Evaluation of hot mix asphalt resilient modulus based on aggregate morphological properties

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Abstract. The standard material used to construct flexible pavement is aggregate. Hot mix asphalt consists of 85 to 95 percent by weight and 75 to 85 percent by volume mineral aggregate, and hot mix asphalt properties and performance are highly affected by these aggregates' morphological properties. One of the most important variables determining the structural number, according to AASHTO design procedures, is the Resilient Modulus of these paving mixtures. In this research, coarse aggregate characteristics such as particle shape (cubical, blade, and disk), particle gradation (upper, middle, and lower specification limits), and surface texture (smooth and rough) were studied to explain their effects on the value of the resilient modulus. To achieve the goal of this study, Marshall Criteria were used to prepare the asphalt concrete mixture at the surface layer at its optimum asphalt content. Using a UTM25 device at a 40˚C test temperature and a 200 ms load duration per ASTM D1234 designation, the resilient modulus was then tested. The findings indicate that aggregate morphological properties highly affect hot mix asphalt's resilient modulus. Aggregate gradation had the most significant effect on the value of resilient modulus, followed by aggregate particles shape, and then, finally by surface texture.

Key words: Hot Mix Asphalt, Aggregate Morphological Properties, Marshall Criteria, Resilient Modulus.

1. INTRODUCTION

The quality of the aggregates used in its creation significantly impact the performance and characteristics of hot mix asphalt due to the high percentage of this material used. When preparing and designing a high performance flexible pavement, an understanding of aggregate properties is thus vital. Many researchers have studied the effects of aggregate morphological properties on hot mix asphalt and pavement performance.

[1] explained that the stability of hot mix asphalt is increased when crushed gravel is used over mixtures with uncrushed gravel. [2] presented the idea that permanent deformation properties are significantly affected by the percentage of crushed coarse aggregate particles used, and that hot mix asphalt rutting possibilities increase as the percentage of crushed coarse particles decreases. [3] established that mixing particles of cubical shape obtained the best resistance to rutting over particles of different shapes; in particular, mixtures with flaky and/or elongated aggregate particles decreased the resistance to shear deformation. [4] found that up to 19 percent flat and elongated particles in the crushed aggregates did not have an adverse effect on the hot mix asphalt volumetric properties, however, and [5] established that the stability, density, and air void for mixtures with cubical aggregates were significantly affected more than the other Marshall properties.

[6] indicated that mixtures prepared with cubical particles showed increased Marshall Stability values of up to 20 percent, and the particle index value of coarse aggregates affected the engineering properties of hot mix asphalt.
[7] noted that Marshall Stability (MS) and bulk density increase when using rough crushed and cubical gravel over using smooth uncrushed and disk or blade shape gravel. Indirect Tensile Strength (ITS) and stiffness modulus also increase when using cubical aggregate shapes rather than when using blade or disk shapes, decreasing failure strain.

2. AIMS OF THE STUDY
The main purposes of this research are to
1. Study the Marshall properties of hot asphalt mixtures prepared with different types of aggregates (varying in gradation, surface texture, and shape).
2. Evaluate the aggregate morphological properties' effects on the hot mix asphalt resilient modulus.

3. MATERIALS SELECTED
Asphalt cement of 40 to 50 penetration grade produced by the Al-Dura refinery was used in this study; the physical properties of this asphalt are explained in Table 1.

Coarse crushed aggregate, uncrushed river gravel, and fine aggregate crushed quartz were examined in this research; Table 2 shows the main physical properties of these aggregates. Figure 1 explains the gradations used (Lower, Middle, and Upper Limits) based on the specifications of SCRB, 2003/ R9, requirements of surface course gradation type IIIA. Table 3 shows the physical properties of limestone dust, prepared in the Karbala government factory, which is used as a mineral filler.

| Test D-1754 After Thin Film Oven |
|----------------------------------|
| - RP% of original               |
| D.5                              |
| 59.76                            |
| More than: 55                    |
| - D @ 25° C, 5 cm/min.( cm)      |
| D.113                            |
| 62                               |
| More than: 25                    |

Pen.: Penetration; R.V: Rotational viscosity; S.P: Softening Point; D: Ductility; F.P: Flash Point; S.G: Specific Gravity; S.T: Solubility in Trichloroethylene; R.P: Retained penetration. The test where proceeded in the laboratory of the Kerbalaa University

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Table 1. Asphalt Cement (40-50) Penetration Grad Properties

| Test Designation of ASTM | Results | Limits According to SCRB |
|--------------------------|---------|---------------------------|
| Pen.@ 25°C, 100 gm, 5 sec. (0.1 mm) | D.5 | 47 | Min. 40 –Max. 50 |
| RV @ 135°C (cP.s) | D.4402 | 486 | ------ |
| SP, (°C) | D.36 | 44 | ------ |
| D.@ 25 °C, 5 cm/min (cm) | D.113 | 137 | More than: 100 |
| FP., (°C) | D.92 | 318 | Least value: 232 |
| SG | D.70 | 1.025 | ------ |
| STTr,% | D.2042 | 99.5 | More than: 99 |
Table 2. Aggregate Physical Properties

| Test          | Designation of ASTM | Results | Limits According to SCRB |
|---------------|---------------------|---------|--------------------------|
|               |                     | Crushed | Uncrushed |                 |
| BSG of C.A    | C.127               | 2.61    | 2.68       | ------          |
| ASG of C.A    | C.127               | 2.69    | 2.74       | ------          |
| W.A of C.A, % | C.127               | 1.58    | 1.02       | ------          |
| PWBLAA of C.A, % | C.131         | 16.40   | 11.71      | 30 Max.        |
| BSG of F.A    | C.127               | 2.67    |            | ------          |
| ASG of F.A    | C.127               | 2.78    |            | ------          |
| W.A of F.A, % | C.127               | 2.51    |            | ------          |

BSG: Bulk Specific Gravity; ASG: Apparent Specific Gravity; W.A: Water Absorption; PWBLAA: Percent Wear by Los Angeles Abrasion; C.A: Coarse Aggregate and F.A: Fine Aggregate. The tests were conducted in the laboratory of the Karbala Technical Institute.

Figure 1: Aggregate Gradation Used for Surface Course (Type IIIA)

Table 3. Mineral Filler: Physical Properties

| Test          | Results |
|---------------|---------|
| S.G           | 2.62    |

Percent Passing from Sieve No.200 (0.075 mm) 93

S.G: Specific Gravity. The test where proceeded in the laboratory of the Karbala Technical Institute.
4. EXPERIMENTAL WORK
A Zingg diagram was utilised on to analyse the aggregate shape. ASTM (D 3398) was adopted to determine the aggregate particle index (PI) for the combined effects of aggregate surface texture and shape.

After preparing the selected materials, specimens were designed according to Marshall Design criteria to determine the optimum asphalt cement content, then specimens were prepared with optimum asphalt content for all types of selected aggregate shapes (cubical, blade, and disk), surface textures (rough and smooth) and gradations (upper, middle, and lower specification limits). The Marshall Stability (MS), Marshall Flow (MF), and Air Voids (AV) at optimum asphalt cement content were then checked for each prepared specimen. Finally, according to the ASTM D1234 designation, the resilient modulus was tested using a UTM25 device at 40°C with 200 ms load duration for all prepared specimens.

5. TEST RESULTS
Two results were attained from the experimental work:

5.1. Effect of Aggregate Morphological Properties on HMA Marshall Properties:
Tables 4 and 5 as well as Figures 2 to 7 demonstrate the results for MS, MF, and AV for the hot mix asphalt specimens prepared with the three shapes of aggregate at three limits of gradation specification and two types of surface texture. It can be seen that the highest values of MS, 20.22 kN and 17.62 kN, were achieved using the cubical shape of aggregate at the middle specification gradation limit for rough and smooth surface textures respectively; the lowest values, 9.92 kN and 8.61 kN, were found when using the blade shape aggregate at the upper specification gradation limit for rough and smooth surface textures, respectively. The lowest values of MF, 3.12 mm and 3.51 mm, occurred when using the cubical shape aggregate at the upper specification gradation limit for rough and smooth surface textures respectively; the highest values of MF, 4.13 mm and 4.75 mm, were reached by using the disk shape aggregate at the lower specification gradation limit for rough and smooth surface textures respectively. Finally, the lowest values of AV, 3.21% and 3.65%, were found by using the cubical aggregate at the upper specification gradation limit for rough and smooth surface textures respectively; the highest values of AV, 4.02% and 4.48%, were reached using the disk shape aggregate at the middle specification gradation limit for rough and smooth surface textures respectively.

| Table 4. Shape and Gradation of Rough Surface Aggregate Texture Effects on Marshall Properties |
|----------------------------------------------------------|
| **Marshall Properties** | **Specification Limit** | **Aggregate Shape** |
| | Upper | Middle | Lower |
| **Blade** | **Disk** | **Cubical** | **Blade** | **Disk** | **Cubical** | **Blade** | **Disk** | **Cubical** |
| **MS** | 9.92 | 15.87 | 19.61 | 14.87 | 16.32 | 20.22 | 10.86 | 12.56 | 15.23 |
| **MF** | 3.31 | 3.65 | 3.12 | 3.35 | 3.75 | 3.22 | 3.99 | 4.13 | 3.86 |
| **AV** | 3.32 | 3.39 | 3.21 | 3.89 | 4.02 | 3.65 | 3.52 | 3.57 | 3.48 |
Table 5. Shape and Gradation of Smooth Surface Aggregate Texture Effects on Marshall Properties

| Marshall Properties | Specification Limit | Aggregate Shape |
|---------------------|---------------------|-----------------|
|                     | Upper | Middle | Lower |
| Blade               |       |        |       |
| MS                  | 8.61  | 14.56  | 16.61 |
| MF                  | 3.71  | 4.10   | 3.51  |
| AV                  | 3.66  | 3.73   | 3.65  |
| Disk                |       |        |       |
| Blade               | 13.28 | 15.73  | 17.62 |
| MS                  | 3.76  | 4.21   | 3.52  |
| MF                  | 4.32  | 4.48   | 4.17  |
| AV                  | 4.48  | 4.75   | 4.14  |
| Cubical             |       |        |       |
| Blade               | 10.07 | 13.11  | 14.28 |
| MS                  | 3.76  | 4.21   | 3.52  |
| MF                  | 4.32  | 4.48   | 4.17  |
| AV                  | 4.48  | 4.75   | 4.14  |

Figure 2 Marshall Stability for Rough Surface Texture

Figure 3 Marshall Stability for Smooth Surface Texture
Figure 4 Marshall Flow for Rough Surface Texture

Figure 5 Marshall Flow for Smooth Surface Texture
5.2. Effects of Aggregate Morphological Properties on Resilient Modulus Value of Hot Mix Asphalt:

Figures 8 and 9 show the effects on the Resilient Modulus of hot mix asphalt specimens prepared with the three shapes of aggregate at three limits of gradation specification for two types of surface texture. It can be seen that the highest values of RM, 9934.09 Mpa and 7507.43 Mpa, were reached using the cubical shape of aggregate at the middle specification gradation limit for rough and smooth surface textures, respectively. The lowest values, 3035.91 Mpa and 3007.22 Mpa, were found when using blade shape aggregate at the upper specification gradation limit for rough and smooth surface textures, respectively.
Tables 6 and 7 represent the aggregate gradation effects on the HMA RM for all aggregate shapes used in this search; it can be seen that the percentage increases are 30.93 to 51.80 and 17.29 to 41.18 with a change of aggregate gradation from upper to lower and from lower to middle for rough and smooth aggregate surface textures, respectively.
Table 6. Resilient Modulus Variation in Percentage between Specification Gradation Limits for Rough Surface Aggregates

| Aggregate Gradation Variation | Aggregate Shape | Blade  | Disk  | Cubical |
|-------------------------------|-----------------|--------|-------|---------|
| Percentage Change in RM       |                 | 48.30  | 36.23 | 45.68   |
| Upper – Lower                 |                 | 51.80  | 31.29 | 30.93   |
| Average Percent               |                 | 40.71  |       |         |

Table 7. Resilient Modulus Variation in Percentage between Specification Gradation Limits for Smooth Surface Aggregates

| Aggregate Gradation Variation | Aggregate Shape | Blade  | Disk  | Cubical |
|-------------------------------|-----------------|--------|-------|---------|
| Percent Change in RM          |                 | 41.18  | 27.14 | 32.60   |
| Upper – Lower                 |                 | 30.96  | 17.29 | 25.08   |
| Average Percent               |                 | 29.04  |       |         |

Tables 8 and 9 represent the effects of aggregate shape on the RM of HMAs for all aggregate gradations adopted in this search; it can be seen that the percentage increases are between 15.40 to 45.24 and 6.90 to 40.81 due to change of aggregate shape from blade to disk and from disk to cubical respectively for rough and smooth aggregate surfaces.

Table 8. Resilient Modulus Variation in Percentage by Aggregate Shape with Rough Surface Texture

| Aggregate Gradation Variation | Aggregate Gradation | Upper  | Lower | Middle |
|-------------------------------|---------------------|--------|-------|--------|
| Percent Change in RM          |                     | 45.24  | 33.42 | 15.40  |
| Blade – Disk                  |                     |        |       |        |
| Disk – Cubical                |                     | 18.12  | 26.30 | 25.96  |
| Average Percent               |                     | 27.41  |       |        |
Table 9. Resilient Modulus Variation in Percentage by Aggregate Shape with Smooth Surface Texture

| Aggregate Shape Variation | Aggregate Gradation | Percent Change in Resilient Modulus |
|---------------------------|---------------------|-----------------------------------|
|                           | Upper              | Lower               | Middle            |
| Blade – Disk              | 40.81              | 26.79               | 13.56             |
| Disk – Cubical            | 6.90               | 11.49               | 18.90             |
| Average Percent           | 19.74              |                     |                   |

Figure 10 shows the effects of aggregate gradation and shape on the average percentage variation of RM.

Figure. 10 Average Percentage Variation in RM for Rough and Smooth Aggregate Surfaces

Table 10 represents the aggregate surface texture effects on the HMA RM for all aggregate gradations and shapes adopted in this research; it can be seen that the percentage increase ranges from 0.95 to 32.32 as the aggregate surface texture changes from smooth to rough for all aggregate shapes and gradation limits.
Table 10. Resilient Modulus Variation Percent According to Variation of Aggregate Surface Texture with all shape and gradation limits

| Aggregate Gradation Specification Limits | Aggregate Shape | Percent Change in Resilient Modulus |
|-----------------------------------------|-----------------|-----------------------------------|
|                                         | Blade | Disk | Cubical |
| Upper                                  | 0.95  | 4.14 | 15.07   |
| Lower                                  | 6.04  | 11.59| 26.41   |
| Middle                                 | 22.92 | 24.91| 32.32   |
| Average Percent                        | 16.04 |

Finally, Figure 11 shows the percent change in the RM value of HMA based on all relevant aggregate morphological properties.

![Figure 11](image-url)

Figure 11 Average Percentage Variation in RM due to Aggregate Morphological Properties

6. CONCLUSIONS

1. According to the laboratory investigation, several conclusions can be drawn:
2. Aggregate morphological properties have a significant effect on the Marshall properties of hot mix asphalt specimens.
3. The maximum value of .S can be reached using a cubical aggregate shape at the middle limit of specification with a rough surface texture. This may be due to the high interlocking rate between the cubical particles at mid-specification limits offering good homogeneity, with the rough surface texture resisting external loading.
4. The minimum value of MF is found when using cubical aggregate shapes at the maximum limit of specification with a rough surface texture; this may be due to the maximum aggregate gradation contain only a small number of small particles.
5. The minimum value of AV is found when using a cubical aggregate shape at the maximum limit of specification with a rough surface texture; this may due to the mix's high density.

6. Aggregate morphological properties also have a significant effect on the resilient modulus of hot mix asphalt specimens.

7. The maximum value of RM is found when using a cubical aggregate shape at the middle limit of specification with a rough surface texture; this may be due to the high levels of interlocks and friction between the cubical particles at mid-specification limits, which results in the mix having good internal resistance to external loads with a rough surface texture.

8. The results of the experimental work specify that the ranked extent to which aggregate morphological properties have an effect on the resilient modulus of hot mix asphalt is first, aggregate gradation at 34.87%; then, aggregate shape at 23.57%; and finally, aggregate surface texture at 16.04%.

7. REFERENCES

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