PETROGRAPHY AND AGGREGATE ANALYSIS OF THE CARBONATES FROM THE BABUZAI AREA, PAKISTAN

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Abstract

This study is conducted to evaluate aggregate characteristics and potential of carbonates rocks of the Kashala Formation, Babuzai area Khyber Pakhtunkhwa Pakistan. Physical and chemical tests were performed to assess aggregate suitability. Laboratory tests reveal Los Angeles Abrasion values of 17%, Flakiness and Elongation Index of 13% and 19.7% respectively, and Clay lumps and friable value of 0.12%. Stripping and Coating value greater than 95%, Specific gravity value (2.7-2.9). The aggregate soundness value was logged at 1.28. These parameter values were evaluated through the ASTM (American Society for Testing and Materials) and BS (British Standards) which specify that the Kashala Formation (KF) of the Alpurai group can be the potential source for dimension stone i.e., natural rock material in form of blocks or slabs quarried for commercial purposes, road, and concrete aggregates. The petrographic studies of the selected samples have majorly 70 to 75% of Calcite with an insignificant amount of 20 to 25% dolomite, 5 to 8% quartz along with ores of 1 to 2%. The small number of quartz grains and ore minerals indicate that sample formation is composed of dolomitic marble having a limited amount of deleterious content such as quartz, dolomite, and clays, which suggests that the carbonates have an insignificant threat of ACR (Alkali carbonate reaction) and ASR (Alkali silica reaction). The study indicates that the carbonates of the Babuzai area fall within the standard specification limits and can be used as a source for the indigenous construction industry.

Keywords: **Aggregate; Babuzai area; KP; NW Pakistan; Petrography**

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Introduction

Tectonically, the Babuzai area is an elevated region less disturbed area having minor faults and intrusions. The coordinates of the study area are Latitude 34° 24’ 53” North and Longitude 72° 10’ 3” East, situated in Tehsil Katlang, District Mardan, Khyber Pakhtunkhwa Pakistan. Babuzai, Katlang, District Mardan, the zone for the aggregates is located on the newly constructed Swat Expressway. The majority of the rocks exposed in the Babuzai area are mostly dolomitic marble, which is lowly metamorphosed having the majority of calcite grains followed by dolomite (Ghaffar *et al*., 2010; Naseem *et al*., 2014a). Pakistan particularly Khyber Pakhtunkhwa has remarkable quantities of carbonate aggregates obtained by crushing intact rock. National Highway Authority (NHA), Pakistan has used carbonate aggregate for the construction of motorways in Pakistan, which were mega projects of the country predominantly the Swat Motorway leading to chakdara area.

The prime aims and objectives of research work are to study and evaluate the best aggregates for construction work through petrographic and standard testing. Further, to understand the physio-mechanical and petrographic characterization of construction materials and to check the suitability and durability of aggregates. Carbonates are the major source of crushed rock aggregates for the construction industry. These aggregates are the foremost used construction raw materials and are used in civil engineering projects, and transport framework such as roads, airport runways, and railways, etc., the appropriateness of carbonate aggregate depend on its analysis against national and international morals (Koukis *et al*., 2007; Ngerebara and Youdeowei 2014; Naseem *et al*., 2014b; Mustafa *et al*., 2015). Mechanical characteristics of crushed aggregates are of prime importance for their utilization as a source and dimension stones i.e., natural rock material in form of blocks or slabs quarried for commercial purposes Aggregate possesses a variety of physical and chemical properties which determine their suitability as a construction material (Furcas and Balletto, 2014; Akram *et al*.,2017; Qureshi *et al*., 2020; Anjum *et al*., 2021).

Stratigraphy of The Study Area

The northwest Indian Plate stratigraphy in north Pakistan can be separated into three components (1) Paleoproterozoic basement rocks, (2) siliciclastic strata of the Neoproterozoic to Cambrian Tanawal Formation, which is intruded by Ordovician granites and (3) a rift-clastic and carbonate shelf sequence deposited from Upper Paleozoic (Carboniferous) to the Triassic (or younger) (Lutfi *et al*., 2021). Most of the Paleozoic-Mesozoic sequence consists of the Alpurai Group and it is distributed into four formations; the Marghazar, Kashala, Saidu, and Nikanai Ghar formations. The metamorphic sequence in Lower Swat is described and placed into the geological framework of Pakistan. The stratigraphic sequence consists of the Precambrian-Cambrian(?) Manglaur formation unconformably overlain by the Alpurai group which is subdivided into the Carboniferous or younger Marghazar formation, and the Triassic or younger Kashala, Saidu, and Nikanai Ghar formations. The stratigraphic chain comprises the Precambrian-Cambrian Manglaur formation unconformably superimposed by the Alpurai group which is further divided into the Carboniferous or earlier Marghazar formation and the Triassic or earlier Kashala, Saidu, and Nikanai Ghar formations. A third component, the Jobra formation of unspecified age exists as irregular lenses unconformably beneath the Alpurai group. Alpari Group of Triassic age or younger represent shelf deposits, which are interpreted as the return of the sedimentation of epicontinental shelf across the entire Lower Swat area and Peshawar Basin (DiPietro *et al*., 1993). In the Swat region of northern Pakistan, several episodes are noted in the metasediments of the Mesozoic Alpurai Group including the Saidu, Nikanai Ghar, Kashala, and Marghazar formations and the Paleoproterozoic Manglaur Formation, which is interrupted by the Permian Swat Granite (Figure. 1) (DiPietro and Lawrence, 1991, DiPietro *et al*., 1993; Anczkiewicz *et al*., 2001, Hussain *et al*., 2020).

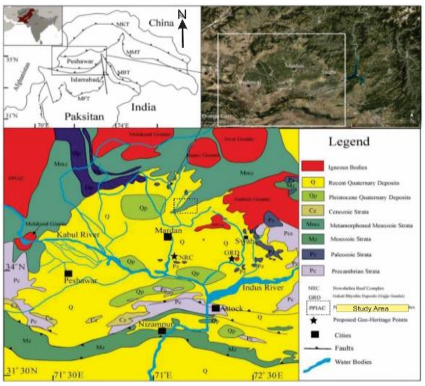

Figure 1. Geological sketch map of North Pakistan with the location of the Mardan region inscribed in a rectangle modified from Yaseen *et al*. (2019)

Sampling and Materials

Geological fieldwork was conducted in the Babuzai area to study and collect rock samples (Figure 2). Localities of sampling were selected based on the best exposure of rocks in the area which has a distinct physical appearance. For performing different material tests the samples were crushed in the crushing plant. Two different sizes of bulk samples were taken for aggregate analysis, and seven representative field samples were thin-sectioned for petrographic investigation. Different tests were performed at the laboratory located at the base camp of Frontier Work Organization (FWO). A petrographic study of the selected samples was performed to know the Mineral contents by grain counting technique at the laboratory of the Department of Geology, University of Peshawar. All the physio-mechanical and petrographic work was performed according to the different international standards American association of state highway and transportation officials (AASHTO), the American society for testing and materials (ASTM), and the British standards institution (BSI).

Different tests are performed on the collected aggregate samples to investigate the physical, mechanical, and chemical properties. The specific gravity, absorption, and Shape tests (flakiness and elongation index) were carried out to determine the physical properties of the collected aggregates. In mechanical properties, Los Angeles abrasion, aggregate crushing value, and aggregate impact value tests were carried out. For chemical properties soundness, coating, and stripping of bitumen tests were carried out (Table 1). Likewise, Petrographic analyses were performed to assess the aggregate mineralogical composition, grain size, grain type, and fabric of rocks. This analysis is used in the characterization of aggregates to evaluate the reactive ingredients (Naseem *et al*., 2019; Rehman *et al*., 2020).

Figure 2. **(a) Showing NE-SW oriented Field photograph of the outcrop of Kashala formation where extensive excavation for aggregates is going on (b) Displaying outcrop of Alpurai group rocks highly fractured (c) Representing Field photograph of sample Dolomitic marble having minor fractures (d) and (e) showing samples collected for thin section study Study Methods**

Specific Gravity

This is a test carried out to determine the strength or excellence of the material. Specific gravity is the proportion of the weight of a specified volume of aggregate to the weight of an equivalent volume of water. Aggregates having high specific gravity are usually stronger than those having low specific gravity value. Materials having high specific gravity values are believed as having high strength. According to ASTM C127/AASHTO T85 standards, the average specific gravity shall be about 2.68. The specific gravity average for an aggregate of 13 mm size in bulk oven-dry is 2.759, SP at saturated surface dry (SSD) is 2.775, and SP for apparent is 2.805 (Table 2). The specific gravity average for an aggregate of 20 mm in size in bulk oven-dry is 2.755, SP at saturated surface dry(SSD) is 2.766, and SP for apparent is 2.786 (Table 3).

Table 1. Show the results of performed Physical Tests on aggregates

S.No	Test Name	Results (%)
1	Los Angeles Abrasion	17
2	Flakiness Index	13
3	Elongation Index	19.7
4	Clay Lumps and Friable Particles in Aggregate	0.12
5	Stripping of Bitumen Aggregate Mixtures	+95
6	Absorption of Aggregates	0.41
7	The soundness of Aggregate using Sodium Sulphate	1.28

Table 2. Show the specific Gravity of 13 mm aggregate

Specific Gravity	Average
a). Bulk oven dry	2.759
b). Bulk Sat. Surf dry	2.775
c). Apparent	2.805

Table 3. Show the specific Gravity of 20 mm aggregate

Specific Gravity	Average
a). Bulk oven dry	2.755
b). Bulk Sat. Surf dry	2.766
c). Apparent	2.786

Absorption of Aggregates

It is a test used to determine the water-holding capacity of aggregates. Water retention of aggregate is a measure of the degree of porosity. This value is considered a degree of sustaining weathering action. According to ASTM-2015, ASTM-C127, the average water assimilation should not be more than 0.6 per unit weight. The amount of absorption of water by an aggregate of 13 mm in size was 0.59%, while that of water absorption by an aggregate of 20 mm in size was 0.41%.

Shape Test (Flakiness and Elongation index)

A shape test is a test used to find out the average percentage of the fractured-shaped aggregate. There are two tests for it. The flakiness index is the measurement of the percentage of how much of the aggregate is in flatted structure out of the total aggregate. An apparatus known as a flakiness gauge is used to pass some aggregates through it to find out the flakiness percentage. Standard ASTM D4791/AASHTO T104 specifies a maximum of 30% flakiness in total aggregate. The calculated flakiness index result is 13% which is accepted and considered a good aggregate for construction. Moreover, the Elongation index is the measurement of finding out the percentage of how much of the aggregate is in elongated structure out of the total aggregate. An apparatus known as an elongation gauge is used to pass some aggregates through it to find the elongation percentage. According to ASTM D4791/AASHTO T104 standards if the percentage of an elongated particle in aggregate increases from 35, 40, and 45 for sizes of 2 ½ to 2, 1 ½ to ¾, and ½ to 3/8 overall 30%, then the aggregate will be not considered good for construction. The calculated elongation index result is 19.7%, which is accepted (ASTM Standard, 2010, 2011; Rehman *et al.*, 2020) (Table 1).

Combined Gradation of Aggregate

In this method, an apparatus is used for the quartering of aggregate to make them well-graded and mix equally. The aggregate is poured into the apparatus called a divider which passes through it. It is used to make the randomly collected sample well graded as samples were taken from a different portion of the aggregates. The particles passed from different sieves according to the aggregate and sieve sizes. Sieve no.1 allows 100% aggregate, sieve no.3/4 allows 95% aggregate, sieve no.1/2 allows 70% aggregate, sieve no.3/8 allows up to 55% aggregate while sieve no.4 allows only 10% of aggregate to pass through it (Table 4). Combined fine and coarse aggregate grading are used to ensure that a reasonable quantity of aggregate with a minimum amount of void spaces is achieved. This will permit the use of a minimum amount of waste (water and cementation material) in concrete, refining the dimensional stability and durability (ASTM, 2013).

Table 4. Show the Gradation of aggregates

Sr No	Aggregate	Used%	1''	3/4''	1/2''	3/8''	4
1	13-20mm	15	15	7.1	2.1	0.1	
2	05-10mm	85	85	84.5	42.2	16.7	0.3
3	Blended Gradation		100	91.6	44.3	16.8	0.3
4	Specification Limit		100	90-100	60-70	20-55	0-10

Table 5. Show a sieve analysis of 13 mm aggregate

ASTM sieve	Size (mm)	Cum. Weight Retained(g)	Cum. Retained	Passing Obtain(%)
1 1/2"	38			
1''	25			
¾''	19	21	0.6	99.4
½''	12.7	1975	56.4	49.7
3/8''	9.5	3840	109.7	19.7
4	4.75	5069.0	144.8	0.4
#8	2.36			

Table 6. Show a sieve analysis of 20 mm aggregate

ASTM sieve	Size (mm)	Cum. Weight Retained(g)	Cum. Retained	Passing Obtain(%)
1 1/2'	38			
1''	25	0	0.0	100.0
¾''	19	895	14.9	47.2
½''	12.7	4009	66.9	14.0
3/8''	9.5	4054	67.6	0.6
#4	4.75			
#8	2.36			

Sieve Analysis

In this procedure sieves of different sizes are used to categorize the aggregate based on their sizes, each sieve has holes from which aggregate passes according to their sizes. They are used for the proper division of aggregate according to the need. The result of 13mm aggregates reflects that majority of aggregate passes through sieve no. 3/4 whose diameter is 19mm while sieve no.4 hardly allows aggregate to pass through it whose diameter is 4.75 mm (Table 5). The result of 20 mm aggregates reflects that majority of aggregates pass through sieve no. 1 whose diameter is 25 mm and sieve no. 3/8 hardly allows aggregates to pass through it whose diameter is 9.5 mm (Table 6).

Los Angeles Abrasion Values (LAV)

This test is used to find out the toughness as well as the durability of aggregate rocks. A machine is used to crush the aggregate and find out the value of the aggregate that remains uncrushed by taking its net to weigh. According to standards ASTM C-133-01/ AASHTO T-96, the percentage of retained aggregate sample for the Los Angeles test is 40% maximum. But in Pakistan, National Highways Authority uses an aggregate having a maximum of 30% of retained percentage. In the case of Carbonate, the Los Angeles Values (LAV) retained percentage comes out to be 17%, which is considered Class B and is accepted for construction work (Naseem *et al*., 2015) (Table 1).

Clay Lumps and Friable Particles in Aggregate

Clay lumps and friable particles are unwanted materials for which a test is done to remove lumps and friable particles from aggregate because this results in stripping, spelling, and raveling and creates weak points and pop-outs if the material is incorporated into the structure. This kind of raw material also tends to fill the void openings aiming for deplete capacity yet cause structure or asphalt or concrete collapse. According to the standards, AASHTO T112/ASTM C142 clay lumps and friable particles in aggregate used for construction work must be less than 5%. It will be much better if clay lumps, and friable particles are limited to about 1% in aggregate. The calculated value for the aggregates is 0.12% of lumps and friable particles which is considered a favorable aggregate (Rehman *et al*., 2020; Anjum *et al*., 2021; Rehman *et al*., 2022) (Table 1).

Stripping of Bitumen Aggregate Mixture

The stripping value test of aggregate is defined as the ratio of the exposed area from bitumen observed visually to the total extent of aggregates in percentage. This test is performed to determine the stripping value of aggregates to be used for the construction of roads, to calculate the stripping of aggregate, to study the effect of additives on stripping, and to discuss the factors affecting stripping. Stripping and coating is a test used for finding out the amount of bitumen stripped to the aggregate. According to ASTM D1075/AASHTO, T182 standards bitumen stripped to aggregate must be greater than or equal to 95%. Mean the percentage for this test of pilling of bitumen must be less than 5%. Our result for this test is above 95%, which means it is a good aggregate and can be used in Asphalt (Roberts *et al*., 1991; Abo-Qudais and Al-Shweily 2007) (Table 1)

The Soundness of Aggregate Using Sodium Sulphate

A soundness test is used to find out the aggregate's resistance to disintegration by the use of a saturated solution of either magnesium or sodium sulfate. Soundness tests measure the resistance of aggregates to fragments by weathering and in certain freeze and thaw rounds. Aggregates that are strong and resilient means hard to weather and are less likely to disintegrate in the field and cause premature HMA pavement distress and potentially collapse. According to the standards, ASTM C88/AASHTO T104 the loss or weathered percentage of aggregate should be less than or a maximum of 12% for using sodium sulphate solution. The percentage we got in this test for loss of aggregate was 1.28%, which means the strength of aggregate is much more and is resistant to weathering (Haynes, 2005)(Table 1).

Petrographic Characteristics

Seven representative samples were collected from the study area for the preparation of petrographic samples. The petrographic analysis was carried out to determine the mineralogy, grain size and types, color, the geometry of minerals, texture, and reactive contents. The reactive contents of aggregate are hazardous which affects the strength, durability, and bonding of aggregate. The reaction of aggregate is the ASR (i.e. alkali-silica reaction) and ACR (alkali carbonate reaction) when the aggregate interacts with water (Ahsan *et al*., 2012; Ullah *et al*., 2020). Thin sections were prepared at the laboratory of the Department of Geology, University of Peshawar, and studied according to the standard method of ASTM C295/C295M-18a and the procedure adopted by Kamran *et al*., 2022 and Anjum *et al*., 2018. The thin sections were studied both in a plane and crossed polarized light. Detailed textural and mineralogical studies were carried out. The

Table 7. Shows the mineral content within collected rock samples

Sample No.	Locality	Mineralogical Composition (%)				
		Calcite	Dolomite	Quartz	Ores	Biotite
PS-0	Babuzai	94	5	0	1	0
PS-1	Babuzai	72	12	11.5	0	0.5
PS-2	Babuzai	70-72	13-15	12	2-3	0
PS-3	Babuzai	84	3-4	10-12	0	0
PS-4	Babuzai	90	5-6	3-4	0	0
PS-5	Babuzai	85	5-10	10-12	2-3	0
PS-6	Babuzai	92	8	0		0
PS-7	Babuzai	80-82	18-20	0	0	0

Table 8. Shows the Petrographic properties of collected samples

Sample No.	Color	Texture	Interference Color	Twinning	Extinction	Relief	Birefringence
PS-0	Greyish	Fine to Coarse	Relatively low	Polysynthetic	Symmetrical, Undulose	High	High
PS-1	Greyish	Fine to Coarse	High	Polysynthetic	Symmetrical, Parallel	High	High
PS-2	Greyish	Fine	High	No	Undulose	Low	High
PS-3	Greyish	Coarse to Medium	Relatively low	Simple,			
Polysynthetic	Symmetrical, Parallel	Medium	High				
PS-4	Greyish	Fine to Coarse	High	Simple	Symmetrical, Parallel	Medium	High
PS-5	Greyish	Fine	High	No	Undulose	Low	High
PS-6	Greyish	Medium to Coarse	High	Polysynthetic	Symmetrical, Parallel	High	High

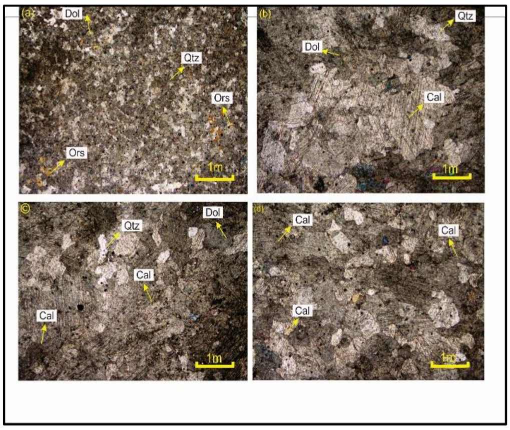

Figure 3. Photomicrographs of thin sections (a) Typical Marble having large calcite grain showing polysynthetic twinning with minor ores and dolomites (b) Dolomitic Marble having fracture filled with quartz (c) medium-grained dolomitic marble (d) Fine to coarse-grained Dolomitic Marble having calcite, quartz, and ore mineral grains (e) Showing eight samples cut for thin section studies from the outcrop. Cal=Calcite, Dol=Dolomite, Qtz=Quartz, Ors=Ores

description of each thin section is given in Tables 7 and 8. A petrographic study of thin sections shows that Kashala formation consists of 70 to 75% Calcite with an insignificant amount of 20 to 25% dolomite, 5 to 8% quartz along with 1 to 2% of ore minerals, which indicates that the Kashala formation of Alpurai group is dolomitic marble. The values of various standardized tests for the studied rocks are within the permissible ranges of standard specifications for construction. The overall study and test results indicate that the Carbonate of the Babuzai area falls within the standard determination limits and can be used as a source for the innate development industry (Figure 3).

Results and discussion

Two different sizes of bulk samples and seven representative field samples for the thin section were collected respectively for aggregate analysis petrographic study. The samples tested were subjected to their suitability for construction compared with standard values. The first gradation test was conducted and combined fine and coarse aggregates grading is used to ensure that a reasonable quantity of aggregate with a minimum amount of void spaces is achieved. This will allow the use of a minimum amount of waste (water and cementation material) in concrete, refining the dimensional stability and durability (ASTM, 2013). Secondly, Sieve analysis was performed to differentiate samples based on their size, the result shows that the majority of the aggregate passes through sieve no.1 while some of the aggregates are retained at sieve no.4, which is assumed as a boundary between the fine and coarse aggregate.

LA (Los Angeles Abrasion) test shows the strength of aggregate. The more the abraded particle the higher will be the LA abrasion percentage, suggesting that concrete will be weaker. The result shows that 17% of aggregate was eroded in the LA machine, it is assumed that the aggregate is harder and resistant to abrasion and that it can be used in construction. In the case of Carbonates, the Los Angeles Values (LAV) retained percentage comes out to be 17%, which is considered Class B and is accepted for construction work (Naseem *et al*., 2015).

In the case of the flakiness index, if the percentage increases from the standards which are 30%, those aggregates cannot be used for construction, especially on roads. As our flakiness index result is 13% which shows that the aggregate contains less flaky particles and can be used in construction work. If the percentage of elongated particles increases in aggregate from the standards which are different for different sieve sizes and overall is 30%, the aggregate cannot be used in construction. The calculated elongation index result is 19.7%, which is accepted mean it can be used in construction work (ASTM Standard 2010, 2011; Rehman *et al*., 2020)

The calculated value for the aggregates is 0.12% of lumps and friable particles which is considered a favorable aggregate. According to ASTM D1075/AASHTO, T182 standards bitumen stripped to aggregate must be greater than or equal to 95%. Mean the percentage for this test of pilling of bitumen must be less than 5%. Our result for this test is above 95%, which means it is a good aggregate and can be used in Asphalt (Roberts *et al*., 1991; Abo-Qudais and Al-Shweily 2007; Rehman *et al*., 2020). Generally aggregates having low specific gravity are more fragile than those having higher specific gravity. The specific gravity for aggregates commonly using in road construction ranges from about 2.5 to 3 with an average of 2.68. The values of the specific gravity of aggregates tested were in ranges from 2.75 to 2.80, which mean that the aggregates are good to be used in any type of construction work.

Additionally, the Water Absorption by aggregate must not be greater than 0.6 per unit weight. The value of water absorption was 0.41 and 0.59, which means the aggregate water absorption value is within a standard limit to be used in construction. Soundness is a test used for finding out the amount of lost material when it is dipped in a chemical solution. According to standards, the maximum percentage of degraded particles must be less than 12%. For using sodium sulphate solution. Our result for the soundness test is 1.28%, which indicates the strength and resistance to erosion of aggregate.

The petrographic analysis of Carbonate shows a limited amount of deleterious content such as dolomite and clays, which suggests that the Carbonate of the Kashala Formation has an insignificant risk of ACR and ASR. The Carbonate is hydrophobic. Thus, it makes a good bonding with the bitumen and is appropriate for asphaltic concrete (Ullah *et al*., 2020).

Conclusions

The Carbonates of the Kashala Formation exposed along the Swat expressway in the Babuzai area are evaluated in terms of their physio-mechanical and petrographic characteristics to evaluate their possibility in construction works as an alternative aggregate source. The conclusions reveal that all the test values of aggregates fall within the standard specification ranges for normal aggregate used in construction work. From the petrographic analysis, any deleterious material was not found above the limits, which can cause structural defects due to alkali-silica reaction (ASR) and alkali-carbon-ate reaction (ACR). It is concluded that values of all the physical parameters are within the range of the standard aggregate limits and hence can be used as an aggregate source for road purposes, concrete and other construction projects. The Carbonate of the study area is reachable and can be transported to diverse regions of the country. It can be smoothly mined through open pit excavation. Development of crushing activities in the study area will deliver a huge quantity of potential aggregate for construction purpose.

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