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Ahmed Abdel-Reheem
*Associate Professor., Structural Engineering Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.*

Hazem Sakr
*Associate Professor Public Works Department., Faculty o f Engineering., El-Mansoura University., Mansoura., Egypt.*

Al-Hosain Aly
*Assistant Lecturer Public Works Department., Faculty of Engineering., El-Mansoura University., Mansoura., Egypt.*



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# Recycling of Dolomite and Basalt Asphalt Mixes of Existing Highway at Damietta Governerate

# اعادة استخدام خلطات الدولوميت و البازلت الاسفلتية على الطرق السريعة بمحافظة دمياط


Dr. Ahmed H. Abdel-Reheem
Associate Professor
Structural Engineering Dept.
Mansoura University
Egypt

Dr. Hazem A. Sakr
Associate Professor
Public Works Dept.
Mansoura University
Egypt

Eng. Al-Hosain M. Aly
Assistant Lecturer
Public Works Dept.
Mansoura University
Egypt



ملخص :

اتجه التفكير في السبعينات الى اعادة استخدام طبقات الرصف السطحية والتي مضى على انشائها فترة كبيرة وادى ذلك الى تدهور مستوى الاداء عليها لكثرة ماحدث بها من شروخ وهبوط لبعض اجزائها او اى عيوب انشائية اخرى. وقد اجرى هذا البحث لدراسة اعادة استخدام اشهر انواع الخلطات الاسفلتية استخداما في مصر وتتضمن خلطات البازلت والدولوميت ولذلك تم اخذ عينات ممثلة للانواع السابقة من قطاعين من طريق كفر البطيخ - البركانية بمحافظة دمياط. وبعد عمل الاختبارات الاستكشافية على الخلطات القديمة تم عمل عينات من الخلطات الاسفلتية المعادة والتي صممت باستخدام طريقة مارشال لتصميم الخلطات الاسفلتية .وقد تم تقييم خواص الخلطات الناتجة باستخدام اختبار مارشال وكانت النتائج التي تم استخراجها تشير الى ان خواص الخلطات الاسفلتية المعاده متشابهة بدرجة عالية مع خواص الخلطات الحديثة .

## ABSTRACT

Recycling of asphalt mixes can be defined as the restoration of aged mixes. The purpose of this research is to evaluate some old asphaltic surface courses in Damietta governerate for their potential of being recycled. Two types of old asphalt surface in Damietta were sampled and transported to the highway laboratory at Mansoura University. One of the two mixes was a dolomite crushed stone mixed at 6.6% asphalt content and the other was a basalt aggregate mixed at 5.2% asphalt content. Control mixes were also prepared using two virgin aggregates similar to those aggregates under study and designed according to Marshall method. It was found that the two Damietta asphalt mixes had high potential to be hot recycled after the addition of a 12% softener and 30% virgin aggregate. No extra addition of asphalt cement was needed in most cases.

## INTRODUCTION

Asphalt recycling can be divided into three major categories. The first is *Surface Recycling* which consists of reworking the surface of pavement to a depth of 1.0 inch(25.0-mm) or less. The second category can be termed *Cold Mix Recycling (In-Place Recycling)*. Such reconstruction is generally done cold, without heating the reused aggregate. *Hot Mix Recycling (Off-Site, Central Plant Recycling)* is the third category where the modified salvage mix is heated before reuse.

The main objective of this study was to generally ivestigate two different asphalt mixes for their potential of being hot recycled following the theird category. A two lanes road in Damietta goverenate connecting two towns known as *Kafr El-Batikh and Al-Rakabia*, had a total length of 15.0 Km., had been selected to serve as a test section. Two old asphaltic mixes had two different base aggregate, basalt and dolomite, were sampled for the purpose of this research.

For the purpose of comparsion, two similar aggregates were sampled, and named as virgin aggregate, from which control mixes were prepared. A series of routine tests were run on the virgin aggrgates, the extracted aggregates and the salvage mixes. Marshall method of design was used to design two control mixes, at 100% virgin aggregate. After knowing the required optimum asphalt content, the recycled mixes were adjusted to that optimum value.

## MATERIALS

### Aggregates

The virgin aggregates were tested against the gradation, abrasion, water absorption and specific gravity. All these tests were performed according to *American Association of State Highway and Transportation Officials (AASHTO)*.

The results of sieve analysis testing according to standard testing (T-27, 37) for each of the coarse aggregate, fine aggregate, sand and the mineral filler employed are given below in table (1). Also the specific gravity and water absorption of coarse and fine aggregates were run according to AASHTO standard testing (T-84, 85, 100) and the results are given in table (2).

### Asphalt Cement

An asphalt cement from a *Suez* petroleum source sampled from the *Damietta* asphalt mix plant was evaluated in laboratory to measure its penetration and flash point according to AASHTO (T-49, 78). The average penetration was found 68.0 and the flash point was determined to be 330C (650F). The specific gravity of that asphalt cement was 1.025.

**Asphalt Softening Modifier**

A modifier commercially known as Dutrex-729 which was essentially aromatic oil with a high flash point was selected because it had a proven performance (9). Also it could be easily obtained from the local suppliers, Misr Petrolum Company. The percent of the added modifier was taken 12% by weight of total liquid content of the salvage mix as recommended by many researches (9). Some physical properties of that material, as provided by the manufacturer, are given in table (3).

**Salvage Mixes**

Five representive samples were taken to evaluate the average value of asphalt content of salvage mixes. It was found 5.20 percent by the total weight of mix for basalt salvage mix and 6.60 percent by the total weight of mix for dolomite salvage mix.

The gradation of the extracted, basalt and dolomite, aggregates are given in table (4) and illustrated in figure (1). To adjust the gradation of the salvage *basalt* aggregate it was blended with 3% virgin mineral filler, as a percent by the total weight of aggregte in the recycled mix as clarified in table (5-a). Also the gradation of the salvage dolomite aggregate was adjusted by blending it with 4% virgin mineral filler, as a percent by the total aggregate weight of the recycled mix, and the results are given in table (5-b).

To evaluate the specific gravities of the extracted aggregate, it was divided into three size fractions:

1. A portion passing from 19.0 mm sieve and retained on 9.5 mm sieve *(coarse aggregate)*

2. A portion passing from 9.5 mm sieve and retained on 2.0 mm sieve *(fine aggregate)*

3. A portion passing from 2.0 mm sieve *(sand and filler)*

By a trial and error approach the percentage of each size fraction in the salvage aggregate was determined and the results for each type are presented in table (6). For each size fraction the different specific gravities were determined according to AASHTO standard and are given in table (7).

## MARSHALL MIX DESIGN

**Specimens Preparation**

Virgin mixes, using both basalt and dolomite aggregates, were designed to be used as a reference for the recycled mixes. Marshall specimens were prepared at asphalt contents 3.5, 4.0, 4.5, 5.0, 5.5, 6.0 and 6.5 percent of total mix weight for basalt aggregate and 4.5, 5.0, 5.5, 6.0, 6.5, 7.0 and 7.5% for dolomite aggregate. These specimens were prepared using the standard Marshall compactor and employing 50.0 blows on each side at a mix temperature of 135 c (265 F). Also asphalt absorption was experimentally evaluated and its average value was found 0.51 % as a percentage of solid aggregate weight for basalt aggregate and 1.46 % for dolomite aggregate.

Two sets of recycled *basalt* mix Marshall size specimens were prepared according to AASHTO standard. In one set 12 % modifier was added as a percent by weight of total liquid content of the salvage mix and the other set was without modifier addition. The specimens of each set were prepared at four levels of virgin aggregate addition 30, 40, 50 and 60 percent by the total weight of aggregate. Three specimens at four levels of asphalt content; 4.5, 5.0, 5.5 and 6.0 percent by the total weight of mix, were prepared for each level of virgin aggregate added.

Also two sets of recycled *dolomite* mix Marshall size specimens were prepared as mentioned above but at five levels of virgin dolomite aggregate addition 10, 30, 40, 50 and 60 percent by the total weight of aggregate. Three specimens were also prepared at four levels of asphalt content; 5.5, 6.0, 6.5 and 7.0 percent by the total weight of mix for each level of virgin aggregate added. All recycled specimens, basalt and dolomite, were prepared by using the equations derived in appendix to calculate the constituents weights of the specimen.

**Marshall Test Results**

The optimum asphalt content as an average value corresponding to maximum stability, maximum density, and 4% air voids was found 5.5 percent by weight of mix for basalt mix and 6% for dolomite mix. Marshall testing results for virgin basalt and dolomite mixes are shown in tables (8-a) and (8-b)respectively. The Marshall testing properties at the optimum asphalt content for each mix type were computed and given in tables (9-a) and (9-b) together with the design criteria. Tables (10) and (11) show the results of adjusted recycled mixes at different levels of virgin aggregate contents percentage by the total aggregate weight of the recycled mix and at four levels of asphalt content when using salvage bazzalt mix in case of without and with modifier addition respectively. Tables (12) and (13) represent the results when salvage dolomite mixes were employed.

## RESULTS ANALYSIS

**Salvage Aggregate**

The grain size distributions of salvage aggregates were presented togther with the design specification, see table (4) and figure (1). It can be noticed that fine material for both aggregates; basalt and dolomite, is lower than required. For example; the percent passing sieve No. 100 for basalt and dolomite were 5.0 and 4.0 percent respectively while the specification required 7.0 to 15.0 percent by total weight of aggregate. Also, for the percent passing sieve No. 200, it was found that for both aggregates the specification limit, (3.0-8.0%), was not reached; 2.0 percent for each of basalt and dolomite.

The lack of fine material might be due to an error in the original design formula during construction on one side and/or due to losing some of it with the extraction solvent. However, it was assumed that the amount of fines in the mix was less than required and the salvage mix was adjusted before remixing by adding 3.0 and 4.0 percent virgin mineral filler, by total weight of aggregate, for basalt and dolomite aggregate respectively. The adjusted gradations for basalt and dolomite aggregates were shown in tables (5-a) and (5-b) respectively.

Tables (2 and 7) compared the percent water absorption and abrasion in water percent for both virgin and salvage aggreagates. It was evident that the percent water absorption for the salvage aggregate was lower than that for virgin aggregate specially for dolomite, (8.44 percent versus 1.46 percent for coarse aggregate). This phenomenon was expected because some of the surface voids of extracted aggregate were locked by previously absorped asphalt and did not allow the same amount of water intrusion as in virgin aggregate. Also the percent moisture absorption of salvage basalt aggregate was lower than that of virgin basalt aggregate. However, the difference was not as high as that for dolomite. The interpretation of this may be that the weak adhesion between asphalt and basalt surface facilitates washing most of oils absorped by the aggregate during the extraction phase. Also the percent abrasion of the salvage aggregates, after 24 hours in water, compared to those of virgin aggregates are very high specially in case of salvage basalt aggregate.

Stability

Results of the virgin and recycled mixes are plotted at different levels of virgin aggregates content for each type of the recycled mix . Figure (2) and figure (3) present the relations between percent of asphalt content and stability at different levels of virgin aggregate added to recycled basalt and dolomite with and without modifier additon respectively. From the results of the recycled basalt mixes we note that the obtained stability of the recycled mix, without modifier addition, has its highest value at 30.0 percent virgin aggregate content. The stability value begins to decrease at small rate till 50.0 percent virgin aggregate content. The rate of stability decrease begins to increase after 50.0 percent virgin aggregate content. However, stability values remain greater than the control mix stability as shown in figure (2). The addition of modifier causes stability to decrease yet still greater than the stability of the control mix. In this case the increase of virgin aggregate content from 30.0 to 60.0 percent brings about a decrease in stability at uniform nearly low rates as shown in figure (2) .

The obtained stability values, for the recycled dolomite mixes, without modifier, are nearly equal at 30.0, 40.0 and 50.0 percent virgin aggregate contents and begin to decrease at 60.0 percent virgin aggregate content. However, at all levels of asphalt content the stability values of recycled mixes are higher than those of the control mixes. The values of maximum stability , of the recycled dolomite mixes without modifier at different levels of virgin aggregate contents occur at an asphalt content greater than the percent of asphalt content corresponding to the maximum stability of the control mix (100% virgin) by 0.5 to 1.0% as in figure (3). Whereas the addition of modifier reduces the stability values specially at virgin aggregate content of 50.0 percent and higher, as clarified in figure (3).

In general the higher stability values of the recycled mixes are attributed to the hardness of the aged asphalt which is the consequence of both physical (volatilization) and chemical (oxidation) change causing an unbalance of the asphalt components. Therefore an increase of asphaltenes at the expense of the maltenes fractions which are gradually converted into asphaltenes will take place. The addition of modifier, decreases asphaltenes content; i.e decreases asphalt hardening, bringing down the stability values of the recycled mixes nearly similar to the stability of the control mix (100% virgin).

**The Percent Air Voids**

The air voids percent of the recycled basalt mixes without modifier are higher than the specification limit for the surface course, (7.5 to 9.0 percent at 5.25 asphalt content percent). Also the percent of air voids at 5.5 percent asphalt content (the optimum asphalt content of basalt virgin mix) are nearly between 7.0-9.0 percent at different levels of virgin aggregate contents. The addition of modifier decreases the percent of air voids specially at high level of virgin aggregate contents. At the same percent of asphalt content, (5.5%), the percent of air voids are nearly between 6.0-8.0 percent.

In case of recycled dolomite mix without modifier at 6.0 percent asphalt content (the optimum asphalt content of virgin dolomite mix ), the percent air voids is nearly between 5.5-7.7% .The addition of modifier is more effective with the recycled dolomite mixes, where at the same percent of asphalt content, the percent of air voids is reduced to 5.2-6.8% . However, at higher values of asphalt content (7.0 percent or more), the percent air voids for both virgin and recycled mixes are almost equal and has a value of about 4.0 percent

The high percent of air voids for recycled basalt and dolomite mixes are due to the lack of complete mixing because the entire crumbling of the old pavement sample was not achieved in the laboratory during mixing and compaction of the recycled mixes. If complete separation of the asphalt concrete particles does not take place, these agglomerates function as aggregates. This is because asphalt concrete particles are coarser than their components. The final outcome of this phenomenen is to produce a coarser, lower density, higher voids finished mix. Observed voids content for the recycled mixes were higher than for either of the control mixes (basalt and dolomite). The modifier addition however; reduces the hardening of the aged asphalt i.e, restores the aged asphalt film coating the aggregate particles to proper consistency which leads to less voids content after compaction for easy sliding of the small particles inside the voids.

Flow

The flow values of the recycled basalt mixes without modifier as given in figure (4) increase slowly as the virgin aggregate contents increase. Although at 5.5 percent asphalt content the flow values range are between 8.8 and 9.3 (0.01 in) and are within the design criteria range ,(8-18), according to AASHTO, they are still lower than the flow of the control mix, (100% virgin). The addition of modifier, as illustrated in figure (4), increased the flow values of the recycled mixes to values nearly equal to the virgin mix flow.

Also the flow values of the recycled dolomite mixes without modifier, as clarified in figure (5), increase as the percent of virgin aggregate contents increase. At 6.0 percent asphalt content the flow values at 30.0, 40.0 and 50.0 percent virgin aggregate contents are nearly equal. A sharp increase in flow values occurs at high content of virgin aggregate (60.0 percent and more). The addition of modifier, as shown in figure (5), adjusted the flow values at all levels of virgin aggregate contents to be nearly equal to the flow value of the control mix (100% virgin).

## CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

This laboratory study was directed towards investigating the potential of two old asphalt mixes made from basalt and dolomite base aggregates for hot recycling. Based on the testing methods adopted, the materials used and the data obtained, the following conclusions could be drawn:

1. Extracted salvage aggregates had lower percent water absorption than virgin. A percent water absorption of 1.74% against 2.95% for basalt and 1.46% against 8.44% for dolomite.

2. A minimum of 30.0 percent virgin aggregate, by total dry aggregate weight in mix, was required for producing recycled mixes which satisfied the Marshall design criteria for asphalt surface course except for the percent air voids (7.6% for basalt and 6.6% for dolomite against 5.0% ).

3. The addition of 12.0 percent Dutrex-729 asphalt softener by total weight of liquid content, commercially available at a reasonable price, to recycled mixes even at the minimum acceptable percent added aggregate had improved the Marshall properties of final mixes especially for recycled dolomite mix.

4. Average Marshall stabilities of recycled mixes were found higher than those of control mixes. Percentages increase of 20.0 and 45.0 for basalt and 27.0 and 56.0 for dolomite with and without modifier addition respectively.

5. Average Marshall flows of recycled mixes were lower than those of control mixes. Percentages decrease of 8.0 and 20.0 for basalt mixes with and without modifier addition respectively. However; for dolomite, the flow values for recycled mixes with modifier were similar to those of control mix whilst it was 20.0 percent lower in case of adding no modifier.

### Recommendations

In view of the conclusions made in this study, the following recommendations are presented:

1. Recycled mixes made from dolomite or basalt have higher potential for use as binder or base course than as a surface course.

2. Asphalt softener should be added to improve the properties of recycled mixes. The percent of added softener by total liquid weight should be investigated.

3. Additional fatigue testing employing asphalt concrete beams and pulsating loads should be performed to investigate the fatigue life of salvage as well as virgin asphalt mixes.

4. Additional research directed to study the parameters which have the potential of reducing the percent air voids of recycled mixes to the range of asphalt surface course design criteria will be a fruitful area of research.

5. Conducting a field testing of surface courses made of recycled mixes is highly recommended in the future to reflect the actual performance under the environmental conditions experienced.

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| Sieve Size (mm) | % Passing | | | | | |
|---|---|---|---|---|---|---|
| | Basalt | | Dolomite | | Sand | Mineral Filler |
| | Coarse | Fine | Coarse | Fine | | |
| 25.0 | 98 | 100 | 100 | 100 | 100 | 100 |
| 19.0 | 50 | 100 | 99 | 100 | 100 | 100 |
| 12.5 | 19 | 96 | 54 | 99 | 100 | 100 |
| 9.5 | 4 | 77 | 25 | 87 | 100 | 100 |
| 4.75 | 1 | 29 | 12 | 8 | 100 | 100 |
| 2.0 | - | 4 | 9 | - | 100 | 100 |
| 0.6 | - | - | - | - | 71 | 97 |
| 0.3 | - | - | - | - | 27 | 95 |
| 0.15 | - | - | - | - | 5 | 93 |
| 0.075 | - | - | - | - | 2 | 92 |

Table (1) Virgin Aggregates Gradation

| Property | | Basalt | | Dolomite | | Sand | Mineral Filler |
|---|---|---|---|---|---|---|---|
| | | Coarse | Fine | Coarse | Fine | | |
| GS. | Bulk | 2.749 | 2.857 | 2.199 | 2.528 | - | - |
| | Dry Surface | 2.830 | 2.939 | 2.384 | 2.645 | - | - |
| | Eff. | 2.990 | 3.111 | 2.700 | 2.863 | 2.657 | 2.664 |
| %Water Abso. | | 2.950 | 2.050 | 8.440 | 4.640 | - | - |
| %Abrasion in Water | | 1.050 | 0.670 | 0.480 | 0.840 | - | - |

Table (2) Virgin Aggregates Specific Gravities and Water Absorption

| Colour | Density at 15 C (Kg/l) | Pour Point (C) | Flash Point COC (C) | Kinematic Viscosity | |
|---|---|---|---|---|---|
| | | | | at 40°C ($mm^2/s$) | at 100°C ($mm^2/s$) |
| Brown | 1.01 | 20 | 220 | - | 18.5 |

Table (3) Physical Properties of Modifier (Dutrex-729)

| sieve size (mm) | % passing | | |
|---|---|---|---|
| | Basalt | dolomite | spec. limits |
| 25 | 100 | 100 | 100 |
| 19 | 90 | 98 | 80 - 100 |
| 12.5 | 88 | 83 | - |
| 9.5 | 77 | 74 | 60 - 80 |
| 4.75 | 62 | 53 | 45 - 60 |
| 2.0 | 43 | 43 | 35 - 50 |
| 0.6 | 28 | 25 | 19 - 30 |
| 0.3 | 15 | 17 | 13 - 23 |
| 0.15 | 5 | 6 | 7 - 15 |
| 0.075 | 2 | 2 | 3 - 8 |

Table (4) Extracted Aggregates Gradation
(Basalt and Dolomite)

| sieve size (mm) | % passing | | | |
|---|---|---|---|---|
| | extr. agg | filler | sum | spe. limits |
| 25 | 100 | 100 | 100 | 100 |
| 19 | 98 | 100 | 95 | 80 - 100 |
| 12.5 | 88 | 100 | 88 | - |
| 9.5 | 77 | 100 | 77 | 60 - 80 |
| 4.75 | 62 | 100 | 63 | 45 - 65 |
| 2.0 | 43 | 100 | 44 | 35 - 50 |
| 0.6 | 28 | 97 | 28 | 18 - 30 |
| 0.3 | 15 | 95 | 17 | 13 - 23 |
| 0.15 | 5 | 93 | 8 | 7 - 15 |
| 0.075 | 2 | 92 | 5 | 3 - 8 |
| component percent | 97 | 3 | | |

a- Basalt

| sieve size (mm) | % passing | | | |
|---|---|---|---|---|
| | extr. | filler | sum | spec. limits |
| 25 | 100 | 100 | 100 | 100 |
| 19 | 90 | 100 | 99 | 80 - 100 |
| 12.5 | 83 | 100 | 88 | - |
| 9.5 | 76 | 100 | 76 | 60 - 80 |
| 4.75 | 53 | 100 | 55 | 45 - 65 |
| 2.0 | 43 | 100 | 46 | 35 - 50 |
| 0.6 | 26 | 97 | 28 | 18 - 30 |
| 0.3 | 17 | 95 | 20 | 13 - 23 |
| 0.15 | 6 | 93 | 8 | 7 - 15 |
| 0.075 | 2 | 92 | 5 | 3 - 8 |
| component percent | 96 | 4 | | |

b- Dolomite

Table (5) Aggregate Gradation Adjustment

| sieve size (mm) | % passing (basalt agg.) | | | | %passing (dolomite agg.) | | | |
|---|---|---|---|---|---|---|---|---|
| | group | | | extr. | group | | | extr. |
| | 1 | 2 | 3 | | 1 | 2 | 3 | |
| 25 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| 19 | 93 | 100 | 100 | 98 | 91 | 100 | 100 | 96 |
| 12.5 | 48 | 100 | 100 | 88 | 36 | 100 | 100 | 83 |
| 9.5 | - | 100 | 100 | 77 | - | 100 | 100 | 74 |
| 4.75 | - | 43 | 100 | 63 | - | 31 | 100 | 53 |
| 2.0 | - | - | 100 | 43 | - | - | 100 | 43 |
| 0.6 | - | - | 66 | 28 | - | - | 57 | 25 |
| 0.3 | - | - | 34 | 15 | - | - | 30 | 11 |
| 0.15 | - | - | 13 | 5 | - | - | 10 | 4 |
| 0.075 | - | - | 4 | 3 | - | - | 4 | 2 |
| group percent | 28 | 28 | 44 | | 25 | 30 | 45 | |

Table (6) Extracted Aggregate Components Gradation
(Basalt and Dolomite)

| specific gravity (GS) | extr. Basalt agg. | | | extr. dolomite agg. | | |
|---|---|---|---|---|---|---|
| | group (1) | group (2) | group (3) | group (1) | group (2) | group (3) |
| total | 2.790 | 2.663 | - | 2.565 | 2.929 | - |
| dry surface | 2.839 | 2.734 | - | 2.603 | 2.995 | - |
| apparant | 2.933 | 2.867 | 2.685 | 2.665 | 3.136 | 2.656 |
| % water abso. | 1.74 | 2.67 | - | 1.46 | 2.24 | - |
| % abrasion in water | 2.65 | 16.0 | - | 0.44 | .64 | - |

Table (7) Extracted Aggregate Components Specific Gravities
( Basalt and Dolomite)

| % A.C | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in |
|---|---|---|---|---|---|
| 3.5 | 939 | 150.6 | 8.1 | 15.2 | 10.1 |
| 4.0 | 1215 | 151.7 | 6.9 | 15.2 | 10.2 |
| 4.5 | 1192 | 152.1 | 5.9 | 15.4 | 9.6 |
| 5.0 | 1617 | 152.6 | 5.0 | 15.7 | 12.0 |
| 5.5 | 1639 | 154.3 | 3.0 | 15.7 | 12.0 |
| 6.0 | 1610 | 153.8 | 2.5 | 15.8 | 14.3 |
| 6.5 | 1360 | 153.3 | 2.1 | 16.5 | 18.6 |

Basalt

| % A.C | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in |
|---|---|---|---|---|---|
| 4.5 | 472 | 135.6 | 9.3 | 18.5 | 9.9 |
| 5.0 | 726 | 136.5 | 8.2 | 15.6 | 12.0 |
| 5.5 | 820 | 137.3 | 6.9 | 15.7 | 12.0 |
| 6.0 | 1103 | 139.0 | 4.6 | 15.6 | 14.0 |
| 6.5 | 1145 | 139.9 | 3.9 | 15.9 | 14.1 |
| 7.0 | 1014 | 139.4 | 3.6 | 15.9 | 14.7 |
| 7.5 | 1087 | 139.3 | 2.9 | 16.2 | 16.0 |

b-Dolomite

Table (8) Marshall Test Results

| optimum asphalt content = 5.5% | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in |
|---|---|---|---|---|---|
| | 1650 | 154.4 | 3.8 | 15.6 | 12.6 |
| design criteria | min. 500 | min. 130 | 3 - 5 | min. 14 | 8 - 18 |

a- Basalt Virgin Mix

| optimum asphalt content = 6% | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in |
|---|---|---|---|---|---|
| | 1140 | 140 | 4.1 | 15.7 | 14.2 |
| design criteria | min. 500 | min. 120 | 3 - 5 | min. 14 | 8 - 18 |

b- Dolomite Virgin Mix

Table (9) Marshall Results at Optimum Asphalt Content

| % vir. agg. | % A.C | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in |
|---|---|---|---|---|---|---|
| 30 | 4.5 | 2421 | 142.5 | 11.5 | 20.4 | 9.4 |
| | 5.0 | 2540 | 141.7 | 10.0 | 20.2 | 9.0 |
| | 5.5 | 2598 | 145.4 | 7.6 | 19.0 | 9.8 |
| | 6.0 | 2515 | 140.6 | 5.1 | 17.9 | 10.0 |
| 40 | 4.5 | 2210 | 147.9 | 12.5 | 21.4 | 8.8 |
| | 5.0 | 2315 | 145.4 | 8.9 | 19.2 | 9.4 |
| | 5.5 | 2470 | 146.7 | 8.6 | 20.1 | 9.7 |
| | 6.0 | 2410 | 148.7 | 5.1 | 18.7 | 10.8 |
| 50 | 4.5 | 2280 | 146.0 | 10.7 | 18.6 | 9.0 |
| | 5.0 | 2305 | 146.9 | 8.1 | 18.5 | 9.6 |
| | 5.5 | 2346 | 147.8 | 7.2 | 18.0 | 10.2 |
| | 6.0 | 2312 | 147.9 | 6.1 | 18.9 | 11.1 |
| 60 | 4.5 | 1980 | 145.1 | 11.2 | 19.1 | 9.2 |
| | 5.0 | 2180 | 145.8 | 8.9 | 19.2 | 9.4 |
| | 5.5 | 2081 | 146.6 | 7.6 | 18.7 | 10.6 |
| | 6.0 | 1870 | 148.3 | 5.9 | 18.4 | 11.7 |

Table (10) Marshall Results of Recycled Basalt Mix
(Without Modifier)

| % vir. agg. | % A.C | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in. |
|---|---|---|---|---|---|---|
| 30 | 4.5 | - | - | - | - | - |
| | 5.0 | 2043 | 144.9 | 8.3 | 19.5 | 11.2 |
| | 5.5 | 2039 | 148.2 | 5.6 | 18.1 | 12.3 |
| | 6.0 | 2008 | 147.2 | 5.5 | 19.0 | 12.7 |
| 40 | 4.5 | 1800 | 144.3 | 9.7 | 19.4 | 10.4 |
| | 5.0 | 1940 | 144.7 | 8.7 | 19.6 | 10.9 |
| | 5.5 | 2012 | 144.6 | 8.0 | 20.0 | 12.0 |
| | 6.0 | 1966 | 147.4 | 5.6 | 19.1 | 13.1 |
| 50 | 4.5 | 1840 | 145.5 | 9.0 | 18.8 | 10.5 |
| | 5.0 | 1805 | 145.7 | 8.2 | 19.1 | 10.6 |
| | 5.5 | 1976 | 147.3 | 6.5 | 18.8 | 12.4 |
| | 6.0 | 1922 | 146.8 | 5.8 | 19.0 | 13.7 |
| 60 | 4.5 | 1780 | 143.9 | 10.9 | 20.4 | 11.0 |
| | 5.0 | 1860 | 146.7 | 7.8 | 18.7 | 11.5 |
| | 5.5 | 1877 | 147.9 | 6.2 | 18.4 | 13.3 |
| | 6.0 | 1706 | 149.3 | 4.7 | 18.1 | 13.7 |

Table (11) Marshall Results of Recycled basalt Mix
(With Modifier)

| % wt. agg. | % A.C | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in. |
|---|---|---|---|---|---|---|
| 20 | 5.5 | - | - | - | - | - |
| | 6.0 | - | - | - | - | - |
| | 6.5 | 1844 | 142.2 | 5.8 | 19.2 | 9.2 |
| | 7.0 | 1906 | 145.8 | 2.9 | 18.4 | 9.4 |
| 30 | 5.5 | 1591 | 137.3 | 10.1 | 20.2 | 8.6 |
| | 6.0 | 1765 | 140.1 | 7.6 | 19.8 | 9.2 |
| | 6.5 | 1967 | 142.0 | 5.6 | 19.1 | 9.5 |
| | 7.0 | 1992 | 144.1 | 3.5 | 18.3 | 9.9 |
| 40 | 5.5 | 1567 | 140.2 | 7.7 | 18.5 | 9.0 |
| | 6.0 | 1674 | 141.0 | 6.5 | 18.5 | 9.4 |
| | 6.5 | 1942 | 141.8 | 5.3 | 18.5 | 9.8 |
| | 7.0 | 1936 | 142.9 | 3.9 | 18.3 | 10.2 |
| 50 | 5.5 | 1568 | 141.5 | 6.4 | 17.1 | 8.7 |
| | 6.0 | 1654 | 142.3 | 5.2 | 17.0 | 9.2 |
| | 6.5 | 1856 | 142.4 | 4.8 | 17.4 | 9.9 |
| | 7.0 | 1995 | 143.4 | 3.1 | 17.3 | 11.0 |
| 60 | 5.5 | 1373 | 140.2 | 6.8 | 17.0 | 10.7 |
| | 6.0 | 1459 | 140.4 | 6.0 | 17.1 | 12.0 |
| | 6.5 | 1695 | 142.1 | 4.2 | 16.8 | 12.3 |
| | 7.0 | 1718 | 141.8 | 3.7 | 17.4 | 14.2 |

Table (12) Marshall Results of Recycled Dolomite Mix (Without Modifier)

| % wt. agg. | % A.C | stability (lb) | density (pcf) | % A.V | % V.M.A | flow .01 in. |
|---|---|---|---|---|---|---|
| 30 | 5.5 | - | - | - | - | - |
| | 6.0 | 1922 | 238.6 | 8.4 | 20.7 | 12.4 |
| | 6.5 | 1941 | 141.3 | 5.9 | 19.5 | 13.3 |
| | 7.0 | 1653 | 143.3 | 3.9 | 18.7 | 13.7 |
| 40 | 5.5 | 1375 | 138.4 | 8.8 | 19.6 | 12.9 |
| | 6.0 | 1570 | 140.0 | 6.4 | 18.6 | 13.2 |
| | 6.5 | 1774 | 140.2 | 6.3 | 19.4 | 13.8 |
| | 7.0 | 1543 | 140.7 | 5.3 | 19.5 | 14.2 |
| 50 | 5.5 | 1318 | 140.3 | 6.1 | 16.7 | 13.2 |
| | 6.0 | 1394 | 141.6 | 5.6 | 17.4 | 14.1 |
| | 6.5 | 1371 | 142.2 | 4.5 | 17.5 | 13.8 |
| | 7.0 | 1354 | 143.4 | 3.0 | 17.3 | 14.9 |
| 60 | 5.5 | 1179 | 139.3 | 7.3 | 17.5 | 13.1 |
| | 6.0 | 1219 | 139.4 | 6.5 | 17.9 | 13.6 |
| | 6.5 | 1277 | 140.7 | 5.2 | 17.6 | 14.5 |
| | 7.0 | 1236 | 142.0 | 3.0 | 18.9 | 15.3 |

Table (13) Marshall Results of Recycled Dolomite Mix (With Modifier)

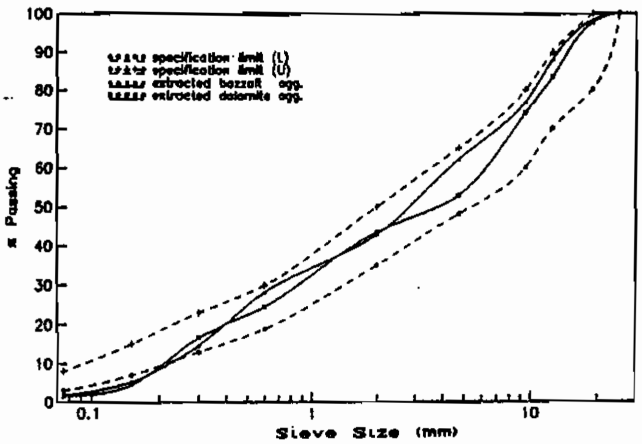
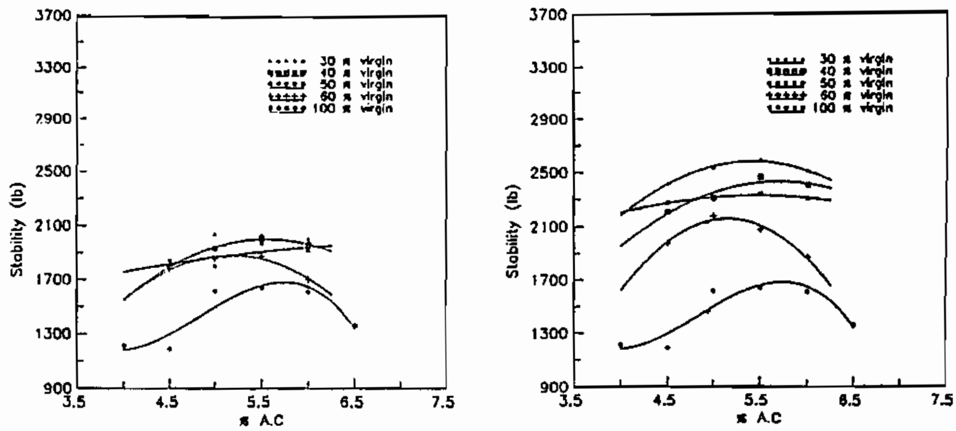
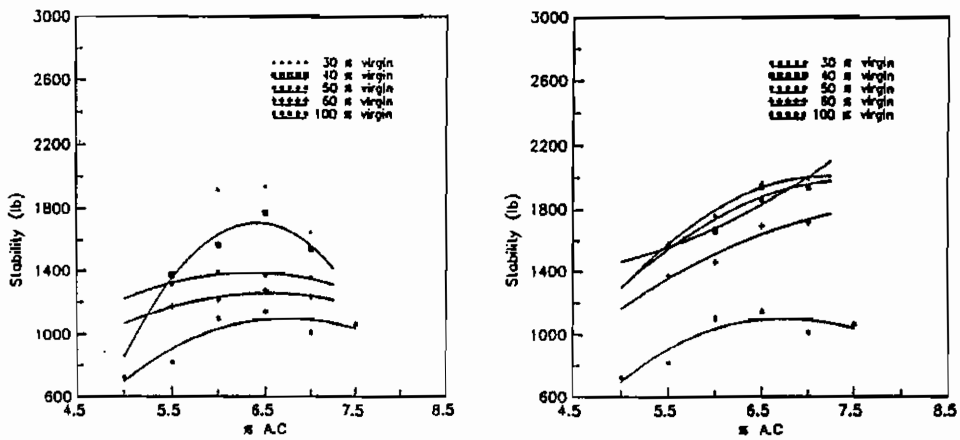



Figure (1) Extracted Aggregates Grain Size Distribution



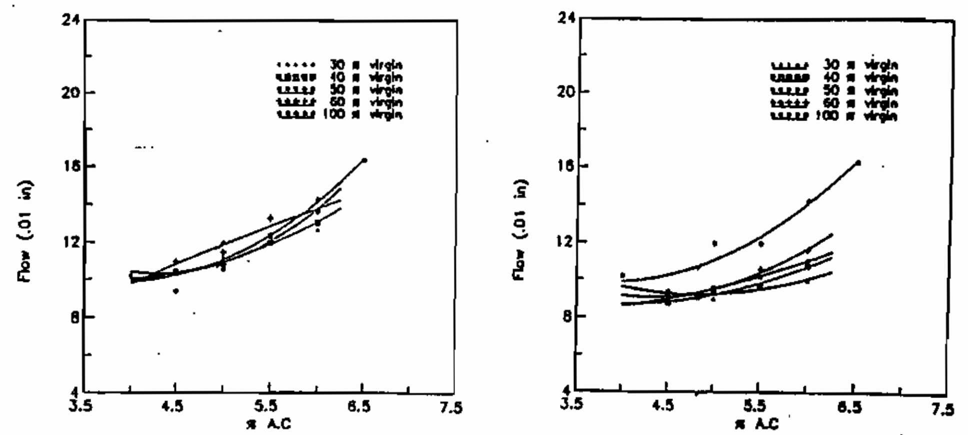

(With Modifier) (Without Modifier)

Figure (2) Stability & % A.C Relation of Recycled basalt Mix



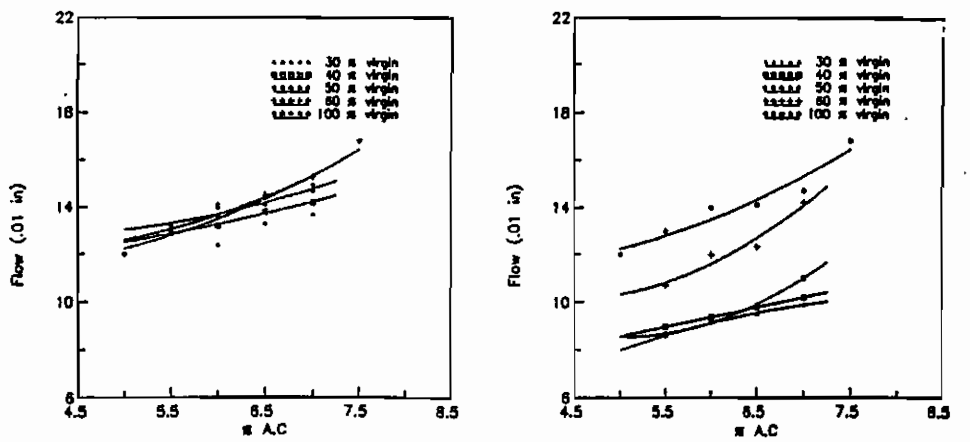

(With Modifier) (Without Modifier)

Figure (3) Stability & % A.C Relation of Recycled Dolomite Mix




(With Modifier) (Without Modifier)

Figure (4) Flow & % A.C Relation of of Recycled basalt Mix




(With Modifier) (Without Modifier)

Figure (5) Flow & % A.C Relation of Recycled Dolomite Mix

## APPENDIX

**Equations for Computing Recycling Mix Constituents**

The following formulas were derived to help in the preparation of recycled specimens.

By assuming the total weight of aggregate, virgin and salvage, required to fill the Marshall mold = W, then;

$W_{vat} = \% V_a \times W$

$W_{sa} = (1 - \% V_a) \times W$

To adjust the gradation of the salvage aggregate add a portion of virgin aggregate with weight = $W_{vac}$ as apercent of the total weight of aggregate, $W_{sa}$ and $W_{vac}$, i.e

$$\% V_{ac} = \frac{W_{vac}}{W_{sa} + W_{vac}} \times 100$$

$$W_{vac} \times (1 - \% V_{ac}) = \% V_{ac} \times W_{sa}$$

$$W_{vac} = \left[\frac{\% V_{ac}}{(1 - \% V_{ac})} \times (1 - \% V_a)\right] \times W \qquad (1)$$

but,

$W_{vat} = W_{va} + W_{vac} = \% V_a \times W$ then

$$W_{va} = \left[\% V_a - \frac{\% V_{ac}}{1 - \% V_{ac}} \times (1 - \% V_a)\right] \times W \qquad (2)$$

Where

$W$ = the total weight of aggregate required to fill the Marshall mold

$W_{vat}$ = the total weight of the added virgin aggregate ($W_{va} + W_{vac}$)

$W_{va}$ = The weight of virgin aggregate added

$W_{vac}$ = The weight of virgin aggregate required to adjust the salvage aggregate gradation

$W_{sa}$ = The weight of salvage aggregate

$\% V_a$ = The percent of added virgin aggreagte ($W_{vat}/W$) x 100

$\% V_{ac}$ = The percent of the virgin aggregate required to adjust the gradation of the salvage aggregate $[W_{vac}/(W_{vac} + W_{sa})] \times 100$

To calculate the required weights o_ asphalt and modifier the following formulas can be used.

In the salvage mix,

$$\% A.C_{sm} = \frac{W_{sb}}{W_{sb} + W_{sa}} \times 100 \qquad \text{then}$$

$$W_{sb}\,(1 - \% A.C_{sm}) = \% A.C_{sm} \times W_{sa}$$

$$W_{sb} = \left[\frac{\% A.C_{sm}}{1 - \% A.C_{sm}} \times (1 - \% V_a)\right] \times W \qquad (3)$$

where

$W_{sa} = (1 - \% V_a) \times W$

The modifier was added as a percent by the total weight of liquid content in salvage mix i.e,

$$\% M = \frac{W_m}{W_m + W_{sb}} \times 100$$

$$W_m = \frac{\% M}{1 - \% M} \times W_{sb}$$

Substitute the value of $W_{sb}$ from equation (3) to get the modifier weight

$$W_m = [\frac{\% M}{1 - \% M} \times \frac{\% A.C_{sm}}{1 - \% A.C_{sm}} \times (1 - \% V_a)] \times W \qquad (4)$$

To evaluate the weight of virgin asphalt needed based on asphalt content percent of the recycled mix, these formoulas can be derived.

$$\% A.C_r = \frac{W_{rb}}{W + W_{rb}} \times 100$$

$$W_{rb} \times (1 - \% A.C_r) = \% A.C_r \times W$$

$$W_{rb} = \frac{\% A.C_r}{1 - \% A.C_r} \times W \qquad (5)$$

but

$$W_{ab} = W_{rb} - W_{sb} - W_m$$

then from equatins (3), (4), and (5)

$$W_{ab} = [\frac{\% A.C_r}{1 - \% A.C_r} - (1 - \% V_a)(\frac{\% A.C_{sm}}{1 - \% A.C_{sm}})(1 + \frac{\% M}{1 - \% M})]W \qquad (6)$$

The sum of salvage aggregate and bitumen weights give the required weight of salvage mix

$$W_{sm} = W_{sb} + W_{sa}$$

$$W_{sm} = [(1 - \% V_a)(1 + \frac{\% A.C_{sm}}{1 - \% A.C_{sm}})] \times W \qquad (7)$$

Where

$\% A.C_{sm}$ = the percent of asphalt content in the salvage mix

$W_{sb}$ = salvage bitumen weight

$\% M$ = the percent of added modifier

$W_m$ = the added modifier weight

$\% A.C_r$ = the total required percent of asphalt content in the recycled mix

$W_{rb}$ = the required bitumen weight in the recycled mix needed to obtain the required total percent of asphalt content

$W_{ab}$ = the virgin bitumen weight required to be added to obtain the required total percent of asphalt content in the recycled mix

**Example Problem**

The following example was prepared to help in using the formulas in appendix (A).

Given:

1. The total weight of aggregate required to fill the Marshall mold (W) = 1350 gm
2. The percent of used virgin aggregate (% $V_a$) = 40
3. The percent of virgin aggregate required to adjust the gradation of the salvage aggregate (%$V_{ac}$) = 3
4. The percent of asphalt content of the salvage mix (% $A.C_{sm}$) = 5.62
5. The percent of modifier (% M) = 0.0
6. The required asphalt content percentage of the recycled mix (% A.Cr) = 5

from equ. (1)

$W_{vac}$ = 25 gm

from equ. (2)

$W_{va}$ = 515 gm

from equ. (4)

$W_m$ = 0.0

from equ. (6)

$W_{ab}$ = 22.8 gm

from equ. (7)

$W_{sm}$ = 858 gm

By knowing the virgin aggregate weight and its constituent percent you can determine the constituents weight as below:

Coarse virgin aggregate weight = 0.25 x 515 = 129 gm
Fine virgin aggregate weight = 0.35 x 515 = 180 gm
Sand weight = 0.35 x 515 = 180 gm
Mineral filler weight = 0.05 x 515 = 26 gm