.746	1.158	1.222	1.447
Compressive Strength (MPa)	128.52	131.35	130.76	129.37
Modulus of rupture (MPa)	12.166	12.879	12.622	12.235
Abrasion Resistance	15.3	16.5	16.2	15.7

Table 5: Physical, mechanical and requirements for sandstone as dimension stone according to ASTM C616-03.

Physical and mechanical property	Test requirements	Classification
Density Min (kg/m^3)	2000 2400 2560	Sand Stone Quartzite sandstone Quartzite
Absorption by weight Max (%)	8.00 3.00 1.00	Sand Stone Quartzite sandstone Quartzite
Compressive strength Min (MPa)	28 69 138	Sand Stone Quartzite sandstone Quartzite
Modulus of rupture Min (MPa)	2 7 14	Sand Stone Quartzite sandstone Quartzite
Abrasion resistance Min	8 8 8	Sand Stone Quartzite sandstone Quartzite

5.4.1.5 Modulus of rupture

Modulus of rupture measurement is the most important requirement for the use of natural stone as a bench or countertop where may be affected by pressure in the middle face, that measurement may control the thickness of slabs which are used as a bench. Natural stone must be installed a top full underlayment support due to the stone's strength limitations.

The modulus of rupture values of sandstone samples is 12.166 MPa for site 1R, 12.879 MPa for site 2R while 12.622 MPa for site 3R and 12.235 Mpa for site 4R (Table 4). The modulus of rupture values is compared with the ASTM C616-03 (Table 5) and appeared acceptable and confirmed that the sandstone is suitable to be used as a dimensional stone.

5.4.1.6 Abrasion resistance

The abrasion resistance values of sandstone samples are 15.3 for site 1R, 16.5 for site 2R, while 16.2 for site 3R and 15.7 for site 4R (Table 4).

According to ASTM C616-03 (Table 5), the abrasion resistance values of Rutbah Formation samples are acceptable as dimension stone, and more acceptable in reflecting the hardness of the rock which is also a reflection of diagenetic processes (cementation by silica and iron oxide and compaction).

The high value of abrasion resistance may reflect the hardness of quartz which is the main component of collected samples. Quartz is harder than other minerals, as measured by the Mohs scale of mineral hardness.

As quartz has a Moh's hardness of 7, only a few materials such as topaz (Mohs 8), corundum (Mohs 9), and diamond (Mohs 10) is hard enough to scratch it. That hardness may reflect the ability of cutting and polishing equipment.

5.4.2 Chemical resistance

There is no standard test method for the determination of chemical resistance of natural stone, therefore similar test method and simulated the standard test method for the determination of chemical resistance of glazed tiles is used according to the Iraqi reference indicative directory number (256/6/1993) issued by Central Organization for Standardization of Quality Control (COSQC).

The specification includes:

1- Examination of acidic resistance by the use of:
- Hydrochloric acid solution at 3% (v/v) volumetric ratio, prepared from concentrated hydrochloric acid (ρ= 1.19 g/ml).
- Citric acid solution 100 (gm/l).
- Hydrochloric acid solution at 18% (v/v).
- Lactic acid solution at 5% (v/v).

2- Examination alkali resistance by the use of:
- Potassium hydroxide solution 30 (gm/l).
- Potassium hydroxide solution 100 (gm/l).

The surface of each sample is exposed to the standard solution of acids and alkalis for 7 days. The standard solution must be shaken out once a day and also replaced after 4 and the 3 days, after 7days the surface of testing samples was washed with water and then dried by a piece of clothing to note the change of the sample's surface.

All tested samples of Rutbah Formation have no visible effects of the appearance of the sample's surface (Table 6).

Table 6: The effect of prepared solutions on Rutbah Formation samples after 7 days exposure.

Solutions	Site 1R	Site 2R	Site 3R	Site 4R
Hydrochloric acid 3%	No visual damage	No visual damage	No visual damage	No visual damage
Hydrochloric acid 18%	No visual damage	No visual damage	No visual damage	No visual damage
Citric acid 100 (gm/l)	No visual damage	No visual damage	No visual damage	No visual damage
Lactic acid 5%	No visual damage	No visual damage	No visual damage	No visual damage
Potassium hydroxide 30 (gm/l)	No effect	No effect	No effect	No effect
Potassium hydroxide 100 (gm/l)	No effect	No effect	No effect	No effect

These results reflect the resistance of quartz as predominant mineral in sandstone samples, in addition to type of cement; iron oxide cement may cause a problem due to iron staining when iron oxide cement affected with acids and alkalis at normal condition; that lead to discoloration.

Assessment by visual test is not enough to give the final opinion of the sandstone resistance against acids therefore another test method is used to evaluate the collected samples depending on loss of weight, by the use of Iraqi standard number (1627/1991) to evaluate the resistance of unglazed ceramic tiles to acid. This test method is used also for sandstone samples using the following reagents:

- Concentrated nitric acid.
- Concentrated sulfuric acid.

In order to remove the dust from the selected samples and then treated with reagents, 30 gm of rock sample powder (the rock sample from each site was crushed into a powder) and then placed in a ceramic vine with 150 ml of distilled water. The ceramic vine with its content was placed in the sand bath for one hour. After one hour the particles were rinsed with cold water, the mass of particles of each sample was taken after being dried by oven with 110˚C. 25gm of dried powder (M_1) from each sample was put in ceramic vine.

Combination of 7ml of nitric acid, 13ml of sulfuric acid was put in the ceramic vine and then added 65ml of distilled water, and then heated by sand bath for several times with added 10 ml of nitric acid and 90 ml of distilled water, the remaining particles after treatment were washed by distilled water for several time to remove any effect of reagents, and then dried by oven with 110˚C for 1 h.

The weight losses for each sample are calculated as follows:

Weight loss (%) = $M_1 - M_2/M_1 \times 100$

Where:

M_1 = mass of particles before treated with reagent.

M_2 = mass of particles after treated with reagent.

There is no pass or fail point for this test but weight loss (%) values can reflect the resistance of quartz arenite to acids. The weight loss (%) values range between 0.16% for site 1R and 0.18 for site 3R, while 0.13% for site 2R and 0.07 for site 4R (Table 7).

Table 7: Weight loss of sandstone (Rutbah Formation) against acid test.

Samples	**Weight before test (g)**	**Weight after test (g)**	**Weight loss (%)**
site 1R	25	24.985	0.16
site 2R	25	24.967	0.13
site 3R	25	24.955	0.18
site 4R	25	24.982	0.07

Less than 0.2% loss in weight form each of tested samples reflects very high resistance of quartz mineral against acids.

The unique physical, mechanical and chemical resistant characteristics of the sandstones made them a good raw material as chemical laboratory tiles bench.

6. Conclusions

The findings from this work can be listed as follows:

a- According to ASTM C616-03, the measurement results of physical and mechanical properties which include bulk density, water absorption, compressive strength, modulus of rupture and abrasion resistance confirmed the suitability of sandstone as dimension stone and classified these samples as quartzite sandstone.

b- Chemical resistance test results show high resistance of sandstone samples against acidic and alkalis prepared solution with low and high concentration depending on the change of samples exposure surface

c- Sandstone samples show high resistance against acids according to the loss of weight reflecting the durability of quartz as predominant mineral within the samples.

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