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ismael Azeez Mohammed
Department ofHighway and bridge,Duhok Technical Engineering college,
ismailazizmuhammed@gmail.com

Faris Mohammed Jasim
Department of Highway and bridges, faris.jasim@epu.edu.iq

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Keywords

Crushed Aggregate, Aggregate Angularity, Volumetric Properties, Harsh mixture HMA

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RESEARCH ARTICLE

Comparison of Full Crushed Aggregate (Harsh Mix of Sandstone) and Partially Crushed Aggregate on some Properties of HMA

Faris Mohammed Jasim[1], Ismael Azeez Mohammed[2]
[1]Department of Highway and bridge, Erbil Technical Engineering College, Erbil Polytechnic University, Erbil, Kurdistan Region, Iraq
[2]Department of Highway and bridge, Duhok Technical Engineering college, Duhok Polytechnic University, Duhok, Kurdistan Region, Iraq.

***Corresponding author:**
Faris Mohammed Jasim
Department of Highway and bridge, Erbil Technical Engineering College, Erbil Polytechnic University, Erbil, Kurdistan Region, Iraq
E-mail
Faris.jasim@epu.edu.iq

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ABSTRACT

Aggregate angularity has an important effect on the performance of HMA. More angular aggregates particles can increase the stone-on-stone interlocking and consequently reduce the permanent deformation. The performance of dense graded asphalt mixture is significantly influenced by the angularity, shape, and surface texture of aggregates. This study determines the effect of using Harsh aggregate (full crushed) and normal aggregate in asphalt mixture, and evaluates the volumetric properties of both mixtures. Marshall Test was carried out in order to assess the resistance of stability of mixtures. It was found that a mixture with harsh aggregate needs (0.2 %) more asphalt compared to normal aggregate. Harsh aggregate induced higher stability and stiffness (12%) and (35%) respectively, compared to normal aggregate. VFA and VMA of full crushed aggregate are more than (13%) compared to VMA% of the normal mix. Therefore, it can be concluded that full crushed aggregate with a more angular shape, provides better stability and stiffness, and increases rutting resistance.

Keywords: Crushed Aggregate, Aggregate Angularity, Volumetric Properties, Harsh mixture HMA.

1. INTRODUCTION

Hot-mix asphalt (HMA) contains a large percentage of mineral aggregate, usually 95% by weight and 80% to 90% by volume. The angularity of aggregates has a significant impact on the performance of asphalt mixtures. Generally, compaction effort is not specified in most asphalt mix design approaches based on aggregate angularity. The aggregate angular shapes are very important in determining HMA Volumetric properties such as Void in Mineral Aggregate VMA, Void Filled with Asphalt VFA, and air voids VA. The mixture's performance includes stiffening, stability, moisture damage, and rutting resistance. It is worth noting that the shape, surface texture, and angularity of mineral aggregate have a considerable impact on the mixture's behavior. The aim of this study is to evaluate the effect of full crushed aggregate on HMA and determine the importance of using harsh aggregate in asphalt concrete to reduce rutting and give better performance than normal mix.

2. LITERATURE REVIEW

Many studies have been undertaken to study the effect of aggregate angularity on the characteristics of asphalt mixtures. (Marks, et al. 1990) investigated the impact of crushed particles on asphalt mixtures. Their research project aims to develop connections between the percentage of crushed particles and pavement rutting resistance using a variety of laboratory test methods. The goal was to examine asphalt blends with varying percentages of crushed particles made from limestone, crushed gravel, and quartzite. Using varying Asphalt Cement AC contents, they infer that increasing the crush percentage improves rutting resistance. The amount of crushed particles has a large influence on the percentage of AC resulting in 4% voids. Furthermore, until there is an excess of AC in the mixture, the percentage of AC in the mixture has no effect on Marshall's stabilities. (Button, et al. 1990; Golalipour *et al.*, 2012) studied the influence of aggregate on the rutting of asphalt pavement. They discovered that the main causes of rutting were excessive bitumen content, excessive fine aggregate, and particles with rounded shapes and smooth textures aggregate that hasn't been crushed, in addition; aggregate gradation affects the permanent deformation of hot mix asphalt. (Lu, X y Isacsson, 2001) his research has found that rutting occurs as a result of cumulative plastic temperature deformation caused by high traffic loads and that high temperature arises when the road lacks sufficient stability of the asphalt material at the surface layer. (Ramli *et al.*, 2013) did research about Fine Aggregate Angularity (FAA) and its effects on the rutting resistance of asphalt mixture, using 80-100 penetration grade AC. Granite and hydrated lime (calcium hydroxide) was used as coarse aggregate and filler respectively, with dense-graded HMA. Using the Marshall method of mix design, determining volumetric properties of the mix, also using a dry wheel tracking test. They conclude that increased stiffness, as shown by higher stability, indicates that the mixture is more resistant to permanent deformation. When compared to natural sand with a smooth surface and spherical shape, the rough surface texture has contributed to better rutting resistance. (Mallick *et al.*, 2009) show that asphalt mixtures with a higher percentage of fractured faces may improve rut resistance.

The effect of fine aggregate angularity (FAA) on the densification characteristics of asphalt mixtures was evaluated with the Superpave gyratory compactor (SGC) by (Stakston, et al., 2002). Aggregates from three different sources were used and analyzed with AC of PG 58-28. Analysis of results has shown that the effect of the FAA is highly dependent on aggregate sources. The results show a constant trend of increasing compaction resistance with higher FAA values, indicating that setting a target FAA value and assuming that it is appropriate for all sources and gradations is not very practical. It also shows that the effect of FAA on improving HMA quality by reducing the energy required for compaction rolling and boosting resistance to densification is strongly dependent on other mixture properties and the range of FAA values.

Because the shear resistance of HMA comes from two parts: aggregate interlocking and cohesion provided by the asphalt binder, the relation of Coarse Aggregate Angularity CAA to the laboratory rutting performance of a dense-graded surface-wearing mixture were studied by (Serkmeister, 2006; Kim and Souza, 2009) Mixtures with different levels of crushed gravel with the same gradation and two types of asphalt binder (PG64-22 and PG76-22) were selected for the mixtures. The study's findings revealed that CAA has a substantial impact on the rutting performance of HMA when the binder grade is highly related to the environmental temperature. The effect of CAA of less angular coarse aggregate on the rutting performance of HMA was proportional to the mixture depth.

(Sengoz, et al., 2014) determined that there is undoubtedly a close association between pavement surface texture and aggregate angularity within the wearing course.

(Huang *et al.*, 2009) performed research on the effects of coarse aggregate angularity and asphalt binder on deformation. Preparing mixes for laboratory rut analyses, three different asphalt binders were tested, to create mixtures with similar aggregate gradations, coarse gravels at five different angularity levels of aggregate were used. When a soft binder was used in the study, the results showed that CAA had a noticeable effect on the laboratory rutting performance of HMA mixtures. Temperatures also played an important role in the rut resistance of HMA.

The angularity of aggregate is one of the most important parameters in asphalt mix design because it plays a critical role in asphalt mixture performance. (Polaczyk *et al.*, 2019) defined aggregate angularity as the sharpness of an aggregate particle's corners (see Fig. 1 aggregate characteristics). A study with PG 64-22 Asphalt cement used two compaction methods: gyratory (Superpave Gyratory Compactor) and impact (Marshall Hammer). Mixtures made entirely f crushed aggregates had much lower locking points than mixtures made entirely of uncrushed aggregates.

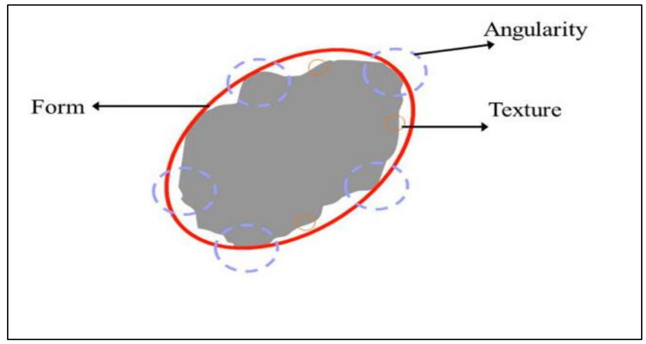

Fig. 1. The concept of aggregate characteristics

3. MATERIALS AND METHODS

3.1. Asphalt cement

Asphalt cement Penetration grade 40-50 was used in this study which is equivalent to PG 70-16tested by Duhok Construction Laboratory. The rheological properties of bitumen were investigated and shown in Table 1 with specifications.

TABLE 1. Binder Rheological Properties

Rheological Properties	Results	Unit	SCRB specification 2003	ASTM Designation No.
Penetration	43	1/10 mm	40-50	D-5-13
Ductility	160	cm	> 100 cm	D-113-17
Softening point	52	°C	---	D-36-14
Flash point	271	°C	> 232	D-92-16
Specific Gravity	1.03	---	---	D-70-97
Penetration of Residue	27	1/10 mm	> 55%	D-5-13
Ductility of Residue	28	cm	> 25 cm	D-113-17
Softening point of Residue	61	°C	---	D-36-14

3.2. Aggregates

Two types of aggregates were used in this research, the first one which is the normal locally used material, which has nearly 91% crushed aggregate, was supplied by Hakar and Bakr Company near Deraboon. The second type of aggregate which is fully crushed (100%) Sandstone aggregate, pure bolder more than 3 inches as shown in Fig. 2 was supplied from a local crusher called Tahir close to Zakho city. Both types of aggregate are from the Khaboor river. The properties of both aggregates are seen in Table 2. The aggregate gradation was designed base on dense graded according to Iraqi Standard Specification for Roads and Bridges (SCRB), taking midpoint of upper and lower limits of specification of Type IIIA Surface or Wearing Course, as shown in Fig. 3

Fig. 2. Bolder dimeter more than 3 inches

TABLE 2. Aggregate Properties

Aggregate Properties	Normal Aggregate		Harsh Aggregate	
	Coarse Aggregate	Fine Aggregate	Coarse Aggregate	Fine Aggregate
Bulk specific gravity	2.663	2.640	2.659	2.641
Apparent specific gravity	2.724	2.720	2.719	2.717
Water absorption	0.73 %	1.12 %	0.83 %	1.15 %
Toughness	22%	-	20%	-

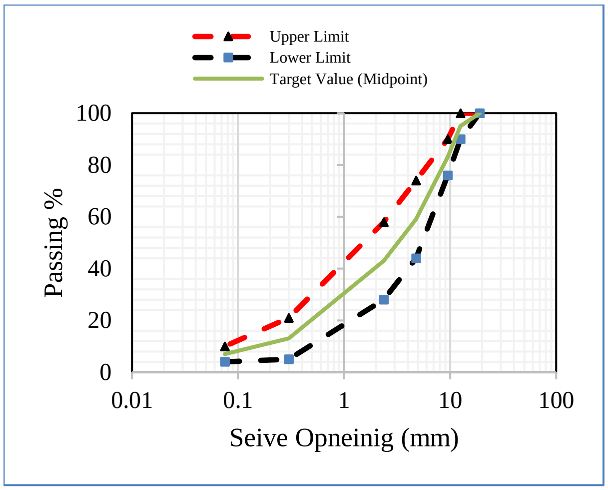

Fig. 3. Aggregate gradation for both type of mixture

3.3. Mixture design

The procedure used to determine the Optimum Asphalt Content OAC is the Marshall Mix Design method according to ASTM D6926-16. The parameters included stability, flow, density, stiffness, air voids VA, void in mineral aggregate VMA, and the void filled with asphalt VFA. Samples were prepared and compacted according to the specification whith75 blows on each side.

3.4. Consensus properties of aggregate

Consensus properties which include, Coarse Aggregate Angularity (CAA) Fine Aggregate Angularity (FAA), and Flat and Elongated Particles, have to take into account.

3.4.1. Coarse Aggregate Angularity

This test was conducted on both aggregates according to ASTM D5821. Measuring the CAA for normal aggregate, as known according to Iraqi specification needs to be at least one crushed face of the aggregate particles. As seen in fig. 4 (A), the aggregate particles for normal aggregate include rounded edges and smooth surface particles. As opposed to harsh aggregate which contains at least three or four fracture faces, cubic shapes, sharp edges, and rough surfaces, as shown in fig. 4 (B).

Fig. 4: Materials used in CAA tests. A) Normal aggregate particles, B) Harsh aggregate particles

The percentage of coarse aggregate particles with fractured faces is used to calculate coarse aggregate angularity. The mass percentage of particles CAA with the specified number(s) of fractured faces is calculated according to Equation (1).

$$CAA = \left[\frac{F}{(F+N)}\right] \times 100 \quad (1)$$

Where:

CAA: Coarse aggregate angularity in percentage.

F: Mass in (grams) of fractured particles with specified number of fractures faced.

N: Mass or count of particles in the non-fractured category.

3.4.2. Fine Aggregate Angularity

Uncompacted Void content of fine aggregate or Fine Aggregate Angularity (FAA) was conducted according to ASTM C1252 and measured uncompacted void content of fine aggregate for both materials. The percent of voids determined by this test with the assumption that the material has angularity, roundness, or surface texture is an indication of its angularity, roundness, or surface texture, the higher the void content, the higher the angularity and rougher the surface of fine aggregate (Kim and Souza, 2009). Moreover, several studies have shown that the effect of fine aggregate angularity (FAA) is greater than that of coarse aggregate angularity (CAA). Fig. 5 shows the preparation of the test. The value of FAA was calculated using Equation (2).

$$FAA = \left[\frac{V-\left(\frac{F}{G}\right)}{V}\right] \times 100 \quad (2)$$

Where:

FAA: Fine Aggregate Angularity in percentage. (Uncompacted voids)

V: Volume of calibrated cylinder in mL.

F: Net weight of sample in cylinder in grams.

G: Bulk dry specific gravity of fine aggregates

Fig. 5. FAA apparatus test

3.4.3. Flat and elongated particles

This test method is conducted to determine flat and elongated particles in both Normal and Harsh aggregate according to ASTM D4791. (Buchanan, 2000) flat and elongated particles affect the strength and tendency to break down during construction and traffic, resulting in placement and consolidation. Samples of test preparation are shown in fig. 6, then calculating the percentage of both aggregate size fractions.

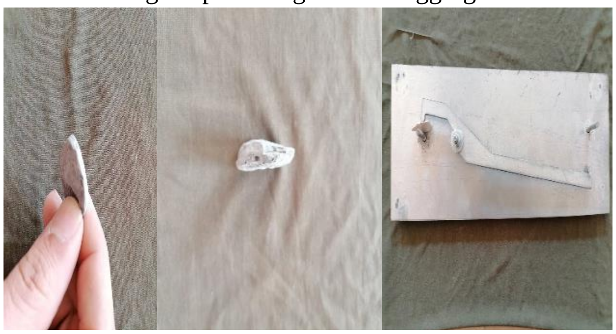

Fig. 6. Proportional caliper Apparatus to identify flat and elongated particles

4. RESULTS AND DISCUSSION

Table 3 shows the result of CAA and FAA for both types of aggregate. From the tests, the value of CAA for the normal aggregate is less than that for the harsh aggregate. The angularity of the normal aggregate is 91% and 100% for the harsh aggregate. Thus, more aggregate angularity gives more stone-to-stone coarse aggregate skeleton. The same table shows the value of FAA for the harsh aggregate is higher than the normal aggregate. The percentage of uncompacted voids is 42% and 32% for harsh aggregate and control aggregate accordingly. As a result, the higher the fine aggregate angularity values, the more angular the particles with rougher surface texture. For flat and elongated particles, the result shows in Table 3, that the harsh aggregate contains 0% of flat and elongated particles, but for normal aggregate, it is 13% (standard minimum of Superpave consensus must be less than 10%). This means that a harsh aggregate results in no flat or elongated particles but mostly cubic shaped, and thus less rutting, more interaction between particles hence more durable, compared to normal one which is highly affected to rutting and consolidation.

TABLE 3. Result of CAA, FAA, and Flat and elongated particles tests

Consensus Properties of aggregate	Normal Aggregate	Harsh Aggregate
Coarse Aggregate Angularity (CAA)	91%	100%
Fine Aggregate Angularity (FAA)	32%	42%
Flat and Elongated Particles	13%	0%

The result of Marshall Stability, Flow, Density and the volumetric properties of both mixtures Normal HMA and Harsh (Full Crushed Aggregate) are shown below in both Fig. 7 and Fig. 8 respectively.

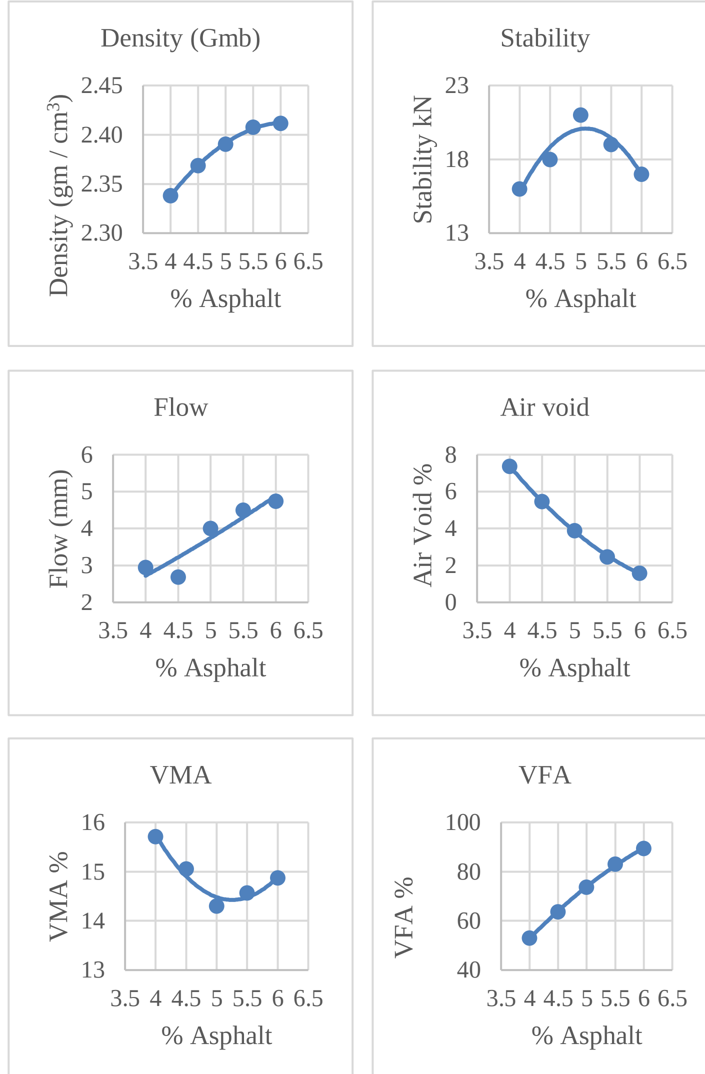

Fig. 7. The result of Normal Mixture HMA Properties

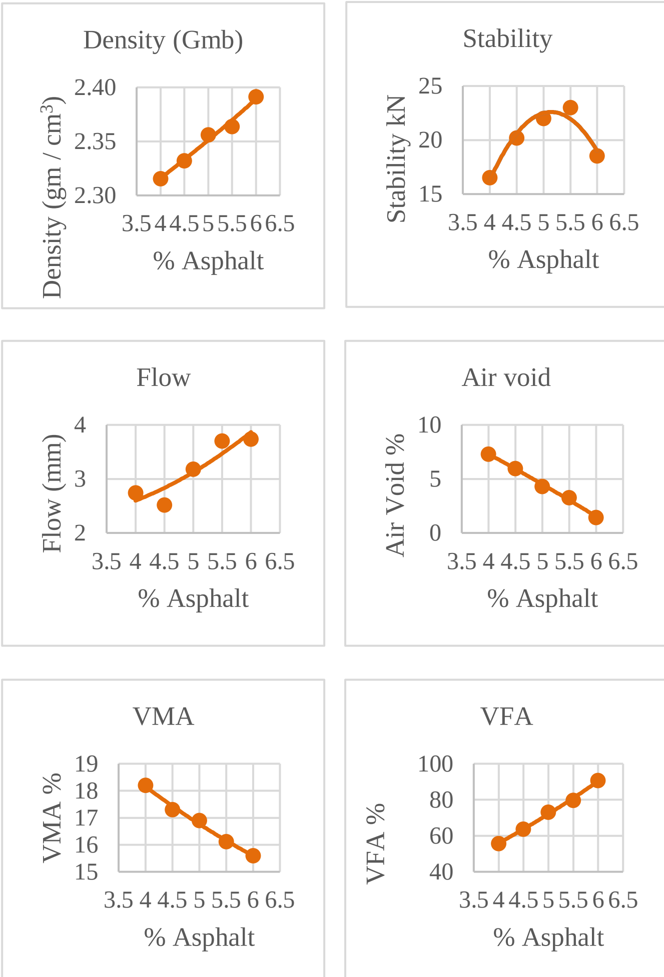

Fig. 8. The result of Harsh Mixture HMA Properties

The effect of full crushed aggregate on Marshall volumetric properties is shown in Table 4. The surface texture and shape of aggregate affect asphalt mix properties which include stability, flow, durability, stiffness, permeability, and air voids in the mixture. Although it affects its workability at optimum asphalt content. It was found that the optimum asphalt content for the control mix with normal aggregate and the harsh mix is 5% and 5.2% accordingly. The OAC is determined to take 4% air voids in the mix. At asphalt content of 5.2% for harsh aggregate, the mixture gives more stability and stiffens for harsh mix compared to normal mixture due to its cubic, rough shape resulting in better interlocking particles. The stiffness is determined as stability divided by the flow of mixtures, see Equation (3). As seen in Table 4 harsh mix has greater stiffness than the normal mix. Higher stiffness as indicated by lower flow shows that the mixture has greater resistance against permanent deformation. At that asphalt content, 5.2% mixture with full crushed aggregate contains 13% more VMA compared to the normal mixture. Which is to use more Asphalt Cement for the harsh mix to achieve low air voids content that could be a result of the better interlocking particles. The stiffness of the mixture determines the interlocking behavior of the mixture hence resulting in better performance of the pavement. This is supported by a higher value of VFA of harsh mix 75.5%, which is 3.4% more than normal mix, which describes the good bonding or better aggregate coating that will give better durability.

$$Stiffness = \frac{Stability(kN)}{Flow(mm)} \quad (3)$$

TABLE 4. Comparison of Marshall properties between Normal and Harsh mixture

Mixture properties	Normal mix	Harsh mix
Asphalt Content (Pb) (%)	5	5.2
Stability (kN)	20.1	22.5
Flow (mm)	3.8	3.3
Air Voids (%)	4	4
VMA (%)	14.5	16.5
VFA (%)	73	75.5
Stiffness (kN/mm)	5.3	6.8

5. CONCLUSION

From this investigation, it can be concluded the following:

1. Coarse aggregate angularity and Fine aggregate angularity of harsh mix are higher than normal mix. Also, the harsh mix does not contain any flat and elongated particles.
2. The percentage of uncompacted voids is 42% for harsh and 32% for normal mix due to the regulation of shapes and texture surface.
3. Harsh mix needs 0.2% more OAC than a normal mix (5% to be 5.2%).
4. Stability of the harsh mixture is 12% more than a normal mixture.
5. Harsh mix has high stiffness 35% more compared to normal mix, and this is a good indication of rut resistance. Better performance in service lives and need of less maintenance.
6. VMA and VFA for the harsh mix is (13% and 4% consequently) more than for the normal mix hence more workability, more durable mix with high performance (less rutting, high skid resistance).

6. RECOMMENDATION

1. The research recommends use the complete crushed aggregate resulting from crushing boulder gravel to ensure the crushing rate.
2. In addition, it is recommended to conduct research to achieve the addition of lower percentages of the modified materials to the asphalt mixture, such as polymers, as a result of using the full complete crushed aggregates compared to the less crushed normal mixtures.

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