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INFLUENCE OF CHEMICAL PROPERTIES AND MINERAL CONTENTS ON SANDSTONE STRENGTH

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ABSTRACT: This paper presents the results of a laboratory investigation on chemical properties, mineralogical content, mechanical properties of the rocks, the influence of the chemical and mineral contents on the rock strength. Experimental works were conducted to investigate the effect of chemical content on rock strength, particularly in sedimentary rock of sandstone. These experimental tests include Alkali-Silica Reactivity (ASR), Petrographic Image Analysis, Unconfined Compression Strength (UCS), shear strength and tensile strength tests. The relationships and correlations of chemical properties, petrographic minerals characteristics and engineering properties of sixteen sandstone samples using simple regression analysis and bar chart were presented herein. The abundance of quartz minerals, carbonate minerals and cement in the sandstone can increase the compressive strength of the rock. Carbonate minerals in the rock can easily dissolve and significantly reduce the compressive strength. The quantity of harmful minerals (opal, chalcedony, volcanic glass, cristobalite, tridymite and cryptocrystalline quartz) is less, showing insignificant shear strength and uniaxial compression strength.

Keywords: Mineral content, Mechanical properties, Weathering, Chemical properties, Sandstone

1. INTRODUCTION

Weathering plays an important role in determining the strength of the rock in tropical countries such as Malaysia, Indonesia, American Latin and others. Furthermore, rock strength is also influenced by the type of rocks, either it is in the group of igneous, sedimentary, or metamorphic. Among these types of rocks, a sedimentary rock with its physical characteristics of bedding, lamination and clastic grains is prone to weathering and thus, it can also weaken the rock mass and material.

The physical and chemical properties of rock such as porosity, density, chemical content, mineralogy and degree of cementation are significantly influenced the rock strength [1, 2]. These types of rocks have their own chemical properties, physical properties and mineral contents which can affect the rock strength as these minerals interlock and bond between them. Cementation is the precipitation of mineral matter (cement) in pores within sediments or rocks and these minerals bonded together in rocks. The strength of rock is increasing proportionally to the degree of cementation and minerals bond in the rocks [3].

The chemical composition of rocks such as quartz, carbonate matrix and cement, calcite, rock fragments and minerals can influence its surface energy and chemical reactivity [4]. The chemical functionalities in rocks play a predominant role in rock strength. Aggregate is an example of rock that contain certain constituents which can react with alkali hydroxides in the concrete during testing, which could increase the rock strength [5]. The reactivity is potentially harmful only when it produces significant expansion. Alkali silica reaction (ASR) is a chemical reaction that occurs between certain reactive minerals in some aggregates and alkali in the pore solution of concrete. The results of ASR from the reaction of disordered forms of silica minerals in the aggregates and the hydroxyl ions (OH–) in the pore fluid of concrete could also influence the strength of the rock [6].

Even though many researchers have been conducted experimental work and relate mineral contents with mechanical properties of rocks but the relationship between the chemical properties and sedimentary rock strength is still not well identified [7-11]. Most of the researchers explained not conclusive finding on rock strength for the three types of rocks, namely igneous, sediment and metamorphic rock based on only chemical and mineral contents of rocks. This paper is presented and identified the relationships between the chemical properties and mineral contents on the strength of weathered sandstone that is widely distributed in tropical countries such as Malaysia. The finding of this research can be used to estimate the compressive, shear and tensile strength of sandstone located in Malaysia for designing pile foundations, raft foundations and retaining walls due to the weathered environment.

2. MATERIAL AND METHODS

A total number of sixteen (16) sandstone rock cores samples were collected from the area of Jerantut in the state of Pahang, Malaysia, for experimental work. The strength tests for sandstone rock were Uniaxial Compressive Strength (UCS), Triaxial Shear test, Direct Shear tests and indirect tensile strength (Brazilian) tests. The experimental testing for Uniaxial Compression Strength was in accordance with the ASTM D7012 specification. This test method covers the determination of the strength of intact rock core specimens under uniaxial compression load. Triaxial shear tests have been used to gain an understanding of rock behaviour under a three-dimensional state of stress through verification and validation using mathematical expressions that have been derived to represent rock behaviour in analytical and numerical models. By using the results of triaxial tests that yield strength criteria have been developed and material-specific strength characteristics are determined. The shear strength of sandstone rock can be obtained from the triaxial shear test and calculated by using Equation 1 as follows:

$$\tau = \sigma \tan\theta + c \tag{1}$$

where; τ is shear strength, σ is shear stress, ɵ is friction angle and *c*, is the cohesion of rock material.

Direct shear strength test of rock core is purposely to establish the shear strength properties of discontinuities in rock. These core samples were tested for their shear strength along the selected fracture plane at the existing natural joint and under a specified value of normal stress. During the shearing process testing, the normal stress was maintained at a constant level and this test is also known as the *single-stage direct shear* test and follows the standard of ASTM D5607-08. Data obtained from this test were shear stress, shear displacement, peak shear strength, and corresponding horizontal displacement where the peak strength occurs.

The tensile test method is also referred to Brazilian test where cylindrical intact rock specimens are loaded at diametrically –opposed surfaces by a uniformly distributed of radial stress. The tensile test for sandstone rock was in accordance with ASTM D3967-08. It is an indirect measurement of the tensile strength of rocks by applying compression load on the rock samples. The splitting tensile strength of the sandstone rock can be calculated using Equation 2 by measuring the maximum load, diameter and length of the sample as given below:

$$\sigma = \frac{2P}{\pi DL} \tag{2}$$

where; σ is splitting tensile strength; P is maximum load; H is height and D is the diameter of a sandstone rock sample.

For chemical contents and mineralogical analysis, Alkali-Silica Reactivity (ASR) and petrographic tests were conducted. The result of the reaction for aggregate with alkali was determined and the procedure for the ASR test is in accordance with ASTM-C289-07. The potentially alkali reactive rocks are not used for the production of aggregates because deleterious aggregates will affect the soundness of concrete structures and adversely impact the construction industries. The main objective of the ASR test is to assess the potential alkali-aggregate reactivity of sandstone samples. Another test for mineralogical analysis is petrographic and follows the standard by ASTM- C295-08 for mineral composition identification in sandstone.

3. RESULTS AND DISCUSSIONS

3.1 Strength Properties

The experimental results for strength properties of sandstone are uniaxial compressive strength, shear strength and tensile strength were presented in this section. Table 1 shows the experimental results for these strength properties for sixteen (16) samples. The shear strength of the sandstone can be calculated using Equation 1. However, some values of shear strength cannot be calculated because the values of cohesion of sandstone (c) and friction angle (θ°) can be measured due to crunching core samples obtained from the site. Furthermore, the splitting tensile strength of the sandstone can be calculated using Equation 2. The maximum compressive strength is 202 MPa which was obtained from Sample 10. Meanwhile, the maximum shear strength is 492.69 MPa which was obtained from Sample 15. Finally, the maximum splitting tensile strength is 25.59 MPa which was obtained from Sample 3. These values of strength properties of sandstone are very important in designing the substructure and superstructures for infrastructures in Jerantut, Pahang, Malaysia.

3.2 Chemical Properties and Mineral Content

Table 2 shows the results of mineral contents were collected from petrographic analysis and alkali-silica reactivity tests.

Table 1. Compressive strength, shear strength and tensile strength of sandstone

Sample	σ_{UCS}, (MPa)	c, (MPa)	θ (°)	$\theta_{at\ joint}$ (°)	τ_{shear} (MPa)	$\sigma_{tensile}$, (MPa)
1	22.0	5	47	35.87	28.59	7.62
2	23.0	7	28	42.16	19.23	16.46
3	40.0	-	-	39.50	-	25.56
4	20.0	5	47	42.16	26.45	6.66
6	33.7	-	-	37.85	-	2.81
7	107.1	-	-	36.12	-	6.24
8	16.3	8	0	28.01	8	14.52
9	81.6	-	-	35.36	-	13.42
10	202.0	-	-	36.62	-	9.36
11	98.0	-	-	41.15	-	23.37
12	63.8	-	-	26.57	-	7.90
13	17.0	3	62	26.57	34.97	6.43
14	4.3	1.5	22	30.16	3.24	12.38
15	193.0	15	68	39.50	492.69	3.02
16	167.0	28	52	38.80	241.75	14.42

Table 2 Results of mineral content and chemical properties of sandstone

Sample	Weathering Grade	Petrographic Analysis				
		Mineral Composition (%)				
		Q	CM	C	R	A
1	II	53.9	41.7	-	3.5	0.9
2	1	66.4	25.9	-	6.9	0.8
3	1	0	86.4	-	13.6	0
4	1	65.9	27.1	-	6.5	0.5
5	I	0	18.5	0	80.9	0.6
6	1	0	56.2	0	43.3	0.5
7	1	92.4	1.6	3.9	1.5	0.6
8	1	54.2	43	0	4	0.5
9	1	18.5	79.1	0	1.5	0.6
10	1	81.9	10.8	5.9	1	0.4
11	1	70.9	19.4	0	9.3	1.2
12	II	82	2.1	12.4	2.4	1.1
13	1	84	2.3	11	2.2	0.5
14	1	76.3	4.1	16.2	2.75	0.65
15	1	42.2	52.1	2	3.2	0.5
16	1	61.9	30	3.1	2	1

Note: Q=quartz; CM=Carbonate matrix and cement; C= Calcite; R= Rock fragments; A= Accessory minerals

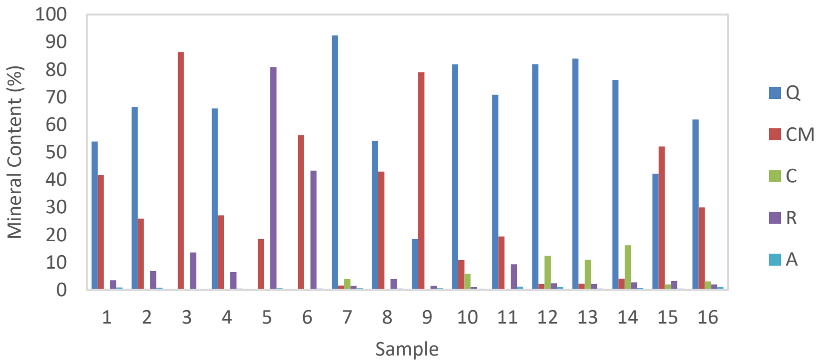

Fig.1. Distribution of minerals in the sandstone rock material

The maximum minerals quartz is 92.4% from Sample 7, carbonate matrix is 86.4% from Sample 3, calcite is 16.2% from Sample 14, rock fragments is 80.9% from Sample 5 and accessory minerals is 1.2% from Sample 11. In addition, Fig. 1 shows the distribution of minerals in sandstone composes of quartz, carbonate matrix, calcite, rock fragments and accessory minerals for 16 samples. Among these minerals, quartz shows the highest content in sandstone with a range from 18.5% to 92.4%, followed by carbonate matrix, 2.1% to 86.4% and rock fragments, 1% to 80.9%. Calcite and accessories minerals present lowest in sandstone ranges from 2% to 16% and 0.5% to 1.1%, respectively. The mineral distribution of sandstone is similar as discussed in petrographic [4], which confirmed that all these samples are sandstone. In some cases, like in sample 1 to sample 6, the calcite mineral is absent. The high content of quartz in sandstone is due to the nature of sedimentation of weathered parent rock such as granite with high content of quartz that broken into a small particle called sand. These quartz grains were transported by the weathering agent like water, glacier, or wind to be deposited and cemented as sandstone.

3.3 Correlation Between Mineralogy and Strength Properties

Three correlations between the mineralogy and strength properties have been conducted. There are between the main minerals and uniaxial compressive strength (UCS), between the main minerals and shear strength and between the main minerals and tensile strength.

3.3.1 Relationship Between Main Minerals and Uniaxial Compressive Strength

The percentage distribution of minerals in sandstone versus samples as shown in Fig. 1 is used to find their relationship with uniaxial compressive strength. Fig. 2 with three axes shows the relationship between the percentages of the main minerals and uniaxial compressive strength (UCS). It is evident that quartz (Q) plays a very important role in uniaxial compressive strength in sandstone as the percentage of quartz increase, the uniaxial compressive strength also increase. Contradictory, the existence in term of percentage of carbonate mineral (CM) in the sandstone can reduce the uniaxial compressive strength. The main reason is that carbonate mineral can easily react with water and wash away thus weakened the material. The strong correlation between quartz content the increasing of quartz increased the strength and the increasing of carbonate mineral decreased the strength of sandstone is that quartz is a high resistance mineral to weathering agent. Meanwhile, carbonate dissolves in water. So that quartz will stay longer in the rock as part of mineral composition and strengthen the rock material while carbonate will and compressive strength is validated by many researchers [10, 11].

3.3.2 *Relationship Between Main Minerals and Shear Strength*

Figure 3 shows the relationship between the percentages of the main minerals and shear strength for all the sixteen samples. Similar to the uniaxial compressive strength of sandstone, quartz also plays a vital role in the increment of shear strength. Meanwhile, carbonate mineral (CM) has a significant role in strength reduction.

The main reason is that as the percentage of quartz increased, the shear strength also increases. In contrast, as the percentage of carbonate mineral increases, the shear strength decreased in the sandstone. It is also noted that the quartz has high resistance minerals to weathering agents such as water, wind, or heat. Meanwhile, carbonate minerals will wash away, thus weakened the material. Furthermore, it can easily react with water and dissolve in water. Therefore, quartz will stay longer in the rock as part of mineral composition and strengthen the rock material while carbonate will wash away, thus weakened the material.

3.3.3 *Relationship Between Main Minerals and Tensile Strength*

For the case of indirect tensile strength, the relationship follows a similar trend as uniaxial compressive strength and shear strength. As the percentage of quartz mineral increases, tensile strength increases and the tensile strength reduce with the reduction of the percentage of carbonate mineral in the sandstone.

Fig.4 shows the relationship between the percentage of main minerals and tensile strength for all sixteen (16) samples. The composition of quartz minerals in sandstone can strengthen the rock as quartz is a strong mineral with a hardness scale of 7. However, samples with a low percentage of carbonate mineral can weaken the sandstone for the same reason where carbonate mineral can easily dissolve in water when reacting with water. Furthermore, the hardness scale of carbonate minerals is less than 3.

3.4 Correlation between Alkali-Silica Reactivity (ASR) and Strength Parameters

Figure 5 shows the relationships between strength and Alkali-Silica Reactivity (ASR) for all the sixteen samples. The linear relationships can be obtained for three relationships such as shear strength versus ASR, UCS versus ASR and tensile strength versus ASR. Based on the linear regression analysis, the value for R^2 for UCS versus ASR is 0.13, tensile strength versus ASR is 0.034 and shear strength versus ASR is 0.003, which showed poor correlations between them. This indicates that the ASR is less significant to the strength of rock material due to that the hydroxyl ions usually originate from the sodium and potassium alkalis in the Portland cement during hydration. The reaction produces a gel-like material that can be expansive when exposed to water. Reactive silica materials that can cause deleterious expansion listed in decreasing order are opal, chalcedony, volcanic glass, cristobalite, tridymite and cryptocrystalline quartz. These ASR minerals are not abundant in the sandstone and thus, will not influence the strength of the rock.

4. CONCLUSIONS

The correlations between the minerals and the strengths of sandstone rock samples were determined by simple regression analysis and bar charts. The following conclusions are drawn based on the experiment works and analysis of 16 samples of sandstone of the rock obtained from the site at Jerantut, Pahang, Malaysia, as follows:

(1) Quartz (Q) plays a very important role in uniaxial compressive strength increment in sandstone meanwhile, the carbonate mineral (CM) has a very important role in strength reduction.
(2) A similar trend is also followed by the correlation for shear strength and tensile strength of sandstone due to the chemical composition and distribution of minerals.
(3) The percentage of strong minerals such as quartz and cement can increase the uniaxial compressive strength, shear strength and tensile strength. In contrast, weak minerals such as carbonate minerals can have opposite effects on the strength parameters of the rocks. The strength increases as the quartz and cement content increases.
(4) Relationships between uniaxial compressive strength and ASR, shear strength and ASR, and tensile strength and ASR show poor correlations between them as the ASR minerals are not abundant in sandstone and present in a very small amount.

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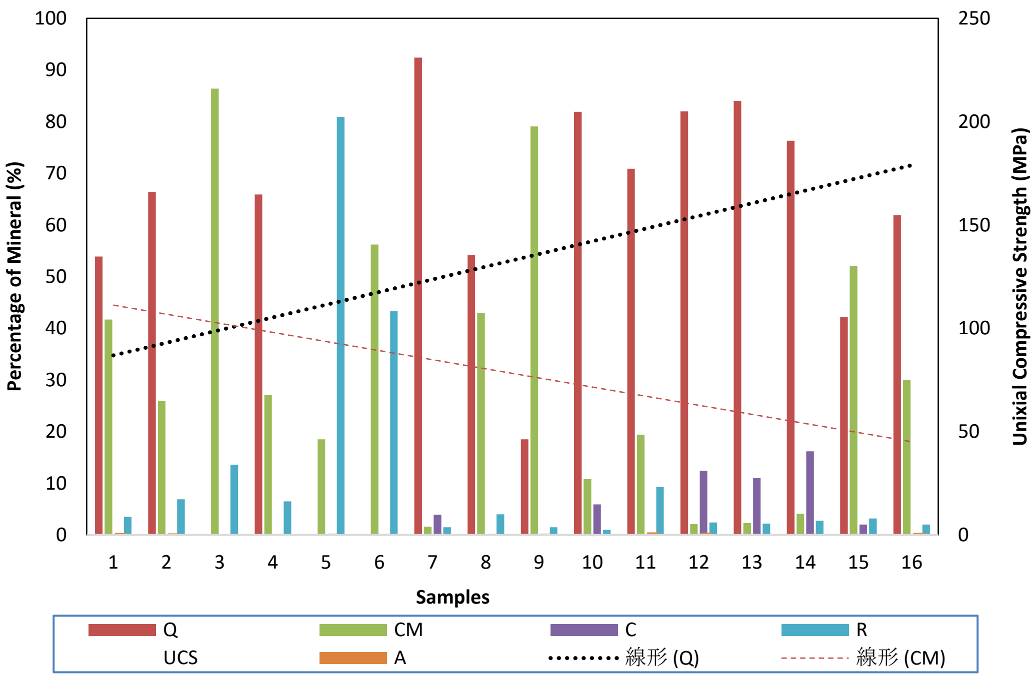

Fig. 2: Relationship between the percentage of minerals and the uniaxial compressive strength

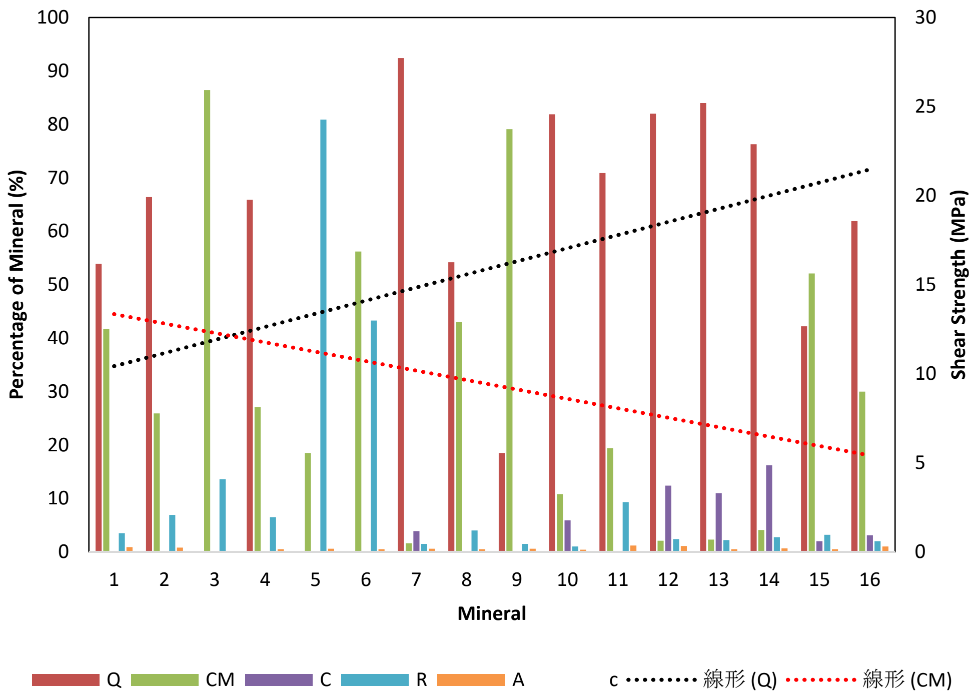

Fig. 3: Relationship between the percentage of minerals and the shear strength

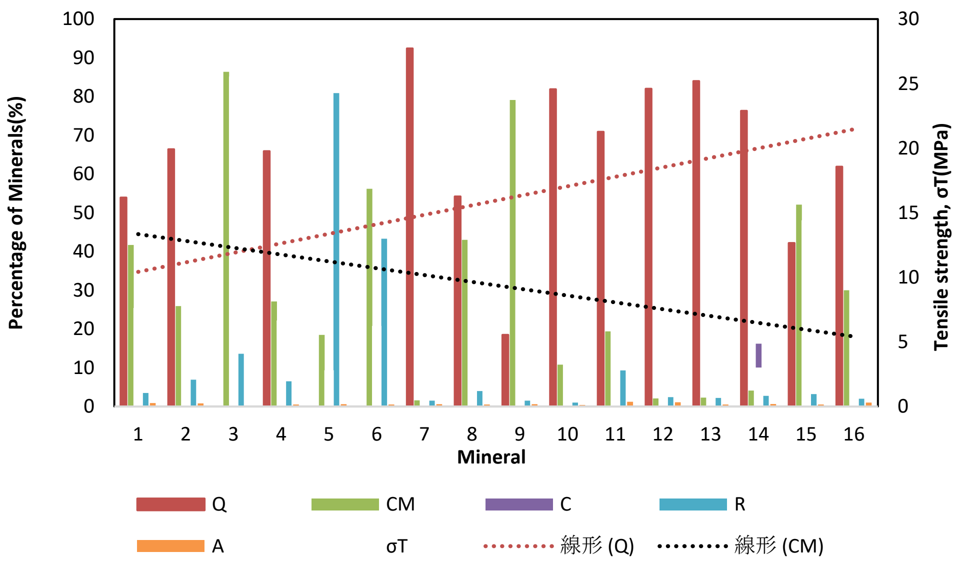

Fig. 4: Relationship between the percentage of minerals and the tensile strength

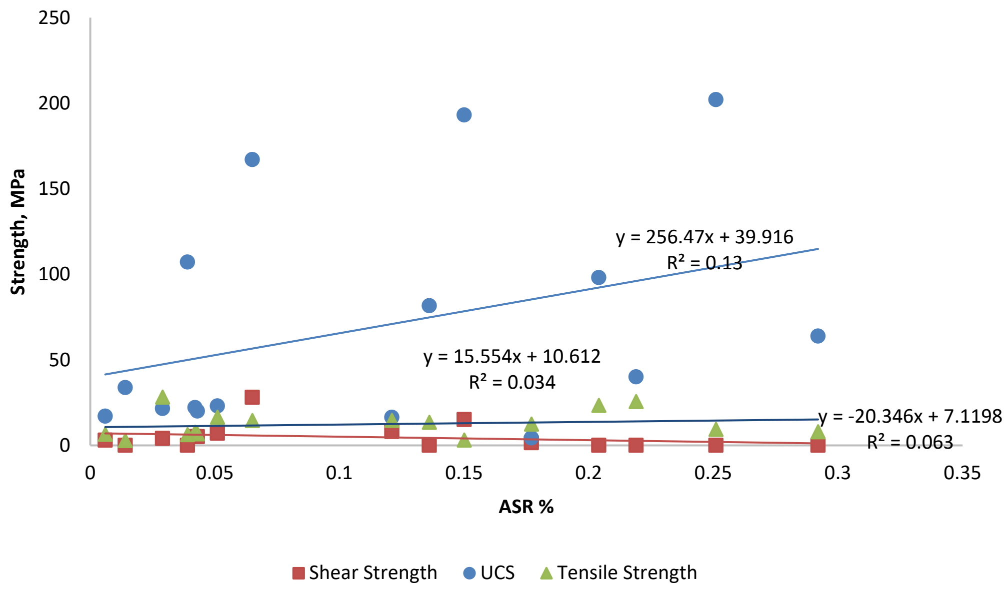

Fig. 5: Relationships between the ASR and strengths of sandstone**.**

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