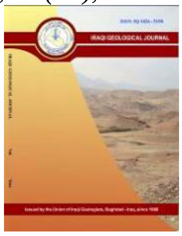
Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Evaluation of Limestone from Cretaceous to Tertiary age in Kurdistan Region of Iraq for Heavy Duty Road Pavement

Aveen A. Surdashy[1,*] and Ahmed M. Aqrawi[1]

[1] Department of Geology, College of Science, Salahaddin University-Erbil, Kurdistan Region, Iraq

* **Correspondence**: Avin.mahmood@su.edu.krd

Received: 24 June 2022

Accepted: 13 September 2022

Published: 31 December 2022

Abstract

Aggregates have an important role in the development and quality of Hot Mix Asphalt pavement, Engineers prefer using different types of acidic aggregates as a dominant road pavement mixture. This study is focused on using a basic aggregate, for this purpose limestone is used as a replacement to sandstone and gravel in the Hot Mix Asphalt for base and binder course, due to its rough, tough, durable and stable properties, that adheres well with the binder due to its hydrophobic properties. A petrographic study and chemical analysis by XRF method was carried out for better determining the mineralogical and chemical contents. Los Angeles Abrasion test carried out for measuring abrasion of the limestone aggregates in Kurdistan Region Iraq from Cretaceous-Tertiary age in different sources of the Shiranish Formation in Pirat, Harir, and Safin, Aqra-Bekhme in Shakrok, the Pila Spi Formation in Pirmam, Khurmala Formation in Safin, the Euphrates Formation in North Qarachugh, and the Qamchuqa Formation in Bana Bawi, while the only last four formations selected for Marshal test depending on wear <45% according to Iraqi SORB, 2003 standards. The soundness test results showed that the selected four samples are within the required specifications. The aggregate-asphalt mixture molds were prepared with the optimum binder content of 4.7%, for the Marshall stability test, which revealed that all the selected four samples are suitable as a heavy-duty pavestone for the base and binder course, with BQ and Pm showed optimum stability results.

Keywords: Limestone aggregates; Hot Mix Asphalt; Marshall stability test.

1. Introduction

Sandstone and gravel are considered as most widespread aggregates used in pavement. However, they have smooth surface, round edges, and hydrophilic properties that make them difficult to adhere to the bitumen and causes stripping of the road pavements, in most cases an anti-stripping material must be used as a treatment. The road pavement in Iraq suffered from several corrosion, cracks, and rutting through lifetime due to the heavy traffic load, the researchers demand to improve the quality of hot mix asphalt (HMA), for this purpose limestone used as an aggregate in HMA without stripping treatment due to its hydrophobic properties which binds strongly with the bitumen due to its opposite charge that attracts the bitumen, have rough surface, near-cubic edges (when crushed), even if there is moisture content inside its voids have a capacity to make hydrogen links within the aggregate and turn it into active-water that makes the bond even stronger (Anderson et al,. 1992). Recently lime used as a filler

DOI: 10.46717/igj.55.2F.4ms-2022-12-19

within sand and gravel in HMA for enhancing quality of road pavement, however using lime in HMA is cost effective therefore it can be replaced by using limestone filler (Zaenuri, 2018).

This study focused on evaluation of limestone rocks from Tertiary to Cretaceous age from the Shiransh Formation in Pirat (Pt), Harir (H), and Safin (S), Aqra-Bekhme in Shakrok (Sh), the Pila Spi Formation in Pirmam (Pm), the Khurmala Formation in Safin (Sk), the Euphrates Formation in North Qarachugh (QN), and the Qamchuqa Formation in Bana Bawi (BQ), as a crushed stone in HMA pavements (Figs.1 and 2). petrographic studies of limestone are selected according to American Railway Engineering Association (AREA) specification requirements that contains <5% fine deleterious substances (friable pieces and clay lumps) which lowers the hardness of the limestone aggregate and recommends <5% organic materials which leads to high porosity hence needs high bitumen%, which is cost effective and not economic. According to LAS (Los angeles test) the aggregates of <40% wear selected due to ASTM C131 (2001). According to XRF test, limestone with high CaO and MgO content selected for better hardness.

Meininger (2002) in his soundness test suggested that limestone aggregates containing carbonates of calcium are chemically attacked by the $MgSO_4$ and $NaSO_4$ solution than carbonates of magnesium due to their higher porosity. Judele (2011) conducted that the minerologic nature of aggregate is vital, since the bitumen prefers basic aggregates, however most of the HMA aggregates are of acidic that continuously causes problems for specialists to increase the bitumen ratios. Williams and Cuningham (2012) used LAS as a preliminary test for obtaining toughness of the aggregates pre-Marshal test in HMA. Ahmed and Attia (2013) found Marshal properties of different types of aggregates by using HMA in Egypt, showed that basalt flow was higher than that of dolomite flow due to its acidic nature, and limestone showed higher stability than basalt and dolomite due to its basic nature. Mahmoud (2014) evaluated the impact of different aggregate types on HMA, he showed that limestone has higher stability and lower flow than basalt with lower stability and higher flow. Pandit et al. (2019) evaluated effect of different aggregate types on Marshal properties of HMA containing fly ash, with limestone showed higher stability values than basalt. Ahmed et al. (2014) studied comparison between angular and round edged gravel in HMA pavement showed that rough and angular edged gravel increased stability values and bulk density and decreased void and flow values compared to smooth round edged gravel. Cui et al. (2014) investigated that limestone and marble have higher water resistance than granite due to their opposite surface charge, and limestone showed higher porosity than marble and granite. Sissakian et al. (2019) studied Suitability of Pila Spi Formation for Cement Industry in Permam Mountain, Erbil, Iraqi Kurditan Region, he concluded that only some parts of this carbonate rock can be used as a cement raw material, due to the high MgO percentage. Al-Yousify and Taher (2021) used Marshal stability test on HMA for three aggregate types of gravel, limestone and crushed stone, with limestone recorded non-acceptable flow value but higher stability values than gravel and crushed stone by 36% and 50% according to Iraqi SORB, 2003.

2. Geological Setting

The studied area is covered by different formations of BQ, Sh, Pt, S, H, Sk, and Pm located in the core or limb of anticlines within the High Folded Zone and QN in eastern plunge of anticline within the Foothill Zone (Table 1), Tectonically the high folded zone is near the subduction zone of Arabian and Iranian plates therefore it was mostly affected by folding, faulting, jointing, tension, and compression, while the foothill zone is slightly affected by tectonism.

2.1. Qamchuqa Formation

The Qamchuqa Formation (Early Aptian – Early Cenomanian), consists of crystalline dolomite, bituminous and hard limestone, massive, hard, bedded, and crystalline with greyish and brownish color. 50-75m thick.

2.2. Aqra-Bekhme Formation

The Aqra-Bekhme Formation (Late Campanian – Late Maastrichtian), located in the carapace of High Folded Zone in North Iraq of Shakrok anticline, consists of reefal limestone, dolomitic, bituminous, fossiliferous limestone, with light grey to brown color. 100-180m thick.

2.3. Shiranish Formation

The Shiranish Formation (Upper Campanian-Lower Maastrichtian), located on High Folded Zone of North Iraq (Bellen et al., 1959), limestones of Pirat, Safin and Hareer anticlines selected, Lower Shiransh consists of marly limestone, well bedded, fossiliferous with glauconite and pyrite, with bluish grey color. 120-2350m.

2.4. Khurmala Formation

The Khurmala Formation (Late Paleocene – Early Eocene), located in the High Folded Zone in Northern Iraq (Bellen et al., 1959), Lower part consists of dolomite and fossiliferous and crystallized limestone, whereas the upper part consists of bituminous and massive limestone, dolostone and chert, brown color, 5-12m thick

2.5. Pila Spi Formation

The Pila Spi Formation (Middle- Late Eocene), located at the contact of High Folded Zone and Low Folded Zone of Northern Iraq (Bellen et al., 1959), Pil Spi consists of well bedded limestone, dolomitic limestone, and fossiliferous to lesser extent. creamy to white color. 55-70m thick.

2.6. Euphrates Formation

The Euphrates Formation (Early Miocene) (Fig. 1), located at Low Folded Zone in Southern Iraq (Bellen et al., 1959), Lower part consists of basal conglomerate and fossiliferous limestone, Upper part consists of hard limestone, yellowish to creamy white. 10-30m thick.

Table 1. Formation, anticline, and location of the selected limestone samples

S.No.	Formation	Anticline	Longitude	Latitude
BQ	Qamchuqa	Bana Bawi anticline	44°57'96"	40°14'26"6
Sh	Aqra-Bekhme	Shakrok anticline	44°82'68"	40°33'31"9
Pt	Lower Shiransh	Pirat anticline	41°26'95"	39°99'91"8
S	Lower Shiransh	Safin anticline	43°59'38"	40°27'96"
H	Lower Shiransh	Hareer anticline	44°04'49"	40°56'54"5
Sk	Khurmala	Safin anticline	43°59'38"	40°27'96"0
Pm	Pila Spi	Pirmam anticline	44°15'52"	36°21'20"
QN	Euphrates	Qarachugh anticline	37°38'13"	39°67'26"

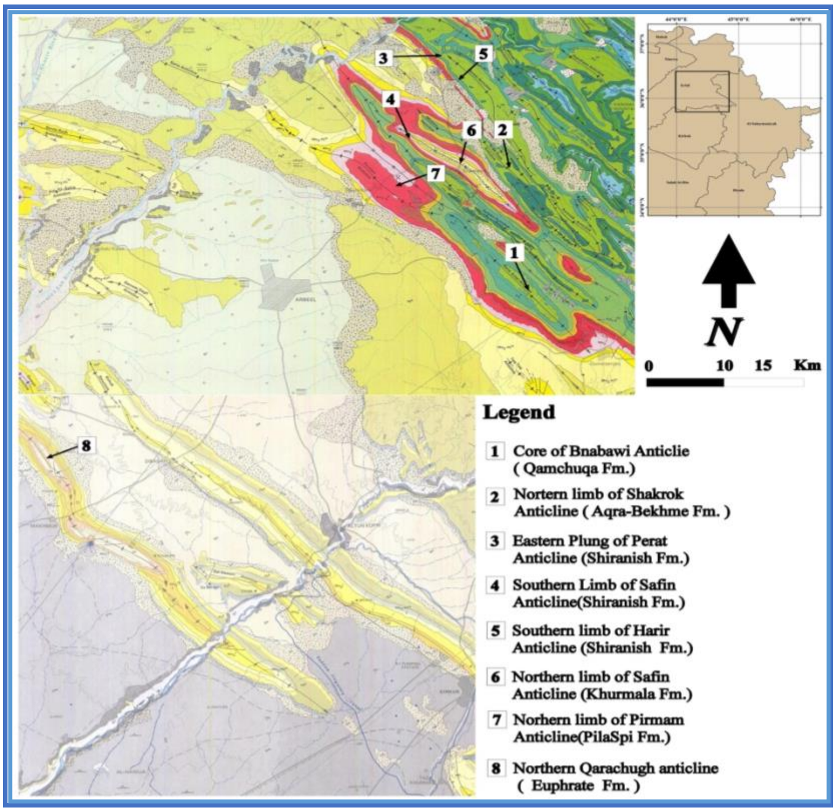


Fig. 1. Geological map showing location of the selected sections for pavement (Sissakian, 2000)

3. Materials and Methods

The fresh rock sample of limestone collected with nearly 20-30cm in dimension near limestone quarries, the site locations, longitude and latitude axis recorded by Garmin GPS type. HCl solution used for comparison between limestone and dolomite rocks in the field.

3.1. Petrographic Study

The petrographic study is one of the preliminary approaches in establishing the mineral content, porosity, grain size, and compressive strength of the rock via diagenesis and weathering evidence in the thin sections that are studied under microscope. Thin slabs of limestone fixed to the thin glass sections according to ASTM C 295 (2016). Then applying alizarin red solution on to the thin section for clear identification of limestone and dolomite (Friedman, 1965), where the calcite takes up red color while dolomite remains uncolored by the solution. consequently (BQ, Sh, Pt, S, H, Sk, Pm, QN) selected for petrographic study under transmitted light microscope under 17X power resolution objective lens in Geology Department, College of Science, Salahaddin University.

3.2. Chemical Study

Chemical analysis carried out by XRF (X-Ray Flourescence) method for determining the type and number of major oxides inside the selected samples of BQ, Sh, Pt, S, H, Pm and QN in Kansaran Binload Laboratory in Iran city. The CaO oxide acts as a lime filler in the HMA, which increases the stability of the road pavement. The MgO is responsible for durability of pavement, which increases the resistance to wear% in LAS test. SiO_2 capable for hardness and hygroscopic capacity (can absorb water), it's a refractory material that can withstand high temperatures, low melting point, and chemically inert, Al_2O_3 is in charge of sustaining corrosion, Fe2O3 presents stiffness for the HMA (Widayanti et al, 2018).

Na_2O, K_2O, TiO_2, MnO, P_2O_5 and SO_3 acts as deteriorate oxides in the road pavement, immediately upon high percentages.

3.3. Los Angeles Abrasion Test

Los Angeles Abrasion test (LAS) is one of the comprehensive tests in pavement for measuring aggregates toughness, attrition (wear % during repeated load by traffic), and hardness, (Williams and Cuningham, 2012). The test procedure was performed according to ASTM C131-01 (2001); AASHTO T96 & 99 (2002), and Iraqi SORB (2003). For this purpose eight different limestone samples were selected from Pila Spi Formation in Pirmam anticline (Sheraswar area) (Pm), Lower part of Shiransh Formation in Pirat (Pt), Harir (H), Shakrok anticline (Sh), and Safin anticline (S), Khurmala Formation in Safin anticline (Kawanian area) (Sk), Qamchuqa Formation in Bana Bawi anticline (BQ), and Euphrates Formations in Qarachugh North anticline (QN) were crushed into different sizes by impact crusher, then sieved by using ten standard US No. sieve sizes (Table 2). According to the Grade B in the gradation table.

Table 2. Number of gradations, revolution and iron balls used for Los Angeles Abrasion Test

Passing (mm)	Retaining (mm)	Weight Grade A	Weight Grade B	Weight Grade C	Weight Grade D	Weight Grade E	Weight Grade F
80	63					2500	
63	50					2500	
50	40					5000	5000
40	25	1250					5000
25	20	1250					
20	12.5	1250	2500				
12.5	10	1250	2500				
10	6.3			2500			
6.3	4.75			2500			
4.75	2.36				5000		
No. iron balls/ rev.		12/500	11/500	8/500	6/500	12/1000	12/1000

5000 gm of the sample selected from each of the eight selected formations separately, then each of them washed with water and dried in oven for 24 hours at 110 C then weight until exact 5000 gm obtained (Fig. 2A), followed by placing inside steel drum with 11 iron balls (each of which 4.8 cm diameter and 445 gm in weight), with 500 revolutions (17 min) in the abrasion test steel drum (21 cm long and 28 cm diameter, attached with 3 wide projecting shelf drum, rotating electrically at 30 r/m.) (Fig.2B) which delineate rotation and dynamic contact of the crushed stone within the iron balls, then the aggregate screened over 1.7 mm (US No. 12) sieve size, the retained aggregate washed and dried in oven at 110 C and weighted to the nearest one gm. The wear % calculated by the following formula according to ASTM C 131 (2006):

$$\text{Wear \%} = \text{O-R/O} .100 \qquad (1)$$

Where;

O= original weight

R= retained weight

Abrasion resistance test carried out in the College of Civil Engineering, Salahaddin University laboratories

Fig. 2. LAS abrasion test A) eight aggregate samples were prepared according to Class B gradation; B) Steel drum with 11 iron balls.

3.4. Aggregate Gradation and Blending

Four types of limestone aggregates (Sk, Pm, BQ, and QN) were selected for gradation and blending, which exhibit low wear% in LAS tets. The improvement of this test is to obtain dense and well graded mixture of different grade sizes as a vital case in road construction to minimize air voids in the HMA (Prowell et al., 2005; Ahmed and Attia, 2013). These four samples were crushed by impact crusher to obtain cubic particle dimensions with angular edges according to ASTM D 3398 (2000). The flaky particles are not accepted which causes bleeding of the road pavement, the aggregate was divided into four quarters, then two of the opposite quarters at right angle to each other were selected and dried in oven at 105C for 4 hrs. The sieves were placed in sieve shaker machine, the dried aggregate poured on the top of sieves, sieved by mechanical process for 2-7 mins (Fig. 3a), weight of each aggregate retained was recorded for calculating cumulative % passing for every sieve on semi log paper (Fig. 3b) according to ASTM C 136 (2006).

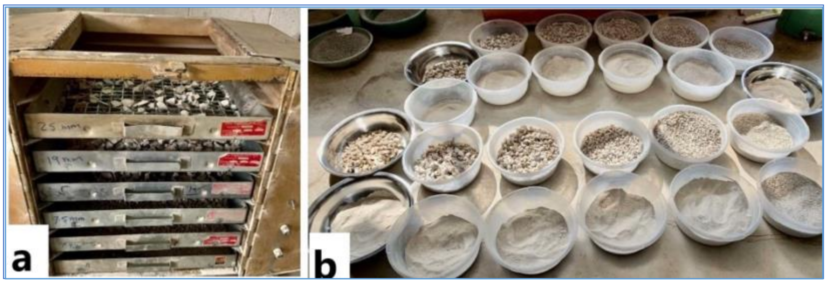


Fig.3. (a) sieve shaker machine (b) aggregate size preparation

3.5. Soundness Test

Soundness test was used for measuring durability, weathering, freeze and thaw cycle of the limestone crushed stone aggregate used in pavement, especially for wearing course layer which is located above the Binder course (Parker and Kandhal, 2004) for (Sk, Pm, BQ, and QN) samples

3.5.1. Na_2SO_4 and $MgSO_4$ solutions

This test procedure exploited for resolving the resistance of the aggregates to weathering, using Na_2SO_4 and $MgSO_4$ solutions. 200 gm of aggregate samples from each of these formations retained No. ½ U.S. sieve size (12.5 mm or 0.5 inchs) and were dried in oven at 110C for 2 hours before submerging in $MgSO_4$ 10% (Gs.=1.297-1.306) and $NaSO_4$ 10% (Gs.=1.154-1.171) for 16-18 hrs in a beaker that covered to inable evaporation and contamination (Fig. 4a, b, and c), this procedure was repeated in 5 cycles, after each cycle the aggregates were drained on a cloth for 15 mins, then dried in oven at 110C for 4-5 hours, which allows salt crystals to precipitate in the limestone aggregates pores and enlarges when dried in each cycle till it breaks up the aggregate into smaller particles, after the final cycle the aggregates washed thoroughly with distilled water without pressing on the aggregate samples (to avoid breaking of particles manually which gives error readings), followed by drying in oven for 5 hrs at 110C, the dried aggregate sample sieved on the same sieve which have retained before to record the % passing this time, and the following formula used for measuring loss% according to AASHTO-T 104 (2007) and ASTM-C 88 (2003).

$$Loss\% = Mo - Mf/Mo * 100 \qquad (2)$$

Where:
Mo= original mass of sample retained ½ sieve size
Mf= final mass of sample retained ½ sieve size

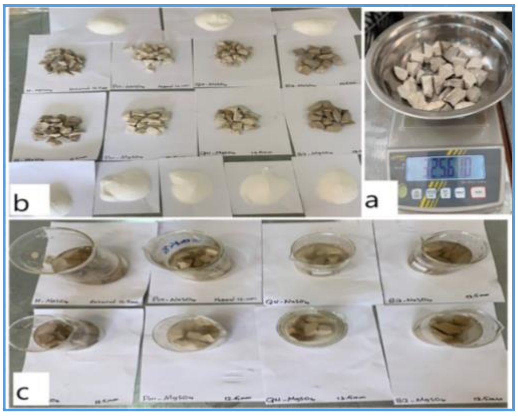


Fig.4. (a) weighting 200 gm of the aggregate; (b) sample preparation for soundness test (c) aggregate submerging inside the solutions

3.5.2. HCl solution

This test procedure exploited for resolving the resistance of the aggregate to acid rain. 100 gm from each of (Sk, Pm, BQ, and QN) are rinsed with distilled water then oven dried at 110C for 4-5 hours, successfully graded by passing 3/8 (9.5 mm) sieve and retained No. 10 (2.36mm) sieve according to ASTM E 11 (2020). the limestone aggregates were submerged in 5% HCl (Gs. 1.19) solution for 24 hrs according to ASTM C 702 (1998). The HCl solution reacts with $CaCO_3$ to form CaCl (calcium salt) and CO2 (Schiffner, 2003), then each beaker was filled by distilled water and allowed until all the insoluble residue settled (to avoid weight loss), afterwards the water rinsed. This procedure was repeated five cycles until all acid was removed from the samples. The insoluble residue was poured into No.200 (0.075mm) sieve, then the retained particles were oven dried at 110C until constant weights were obtained according to ASTM C 117 (2017).

$$Loss\% = Wo - Wf/Wo * 100 \qquad (3)$$

Where:
Wo= weight of original sample retained sieve (0.075mm)
Wf= weight of final sample retained sieve (0.075mm)

3.6. Marshall Stability Test

This test procedure established for stability of limestone aggregates in Binder course layer beneath the wearing course and above the Base course according to ASTM D (1559), 1976 and AASHTO T-245, (1990). However, this course layer is not directly in contact with weathering but it's crucial to have sufficient stability, strength and hardness to minimize the stress that is directed by traffic loads forwarded from wearing course above it according to Center for Transportation Infrastructure (ASTM D 6931, 2020). The samples that showed <45% LAS value was selected for Marshal test including (Sk, Pm, BQ, and QN), each aggregate blend was mixed with four binders' content % (3.7, 4.2, 4.7, and 5.2) Four samples of different aggregate types were made for each of the binder contents, the aggregates and the binder asphalt were heated in oven for >1 hr at 150C, 1200gm of the aggregates were placed on balance (Fig. 5a and b), then the binder % were added thoroughly according to the equation

$$Bw= Ta* B\% /100 \qquad (4)$$

Where:

Bw= Binder weight (gm)

Ta= total aggregate weight (gm)

B= Binder content %

The aggregate and asphalt mixture were placed on a heater and mixed manually (Fig. 6c and d), then poured into a preheated mould of 10 cm diameter and 7cm height according to ASTM D 3549, (2003) (Fig. 5e), afterwards, compacted by applying 75 blows on each side (for heavy duty traffic road pavements) (Fig. 6f), by using compaction hammer of a flat tamping face of 4.55 (10 lbs) weight provided to drop at a free fall of 45.7 cm (18 inch) according to ASTM D 6927 (2020) and AASHTO T 312, (2019). Then the aggregate-asphalt mixture was extracted from the mould by using specimen extractor loading jack (Fig. 5g), subsequently, the mixture was let to cool down in room temperature over-night (Fig. 5h), then placed in a pre-heated water bath at 60°C for 30-40 mins, this tempreture represents the weakest aggregate-asphalt mixture condition for measuring its stability value

The stability test of the mix represents maximum load carried by the compacted cylindrical molded specimen at standard temperature of 60C, for measuring their maximum strength (KN) by applying a load of 50mm/1min rate AASHTO T 283, (1996) (Fig. 6E). successfully, the flow was measured as a relation between maximum load and no load carried by the specimen until the mixture was deformed (Fig. 6F), which represents traffic intensity, flexibility of the mixture, brittleness and deformation under load in (0.25 mm) by Marshal Device according to ASTM D1559, (1976).

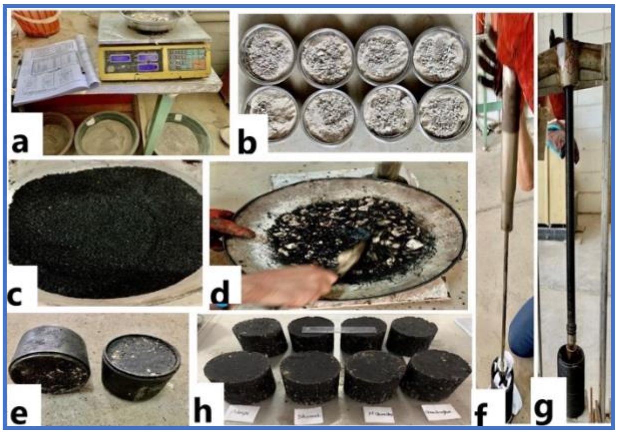


Fig.5. (a) electronic balance; (b) aggregate mixtures; (c) asphalt; (d) mixing the aggregate with asphalt manually; (e) cylindrical molds; (f) hammer; (g) mould extractor

3.6.1. Specific gravity of aggregate

Specific gravity of aggregates was obtained according to (ISS for roads and bridges) and AASHTO, T 84 & 85 (2007) and ASTM C 127, (1999). Weighting 2000 gm of dry sample (Wd), then submerging in water by setting them down inside a basket hanged with a balance, recording submerged weight (Wss) (Fig. 6a). The Wss were recorded by drying the aggregates in a cotton cloth only to remove the surface water and weighted

$$Bv = Wss - Wsw \quad (5) \quad \text{and} \quad Ga = Wd/Bv \quad (6)$$

Where; Ga= specific gravity of aggregate Bv= bulk volume of aggregate
Wss= saturated surface dry weight of the aggregate (gm)
Wsw= submerged weight of the aggregate inside water (gm)
Wd= dry weight of the aggregate in air (gm)

3.6.2. Specific gravity of bitumen

The specific gravity of bitumen was measured by weighting an empty pycnometer, then pouring 10 ml bitumen of 75 gm density, and melted at 100°C onto the empty pycnometer, accordingly pouring water onto the flask till 50 ml and was weighted (Fig. 6D). The following equation was used according to ASTM D70, (2018).

$$Gb = \frac{Wb-We}{(Ww-We)-(D-Wb)} = \frac{53-24}{(75-24)-(75-53)} = \frac{29}{29} = 1 \quad (7)$$

Where; Gb= specific gravity of bitumen
We= Weight of empty pycnometer= 24 gm
Wb= Weight of pycnometer partially filled with bitumen= 53 gm
Ww= Weight of full water pycnometer= 75 gm
D= mass of pycnometer, asphalt and water =75 gm

Fig.6. (a) weight of aggregate in water; (b) weight of the molded mixture in air; (c) weight of the molded mixture submerged in water; (d) specific gravity of bitumen by weight (pycnometer); (e) marshal stability test; (f) flow of the HMA moulds

3.6.3. Specific gravity of the aggregate-asphalt mixture

Specific gravity of aggregate-asphalt mixture was obtained by weighting dry weight (B) (Fig. 7B), then submerging the aggregate-asphalt mixture in water by placing inside a basket (Fig. 7C), afterwards, (C) was recorded in gms (Fig. 7A), the (D) was recorded by drying the aggregates in a cotton cloth only to remove the surface water then weighted. The bulk gravity (G) of the aggregate-asphalt mixture detected according to (AASHTO, T 84 & 85, 2007) (ISS for roads and bridges) and ASTM D 1188 (2015) and ASTM D 2726 (2017). Marshall stability equation was applied for measuring quality of the limestone aggregate in road pavement construction according to (Wallace and Martin, 1962)

A= total volume of bitumen %
B= dry weight of the aggregate-asphalt mixture in air (gm)
C= submerged weight of the aggregate-asphalt mixture in water(gm)
D= suspended surface dry weight of the aggregate-asphalt mixture in air (gm)
E=D-C Where; E= Bulk volume (CC)
F= B/E Where; F= specific gravity or bulk gravity of aggregate-asphalt mixture (gm)
G= W/Gb+Ga and Ga= 100-A/Ga Where G= specific gravity of HMA and W=100)

3.6.4. Stability, flow, and void % of aggregate-asphalt mixture

The stability, flow, and void % of the aggregate-asphalt mixture calculated according to AASHTO T 283 (1996).

H= A*F/Gb Where H= total volume of the bitumen %
I= (100-A) *F/Ga Where I= total volume of aggregate
J= 100-H-I Where J= total volume of voids %
K= 100-I Where K= volume of voids in the aggregate
L= H/K*100 Where L= volume of voids filled by bitumen %
M= 100- 100*F/G Where M= total volume of the voids in the aggregate-asphalt mixture %
N= 1.0*F Where N= unit weight of the bulk aggregate-asphalt mixture (gm/cc)
Ō= correction factor table by (Wallace & Martin, 1967) depends on the value of E
O = marshal stability value of the aggregate-asphalt mixture (KN)
P= O*correction factor, it (depends on the E value) according to AASHTO 245 (2015) and ASTM D1559 (1993). Where P= adjusted stability value (KN)
Q= marshal flow value
R= Height of the aggregate-asphalt mixture cylindrical mould
S= ((Ga-F/Ga)-0.10)*100 Where S= volume of air voids % inside the HMA
T= (100-(F*(100-Gb)/Gb)/Gb+F Where T= volume of voids in the mineral aggregate
U= (T-S/T)*100 Where U= volume of the voids filled with asphalt
V= marshal stiffness value (N/mm)

4. Results and Discussion

4.1. Petrographic Study

The Petrographic study for the Shiransh Formation in Pirat (Pt), Harir (H), and Safin (S), Aqra-Bekhme in Shakrok (Sh), the Pil Spi Formation in Pirmam (Pm), the Khurmala Formation in Safin (Sk), the Euphrates Formation in North Qarachugh (QN), and the Qamchuqa Formation in Bana Bawi (BQ) showed that BQ contains dolomitic mudstone microfacies and some calcite with micrite matrix, with low amount of clay coated calcite grains (Fig. 7a). Sh thin sections shows foraminiferal wackestone with sparite matrix and some pyrite grains (Fig. 7b). Pt represents planktonic foraminiferal packstone with micrite matrix, low microcrystalline dolomite and very low pyrite grains (Fig. 7c). S represents planktonic foraminiferal packstone with micrite matrix and low microcrystalline dolomite, pyrite and organic matter (Fig. 7d). H represents bioclastic wackestone with micrite matrix and stylolite filled with organic matter (Fig. 7e). Sk represents dolomitic mudstone with low calcite and micrite matrix (Fig. 7f). Pm represents bioclastic wackestone with high dolomitized grains and low calcite (Fig. 7g). QN represents dolomitized bioclastic wackestone (Fig. 7h) with sparite and low micrite matrix.

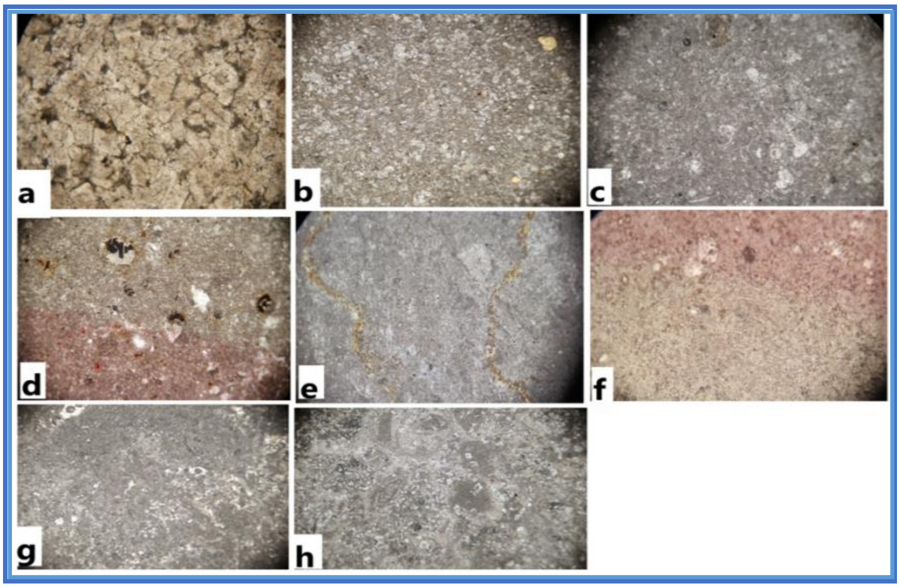


Fig.7. Petrographic study of the selected sections under transmitted light microscope (a); BQ; (b); Sh (c); Pt; (d) S; (e) H; (f) Sk; (g) Pm; (h) QN

4.2. Chemical Study

The chemical analysis of the studied samples shows that (BQ, Sk, Pm, and QN) contain high amount of MgO of nearly 21%, and Sh, Pt, H contain low amount of MgO of nearly 0.4 to 0.6% (Table 3), while S contains slightly low amount of MgO of 6%. Sh, Pt, H, and S contain higher CaO ratio than BQ, Sk, Pm, and QN. SiO_2 are high in BQ, H, and Sk, with Pm contains highest ratio, but Sh, Pt, and S contains low SiO_2. Al_2O_3 and $Fe_2O_3$are low within all of the samples. Na_2O, K_2O, TiO_2, MnO, P_2O_5, SO_3 are low within all samples which are main components of clay represent low amount of clay.

Table 3. Chemical analysis of the selected samples for determining the oxide ratios.

S.No.	BQ	Sh	Pt	S	H	Sk	Pm	QN
SiO_2	2.09	0.70	0.48	0.11	2.13	2.03	4.59	1.45
Al_2O_3	0.49	0.32	0.41	0.05	0.47	0.50	0.64	0.28
Fe_2O_3	0.62	0.06	0.11	0.02	0.14	0.20	0.18	0.11
CaO	29.35	54.57	54.18	50.74	53.23	29.53	27.68	30.54
Na_2O	0.06	0.06	0.04	0.04	0.09	0.07	0.07	0.06
K_2O	0.03	0.02	0.11	0.01	0.02	0.01	0.01	0.01
MgO	21.11	0.65	0.44	6.25	0.63	21.22	21.51	21.58
TiO_2	0.011	0.001	0.003	0.003	0.002	0.008	0.014	0.002
MnO	0.012	0.007	0.009	0.001	0.009	0.060	0.032	0.003
P_2O_5	0.032	0.062	0.115	0.017	0.035	0.010	0.051	0.136
LOI	46.04	43.43	42.98	41.61	43.08	46.06	44.87	46.71
SO_3	0.08	0.02	0.02	0.01	0.01	0.01	0.28	0.04

4.3. Los Angeles Abration Test

Low wear% ratios are desirable in LAS test, which represents that the limestones resistance to abrasion is high. According to American Railway Engineering Associations (Area, 1959) the %wear should be <40%, however according to ASTM C131 (2006) associations <45% accepted, and according to SORB (2013) values of agency link wear% should be <45%. While the Iraqi SORB (2003) recommends <40% wear value. (Sk, Pm, BQ, and QN) showed desirable results of (28, 30, 27, and 32), which are <40%. However (H, Pt, Sh, and S) showed undesirable results of (45, 44, 44, and 43) which are >45% LAS values which are not desirable in HMA road pavements (Table 4), therefore they are neglected. BQ and S with 27 and 28% LAS represent higher resistance to abrasion than Pm and QN with 30 and 32% LAS respectively.

Table 4. Wear% (abrasiveness) of the limestone crushed stone

S.No.	Grade	Original weight gm	Retained weight gm	Wear %	Allowable loss
Pm	B	5000	3483	30	Desirable
Sk	B	5000	3607	28	Desirable
BQ	B	5000	3632	27	Desirable
QN	B	5000	3393	32	Desirable
S	B	5000	2780	43	Non-Desirable
Pt	B	5000	2843	44	Non-Desirable
Sh	B	5000	2922	44	Non-Desirable
H	B	5000	2760	45	Non-Desirable

4.4. Aggregate Gradation and Blending

plotting the Cumulative percentage passing (finer%) in each sieve against the particle size (mm) in semi log paper (Fig. 8), the type of gradation was obtained from the shape of the curve plotted, shows well graded dense mixture blending of various particle size aggregates for obtaining an optimum stability and durability results. The results complied with the Iraqi SORB (2003) specifications.

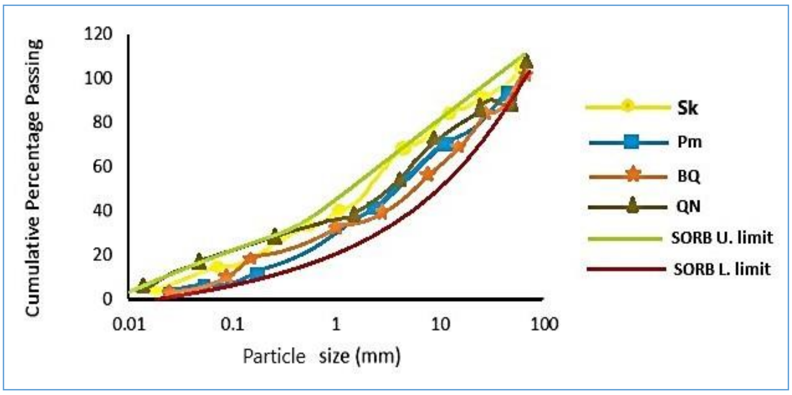


Fig.8. Grading curve of (Sk, Pm, BQ, and QN) aggregates according to Iraqi SORB, 2003

Aggregate-asphalt mixture prepared from crushed limestone of coarse aggregate (4.75-25.4 mm) (Table 5), fine aggregate (0.01- 4.75 mm) (Table 6), and filler (<0.01 mm or 75 µm) according to the Iraqi SORB (State Corporation for Roads and Bridges, 2003).

Table 5. Coarse aggregate size mixture grading according to U.S. sieve sizes

U.S. Sieve Size		Total weight of aggregate passing %	
mm	**Imperial**	**Binder Course**	**Retained weight (gm)**
25.0	1	100	0
19.0	¾	90-100	60
12.5	½	70-90	240
9.5	3/8	60-80	360
4.75	No.4	42-60	588

Table 6. Fine aggregate size mixture grading according to U.S. sieve sizes

U.S. Sieve size		Total weight of aggregate passing %	
mm	**imperial**	**Binder course**	**Retained weight (gm)**
2	No.10	27-47	756
1	No.18	20-37	858
0.6	No.30	15-30	930
0.25	No.60	8-20	1032
0.125	No.120	6-15	1074
0.075	No.200	5-10	1110
filler	Passed No.200	0-5	1200

4.5. Soundness Test Results

4.5.1. Na_2SO_4 and $MgSO_4$ solutions

Soundness test results showed that the selected aggregates are suitable as mature road stone pavement according to ASTM-D 6927 (2020) permits 12% when $NaSO_4$ is used, and 18% when $MgSO_4$ is used (Table 7). It's obvious that QN and BQ have lower freeze and thawing mechanism in both solutions due to their low porosity than S and Pm.

Table 7. % weight loss of limestone aggregates by soundness test

S. No.	% Loss by Na_2SO_4	% Loss by $MgSO_4$
Sk	7	12
Pm	9	15
BQ	5	10
QN	3	8

4.5.2. HCl Solution

HCl reaction test showed that the selected aggregates from Sk,Pm, BQ and QN are not suitable as a mature road stone pavement for wearing course, (Table 8) according to ASTM C 117 (2017) allows 10% loss when HCl used.

Table 8. % weight loss of limestone aggregates by HCl solution

S. No.	% Loss by HCl
Sk	13
Pm	12
BQ	10
QN	11

4.6. Marshal Stability Test

4.6.1. Specific gravity of aggregate

Specific gravity of aggregate (Ga) is between 2.60 to 2.65 gm (Table 9) which are accepted for road pavement according to AASHTO, T 84 & 85 (2007) that require 2.6-3.0 gm.

Table 9. Specific gravity of aggregates (S, Pm, BQ, and QN)

S.No.	Wd (gm)	Wsw (gm)	Wss (gm)	Ga (gm)
Sk	2000	1249	2009	2.63
Pm	2000	1246	2010	2.61
BQ	2000	1220	2004	2.65
QN	2000	1244	2011	2.60

4.6.2. Specific gravity of bitumen

The specific gravity of bitumen is 1 gm which is desirable to be used in heavy duty road pavements according to ASTM D70 (2018) which recommends 0.95-1.05 gm

4.6.3. Specific gravity of the aggregate-asphalt mixture

Table 10 shows result values of the aggregate-asphalt mixture specific gravity ranges from lower value of 2.37 gm/cm^3 for BQ to higher value of 2.44 gm/cm^3 for Sk.

Table 10. Specific gravity of the aggregate- asphalt mixture

S. No.	G (gm)
Sk	2.44
Pm	2.43
BQ	2.37
QN	2.42

4.6.4. OBC, stability, flow, and void % of aggregate-asphalt mixture

The OBC (optimum binder content) for all of the four aggregate types (Sk, Pm, BQ, and QN) with (3.7, 4.2, 4.7, and 5.2%) binder content showed optimum results at 4.7% binder content (Fig. 9 and 10), therefore this binder ratio used within all four aggregates for best results of air voids, flow, VMA % (voids in mineral aggregate), VFA% (voids filled with asphalt).

The total volume of aggregate (I) showed desirable values of 75 and 77% for Pm and QN, while S and BQ showed non-desirable values according to (ISSN, 2021 for roads and bridges) and AASHTO, T165 (2002) that permits 60-80% as a total volume of aggregate. Volume of voids in the aggregate (K) within all four aggregate types are well graded according to the standard specifications of (ISS for roads and bridges) and AASHTO, T165, (2002) which allows >35% for poorly graded and <25 for well graded. The stability ratios (O) for all four aggregates are >7 KN according to Iraqi SORB (2003) and ASTM D 7012 (2014) and ASTM D 3666 (2016), with BQ stability of 37 KN recorded highest value than H, Pm, and QN of 27, 29 and 27 respectively (Fig. 11). Flow results (Q) showed maximum value for QN with 4.44 mm and for S is 4.03 mm which is higher than the Iraqi SORB (2003) standard ratio of 2-4 mm, which makes them susceptible for deformation and deterioration (Table 11) while both Pm and BQ of 3.8- and 3.4-mm flow values are within the standard ratios. The air voids (S) for (Sk and BQ) are within the standard ratio of (3-5%) according to Iraqi SORB (2003) but Pm showed higher air void values of 5.70%, while QN showed lower air void ratio than the standard ratio of 2.31, which is not acceptable for binder course of pavement. The volume of voids in the mineral aggregate VMA % values (T) for all four aggregate samples (Sk, Pm, BQ and QN) are within the standard ratio of >13% Iraqi SORB, 2003. Voids filled by asphalt VFA % (U) for Sk and BQ showed desirable value of 78 and 76% according to AASHTO T165, (2002) which permits (60-80%), while (Pm and QN) with 59 and 83% are not desirable. According to Iraqi Standard SORB (2003) which permits VFA% of (65-75%), then (Sk, Pm, and QN) samples are not desirable, while BQ with 76% is nearly desirable. The stiffness value (V) of Pm and BQ is higher than Sk and QN, which represents that they are deformed less than the former two.

Table 11. HMA design data by Marshall method

S.NO.	A	B	C	D	E	F	G	H	I	J	K
Sk	4.7	1251.0	722.0	1265.0	543.0	2.30	2.48	10.83	83.48	5.69	16.52
Pm	4.7	1237.0	682.0	1243.0	561.0	2.20	2.43	10.36	75.05	14.59	24.95
BQ	4.7	1231.0	676.0	1232.0	556.0	2.21	2.37	10.39	82.59	10.14	20.50
QN	4.7	1212.0	709.2	1240.0	530.8	2.28	2.58	10.73	77.72	11.55	22.28

Table 12. HMA design data by Marshall method

S.NO.	L	M	N	ō	O	P	Q	R	S	T	U	V
Sk	65.56	7.25	2.30	0.93	27.61	25.68	4.03	63	3.00	13.65	78.02	5292
Pm	41.53	9.12	2.20	0.86	29.68	25.52	3.89	63	5.70	13.98	59.22	6073
BQ	50.68	6.76	2.21	0.89	36.68	32.64	3.42	63	3.33	13.95	76.14	8835
QN	48.16	11.55	2.28	0.96	27.20	26.11	4.44	63	2.31	13.72	83.16	4835

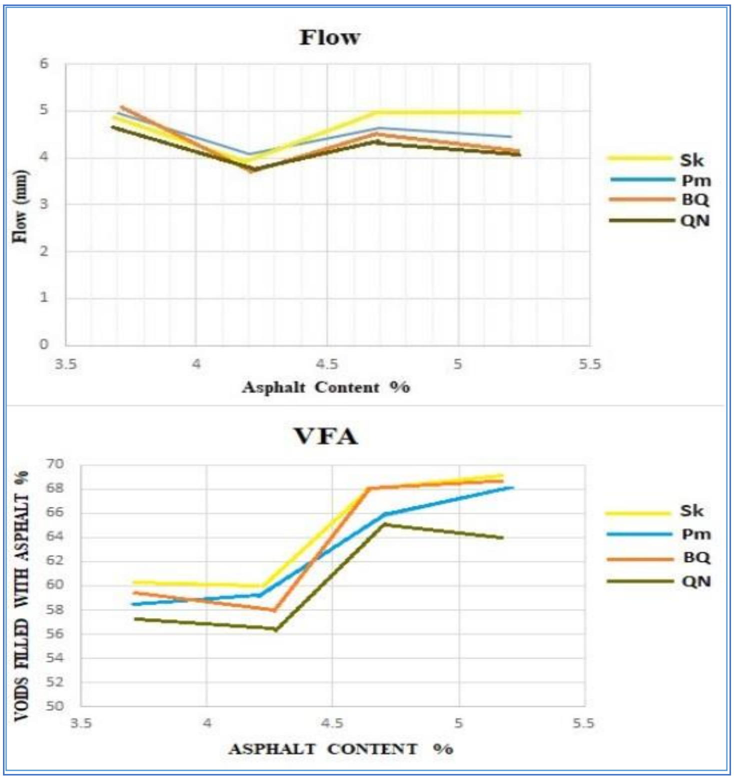


Fig.9. the aggregate-asphalt mixture showed OBC of 4.7% for flow, and VFA in (Sk, Pm, BQ, and QN) samples

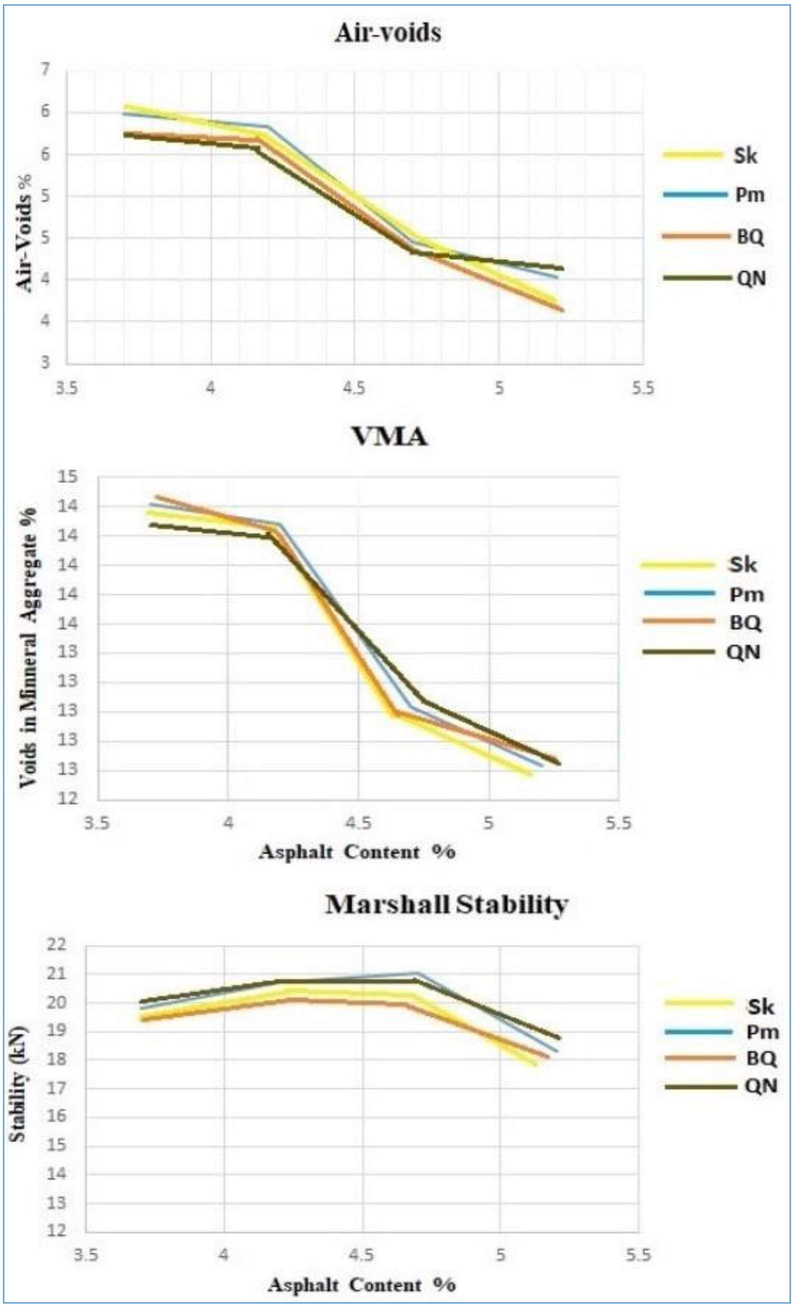


Fig.10. the aggregate-asphalt mixture showed OBC of 4.7% for air-voids, VMA, and Marshall stability in (Sk, Pm, BQ, and QN) samples

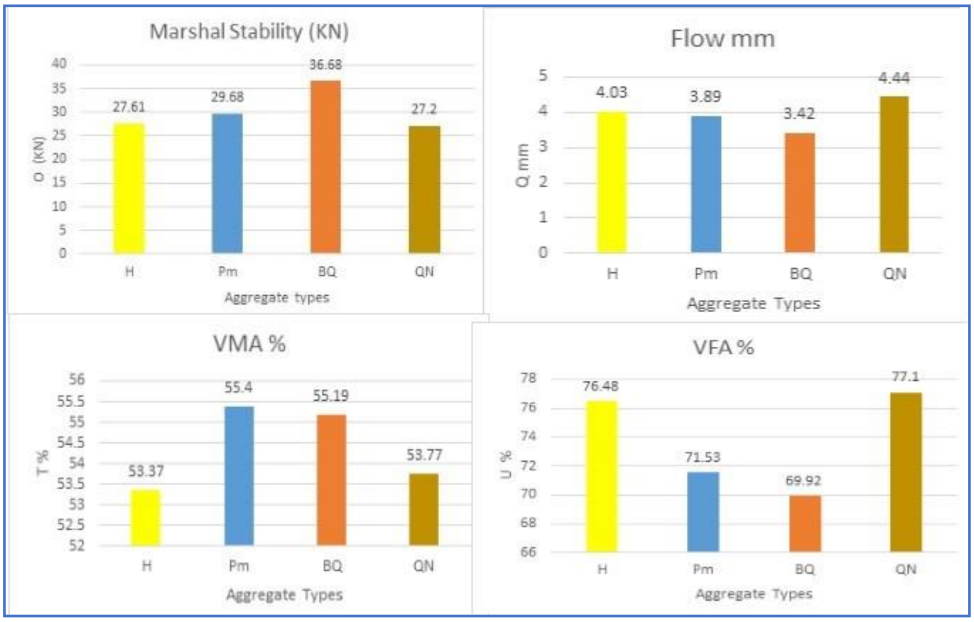


Fig.11. Marshall stability test data design for Sk, Pm, BQ and QN

5. Conclusions

From the evaluation of eight different limestone aggregates (Sk, Pm, BQ, QN, H, Pt, Sh, and S) the LAS abrasion test showed that only Sk, Pm, BQ, and QN have optimum abrasion values <40% wear, due to their high dolomite (MgO) and silica (SiO_2) ratio according to petrographic and XRF test. These four aggregates are selected for Marshall test in order to evaluate their stability, flow, air void, VFA, and VMA%, with 4.7% OBC selected for preparing the aggregate-asphalt mix, BQ showed optimum values within all of the Marshall standards, Pm and Sk showed desirable values with lesser extends, since Pm takes advantage in flow values, VMA and stiff values, while Sk takes advantage in air void, VMA and VFA, while QN only showed advantage in stability values and VMA. (Sk, Pm, BQ, and QN) are not suitable in wearing course due to low resistance to HCl, but they can withstand Na2SO4 and $MgSO_4$, which they can be used as binder and base course without adding fly-ash, lime, rubber, polymer, slag, and basalt fibers as a treatment. Economically limestone uses in HMA as a base and binder coarse increases the resistance to fracture and stiffness of the road pavement due to its high stripping ratio, which adhere well with the bituminous, without the need of anti-stripping treatment by hydrated lime like the case when sand and gravel used as a road pavement, limestone is responsible for changing the oxidation chemistry in the binder that decreases age hardening, cubical shape can be easily obtained in limestone aggregates by crushing however the same case is difficult to be obtained with hard, rounded edge sand and gravel aggregates. Limestone quarried easily without land ruining, however sand and gravel obtained along the rivers, which by the time tend to redirect and destroy the river.

References

AASHTO, T 245., 1990. Association of state highway and transportation officials. Standard specification for transportation materials and methods of sampling and testing.

AASHTO, T 283., 1996. Standard method of test for measurement of vehicular response to traveled surface roughness, 20th Edition, American Association of State Highway and Transportation Officials.

AASHTO, T 96 and 99., 2002. Standard method of test for resistance to degradation of small-size coarse aggregate by abrasion and impact in the Los Angeles Machine, 27th Edition, American Association of State Highway and Transportation Officials.

AASHTO, T 165., 2002. Standard method of test for effect of water on cohesion of compacted bituminous mixtures. standard specifications for transportations materials and methods of sampling and testing, 27th Edition, American Association of State Highway and Transportation Officials.

AASHTO, T 85., 2007. Specific gravity and absorption of coarse aggregate. standard specifications for transportations materials and methods of sampling and testing, 27th Edition, American Association of State Highway and Transportation Officials.

AASHTO, T 104., 2007. Soundness of aggregate by use of sodium sulfate or magnesium sulfate. standard specifications for transportations materials and methods of sampling and testing, 27th Edition, American Association of State Highway and Transportation Officials.

AASHTO, T 245., 2015. Standard method of test for resistance to plastic flow of asphalt mixtures using marshall apparatus, 27^{th} Edition, American Association of State Highway and Transportation Officials.

AASHTO, T 312., 2019. Standard method of test for preparing and determining the density of asphalt mixture specimens by means of the superpave gyratory compactor, 27^{th} Edition, American Association of State Highway and Transportation Officials.

Ahmed, H. Y., Hashem, M. D., Rashwan, N. K., Abdalla, S. A., 2014. Investigation of aggregate particles shape. Journal of Engineering Sciences Faculty of Engineering, 42, 1349-1366.

Ahmed, M. A., Attia, M. I., 2013. Impact of aggregate gradation and type on hot mix asphalt rutting in Egypt. International Journal of Engineering Research and Applications, 3(4), 2249-2258.

Al Yousify, S., Taher, S. M., 2021. An evaluation of the effect of aggregate type on hot mix asphalt properties in Kurdistan Region of Iraq. Journal of University of Duhok (Pure and Engineering Sciences), 24 (2), 124-135.

Anderson, D. A., Dukatz E. L., Petersen J. C., 1992. Asphalt paving technology. Pennsylvania State Univ, PA, USA, 51, 298-30.

Area, 1959. Specifications for prepared stone, slag and gravel ballast, in Manual for Railway Engineering. American Railway Engineering Association, Chicago, 1-4.

ASTM, D1559., 1976. Resistance to Plastic Flow of Bituminous Mixtures using Marshal Apparatus. Book of American Standard of Testing Materials, 4 (20), 1-5.

ASTM, D1559., 1993. American Society for Testing and Materials (Highways and Transportation). Annual Book of ASTM, 4 (2), 3-7.

ASTM, C702., 1998. Standard Practice for Reducing Samples of Aggregate to Testing Size. Book of American Standard of Testing Materials, 4 (2), 77.

ASTM, C127., 1999. Specific Gravity and Absorption of Aggregates. Annual Book of ASTM Standards, 4 (2), 4-9.

ASTM, D3398, 2000. Standard Test Method for Index of Aggregate Particle Shape And Texture. Annual Book of ASTM Standards.

ASTM, C131, 2001. Standard Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. Annual Book of ASTM Standards., 4 (2), 63.

ASTM C88-99a., 2003. Test Method for Soundness of Aggregates by Use of Sodium Sulfate or Magnesium Sulfate, Annual Book of ASTM Standards., 4 (2), 42–46.

ASTM, D3549, 2003. Standard Test Method for Thickness or Height of Compacted Bituminous Paving Mixture Specimens, Annual Book of ASTM Standards., 4 (2), 87–88.

ASTM, C131., 2006. Test Method for Resistance to Degradation of Small-Size Coarse Aggregate by Abrasion and Impact in the Los Angeles Machine. Book of American Standard of Testing Materials., 4 (2), 37-40.

ASTM, C136., 2006. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates. Annual Book of ASTM Standards., 4 (2), 37.

ASTM, D7012., 2014. Standard Test Method for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperatures, Annual Book of ASTM Standards., 4 (2), 1–9.

ASTM, D1188., 2015. Standard Test Method for Bulk Specific Gravity and Density of Compacted Bituminous Mixtures Using Coated Samples, Annual Book of ASTM Standards., 4 (7), 120.

ASTM, C295., 2016. Standard Test Method Guide for Petrographic Examination of Aggregtaes for Concrete. Annual Book of ASTM Standards., 4 (2).

ASTM, D3666., 2016. Standard Specification for Minimum Requirements for Agencies Testing and Inspecting Road and Paving Materials. Annual Book of ASTM Standards., 4 (7), 11.

ASTM, C117., 2017. Material Sieve analysis in Mineral Aggregates of Fine and Coarse Aggregates to Testing Size. Book of American Standard of Testing Materials.

ASTM, D2726., 2017. Standard Test Method for Bulk Specific Gravity and Density of Compacted Asphalt Mixtures. Book of American Standard of Testing Materials.

ASTM, D70., 2018. Standard Test Method for Density of Semi-Solid Asphalt Binder (Pycnometer Method). Book of American Standard of Testing Materials.

ASTM, E11., 2020. on Quality & Statistics of the appropriate use of sieving control methods related to materials production and use. Annual Book of ASTM Standards., 4 (2), 33.

ASTM, D6927., 2020. Standard Practice for Preparation of Asphalt Mixture Specimens Using Marshall Apparatus. Annual Book of ASTM Standards., 4 (2), 23.

ASTM, D6931., 2020. Standard Test Method for Indirect Tensile (IDT) of Strength of Bituminous Mixtures., 4 (2), 57.

Bellen, R. C., Dunnington, H. V., Wetzel, R. F., Morton, D., 1959. Lexique Stratigraphique International Asie. Iraq. International Geology Congress Stratigraphy, 10a, 333.

Cui, S., Bamber, R. K., Anthony. J., 2014. Durability of asphalt mixtures. effect of aggregate type and adhesion promoters. International Journal of Adhesion and Adhesives, 54, 100-111.

Friedman, G. M., 1965. Terminology of crystallization textures and fabrics in sedimentary rocks. Journal of Sedimentary Research, 35, 643-655.

Judele, L., 2011. The Mechanism of Bitumen Adhesion to Aggregates, The Influence of Mineralogic Nature. Technical University of Iaşi, Faculty of Civil Engineering and Building Services.

Mahmoud, A. H., 2014. Effect of aggregate gradation and type on hot asphalt concrete mix. Journal of Engineering Science Assuit University, Faculty of Engineering, 42 (4), 567-574.

Meininger, R. C., 2002. Validity of the Sulfate Soundness Test.

Pandit, A., Mistry, R., Roy, T. K., 2019. Effect of aggregate type on marshal properties of bituminous mix containing fly Ash as filler. AIP Conference Proceedings, 21-58.

Parker, F., Kandhal, K., 2004. Aggregate toughness, abrasion resistance, durability, and soundness tests related to asphalt concrete performance in pavements. NCAT National Center for Asphalt Technology, 94-98.

Prowell, B. D., Zhang, J., Brown, E. R., 2005. Aggregate properties and the performance of Super pave design Hot Mix Asphalt. Transportation Research Board.

Sissakian, V.K., 2000. Geological Map of Iraq, Scale 1:1000000. 3rd Edition, Iraq Geological Survey Publications, Baghdad.

Sissakian, V. K., Hamoodi, D. A., Omer, H. O., and Nyazi, S, A., 2019. Assessmrnt of the carbonate rocks of the Pila Spi Formation for cement industry, in Permam Mountain, Erbil, Iraq Kurdistan Region. UKH Journal of Science and Engineering, 3 (1), 1-9.

Schiffner, H. M., 2003. Test method for determining hydrated lime in asphalt Cement- Lime- Gypsum International, 56 (6), 76-82.

SORB, R9, 2003. General Specifications for Roads and Bridges. Hot Mix Asphaltic Concrete Pavement. Baghdad, Department of Planning and Studies, Republic of Iraq, Ministry of Housing and Construction.

SORB, R3, 2013. General Specifications for Roads and Bridges. Hot Mix Aspahltic Concrete Pavement. United States for Roads and Bridges.

Wallace, H. A., Martin, j. r., 1962. Asphalt Pavement Engineering. McGraw-Hill Inc, US Book, 357.

Widayanti, A., Soemitro, R, A., Ekaputri, J, J., Suprayitno, H., 2018. Characterization of Reclaimed Asphalt Pavement (RAP) as a Road Pavement Material. Matec Web of Conferences. Institut Tecnologi Sepuluh. Civil Engineering Dept. Indonesia, 181.

Williams, S. G., Cunningham, J. B., 2012. Evaluation of Aggregate Durability Performance Test Procedures., TRC-0905, 77.

Zaenuri, M., 2018. Research on the use of limestone as a rough aggregate and filler on mixedasphalt. UK, 2, 32-46.