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Modelling Study on the Suitability of Demolishing Waste for the Production of Hot Mix Asphalt

Assist. Prof. Dr. Hamed M. Jassim [#1], Assist. Lect. Omar T. Mahmood [*2], Assist. Lect. Sheelan A. Ahmed [*3]

[#] *Department of Geotechnical Engineering, Faculty of Engineering, Koya University, Erbil, Iraq*
[*] *Department of Civil Engineering, Faculty of Engineering, Koya University, Erbil, Iraq*
[1] *hamed. jassim@koyauniversity. org*
[2] *omar. taha@koyauniversity. org*
[3] *sheelan. abdulwahid@koyauniversity. org*

Abstract

Demolished wastes are major part of industrial waste. In general, demolished wastes are heterogeneous and consist of a large variety of building materials. Since the early 1980s the processing of building rubble has become more and more common in most industrialised countries. After appropriate processing, the major part of these materials meets the technical properties for reuse. Providing information about demolished wastes to promote its usage as a road construction aggregate increases confidence in terms of its engineering impacts. Building demolished wastes, regarded as a material with limited economic potential, can be identified as potentially having suitable material characteristics for a base course aggregate and may provide an ideal solution to minimize the problems of raw materials exhaustion while providing other various economic and environmental benefits. Since the last decade, Iraq witnessed wide development campaign especially in the construction field. There is an increasing pressure on the construction industry to reduce costs and improve the quality of our environment. The fact is that both of these goals can be achieved at the same time. Although construction and demolition constitute a major source of waste in terms of volume and weight, its management and recycling efforts have not yet seen the light. This paper focused on utilization of demolished wastes as aggregate in hot mix asphalt for surface layer. For this purpose, the demolished wastes separated into seven main materials (concrete elements , blocks, bricks, ceramic tiles, marble tiles , terrazzo tiles and granite tiles) were crushed manually and tested to determine their properties, to be used as aggregate in the mixtures and blended with six different percentages of asphalt content to determine the optimum asphalt content of each demolished material at which the results of Marshall test properties and index of retained strength can be used to develop numerical models to predict the suitability of demolished wastes for the production of hot mix asphalt for surface layer of pavement.

Keywords*:* Construction and Demolished wastes, Demolished wastes Properties, Hot Mix Asphalt, Marshall Properties, Marshall Stability, Modelling Study, Recycle Materials

I. INTRODUCTION

Construction and demolition debris" mean those materials resulting from the alteration, construction, destruction, rehabilitation, or repair of any physical structure that is built by humans, including houses, buildings, industrial or commercial facilities, or roadways. "Construction and demolition debris" include particles and dust created during demolition activities. The increasing attention being paid to environmental problems has recently aggravated the difficulty of recovering aggregates from quarries for civil engineering purposes and, at the same time has made the regulations for the management of waste dumps even more restrictive. Therefore, during the last years many interesting researches about the wastes reuse have been developed; particularly, careful experimental studies about aggregate scraps, coming from building demolished wastes, showed the possibility of their use for embankments, subgrade and subbase layers of road pavements and also in cement mixtures and in medium-low resistance concretes [1]. In Germany, approximately 70 percent of this rubble is recycled. However, large quantities of the recycled material are used for pavements and road construction, landfill site constructions and other low grade uses. The study will also demonstrate that compositing offers a suitable use for such materials, thus reducing landfilling. The input material for the demonstration project was demolition rubble which is one of the most important waste streams in terms of mass and volume [2]. [*Farias A. , Facale S. , Gusmão A. , Maia G. 2013*] analysed the technical and economic feasibility to the use of wastes originated from the deep excavation activity and by demolition of old constructions for the application in layers of subgrade, sub-base and base in paving project. A comparative analysis was carried out between recycled material costs and the aggregate commonly used in paving project, discovering, besides the technical advantage, also the economic advantage of this alternative material. [I. Vegas; J. A. Ibañez; A. Lisbona; A. Sáez de Cortazar; M. Frías, *2011*] determined the physical, chemical and mineralogical characteristics of mixed recycled aggregates which were produced from the treatment of mixed rubble for use in unbound structural layers of road. The results of this research show that the combined presence of concrete and ceramic materials induces pozzolanic reactions, which contribute to an increase in the bearing capacity of the compacted mixed recycled aggregate. Generally, mixed recycled aggregates with ceramic material contents below 35%, organic matter contents below 0. 8% and water soluble sulphate contents below 0. 4% constitute a granular material that is technically feasible for use in unbound structural road sections. [*M. Cupo-Pagano, A. D'Andrea, C. Giavarini and C. Marro, 1994*] studied the influence of demolished wastes on the performance of asphalt mixture. Demolished wastes were processed into recycled aggregate of different sizes which can be divided into recycled coarse aggregate (RCA, particle size of > 4. 75 mm) and recycled fine aggregate (RFA, particle size of ≤ 4. 75 mm). Three types of AC-25 asphalt mixtures were prepared: RCA asphalt mixture prepared with RCA and limestone fine aggregate; RFA asphalt mixture prepared with RFA and limestone coarse aggregate; and the ordinary asphalt mixture prepared with natural limestone coarse and fine aggregate. A series of laboratory tests on recycled aggregate and asphalt mixture were carried out, including scanning electron microscopy test, immersion Marshall test, freeze–thaw split test, bending test at low temperature and rutting test at high temperature. Results showed that RCA asphalt mixture has higher optimal asphalt content and greater rutting resistance than the other two types. The cracking resistance of RCA asphalt mixture at low temperature is better than that of RFA asphalt mixture; while the water damage resistance of RFA asphalt mixture is better than that of RCA asphalt mixture. [*Shen, D. H. and Du, J. C, 2004*] evaluated the permanent deformation for hot mix asphalt with reclaimed building materials (RBM). The results indicate to the performance of hot mix asphalt with reclaimed building materials (RBM) is related to the heavily crushed face and high absorption of asphalt cement aggregate. Compared with RBM mixtures, river crushed stone aggregate does not perform so well as 100% RBM and coarse RBM plus fine CS. The instability of the deformation depth of 50% RBM plus 50% CS makes it not qualified for use. An analysis of variance of permanent deformation test shows that the types of aggregate have a significant effect, no matter what test temperatures and binders are used. The asphalt cement either AC-10 or AC-20 used has no significant effect on the permanent deformation performance. [*I Pe´rez, A R Pasandı´n and J Gallego, 2012*] used indirect tensile stress tests to evaluate the stripping behaviour of hot asphalt mixtures. The mixtures tested were fabricated with (0, 20, 40 and 60) % recycled aggregates. Two types of natural aggregates were used: schist and calcite dolomite. An increase in the percentage of recycled aggregates was found to produce a decrease in the tensile stress ratio of the hot asphalt mixtures. The percentage of recycled aggregate also affected indirect tensile stress, especially in the dry state. The type of natural aggregate did not have a significant effect on indirect tensile stress. The hot asphalt mixture specimens made with different percentages of recycled aggregates from construction and demolition debris and of natural quarry aggregates showed poor stripping behaviour. This stripping behaviour can be related to both the poor adhesion of the recycled aggregates and the high absorption of the mortar of cement adhered to them.

II. MATERIALS CHARACTERIZATION

The materials used in this study are locally available and currently used in road construction in northern Iraq.

A. Aggregates and Demolished wastes

The mid of ASTM-D3515 specification for grading was chosen to separate the crushed aggregate and demolished wastes to the specified sizes as shown in Table (1) . The properties of different types of aggregate are shown in Table (2).

TABLE (1): SELECTED COMBINED GRADATION OF AGGREGATE AND FILLER (%PASSING BY WEIGHT)

Sieve No.	Sieve Size (mm)	Specification Limit ASTM-D3515	Mid of Specification % Passing
3/4"	19. 0	100	100
1/2"	12. 5	90-100	95
3/8"	9. 5	----	83
No. 4	4. 75	44-74	59
No. 8	2. 36	28-58	43
No. 50	0. 30	5-21	13
No. 200	0. 075	2-8	5

TABLE (2): AGGREGATE AND DEMOLISHED WASTES PROPERTIES

Properties	ASTM	Crushed Aggregate	Demolished wastes						
			Concrete Elements	Blocks	Bricks	Tiles			
						Ceramic	Terrazzo	Marble	Granite
Bulk Specific gravity	C127	2. 692	2. 544	2. 520	2. 312	2. 475	2. 494	2. 672	2. 688
Water Absorption		0. 684	1. 343	1. 773	2. 18	1. 852	0. 841	0. 788	0. 405
% Coating and Stripping of Bitumen	D1664	97	98	97	89	91	96	93	93
% Wear (Los Angeles abrasion)	C131	19. 4	25. 6	27. 6	32. 2	29. 3	27. 1	22. 5	23. 2
% Deleterious Materials	C142	0. 87	0. 58	1. 02	2. 03	0. 97	0. 77	0. 08	0. 13

1) Demolished wastes

The demolished wastes were brought from demolished building of Al Rafidain bank in Koya city in northern Iraq (shown in Figure 1) containing bulky and heavy materials such as concrete elements , blocks, bricks, different types of tiles , gypsum (the main component of drywall), metals, glass, plastics, and salvaged building components (doors, windows, and plumbing fixtures).

Figure (1) Demolished building of Al Rafidain bank in Koya city

2) Crushed Aggregate

The crushed aggregate used in this investigation was brought from Freba hot mix plant, and these were originally brought from Darbande Zeoi quarry near Sulaimanyah city in northern Iraq and crushed at the asphalt plant by mechanical crusher.

B. Asphalt Cement

The Asphalt cement grade (40–50) was brought from Baiji refinery. Many tests were performed on it to ensure the suitability of the material. Table (3) shows the physical properties of asphalt cement.

TABLE (3): PHYSICAL PROPERTIES OF ASPHALT CEMENT

Properties	**Unit**	**ASTM**	**Value**
Penetration at(25ºC, 100g, 5 s)	0. 1 mm	D5	44
Specific gravity at 25ºC	----	D70	1. 035
Kinematic viscosity at 135ºC	Cst	D2170	390
Softening point (Ring and Ball)	ºC	D36	51. 5
Ductility (25ºC, 5 cm/min)	cm	D113	118
Flash point	ºC	D92	280
Fire point	ºC	D92	292
Loss on heat (5 hrs, 163ºC)	%	D1754	0. 6

*C. **Filler***

The filler used was Portland cement which was brought from Al-Mas cement factory. Its physical properties are presented in Table (4).

TABLE (4): PHYSICAL PROPERTIES OF PORTLAND CEMENT FILLER

Properties	**Unit**	**Value**
Specific Gravity	----	3. 151
Unit Weight	gm/cm^3	1. 165
Passing Sieve No. 200	%	99

III. AGGREGATE AND DEMOLISHED WASTES TESTS

A. Specific Gravity and Water Absorption (ASTM C127)

This method covers the determination of specific gravity and water absorption of coarse aggregate. Specific gravity may be expressed as bulk specific gravity (saturated–surface–dry (SSD)) or apparent specific gravity. This method is based on the immersion of the sample of aggregate (3kg) in water for approximately 24 hr to essentially fill the pores. It is then removed from water and the surface of the particles is dried and weighed. Subsequently, the sample is weighed while submerged in water. Finally the sample is oven-dried and weighed a third time. Using the weights thus obtained and formulae in the method, it is possible to calculate three types of specific gravity and absorption.

$$\text{Bulk Specific gravity} = \frac{A}{(B - C)} \quad (1)$$

$$\text{\% Water Absorption} = \frac{B - A}{A} \times 100 \quad (2)$$

Where:
A: weight of oven-dry test sample in air, (gm).
B: weight of saturated – surface – dry test sample in air, (gm).
C: weight of saturated test sample in water, (gm).

B. Resistance to Degradation by Abrasion and Impact in the Los Angeles Machine (ASTM C131).

This method covers a procedure for testing size of coarse aggregate smaller than 1½ in (37. 5 mm) for resistance to degradation using the Los Angeles testing machine. A 5000 gm sample of aggregate having B grading (2500 gm passing sieve 3/4"-retained on 1/2" and 2500gm passing sieve 1/2"-retained on 3/8") is placed in steel drum along with 11 steel balls each weighing about 420 gm. The drum is rotated for 500 revolutions. A shelf within the drum lifts and drops the aggregate sample and steel balls about 69 cm (27 inches) during each revolution. The resulting vigorous tumbling action combines impact, which causes the more brittle particle to shatter, with surface wear and abrasion as the particles rub against one another and against the steel balls. Following the completion of 500 revolutions, the sample is removed from the testing machine and sieved dry over a 1. 77 mm (No. 12) sieve. The percent passing the 1. 77 mm (No. 12) sieve, termed the percent loss, is the Los Angeles degradation value for the sample.

C. Deleterious Materials (ASTM C142)

ASTM C142 is used as a standard test method for determination of clay lumps and friable particles in aggregates. Aggregate is weighed and soaked in water for 24 hours. Any particle which can be broken with the fingers after soaking and removed by wet sieving are classified as clay lumps or friable particles, and the percentage of this material is calculated by weight of the total test sample.

D. Coating and Stripping of Bitumen – Aggregate Mixtures (ASTM D1664)

This method describes coating and static immersion procedures for determining the retention of a bituminous film on an aggregate surface in the presence of the water. The selected and prepared aggregate is coated with the bitumen at specified temperature appropriate to the grade of bitumen used. The aggregate is coated with bitumen and subjected to a curing for 2 hr at 140 °F (60 °C), after curing the coated aggregate is immersed in distilled water for 16 to 18 hr. At the end of the soaking period, and with the bitumen-aggregate mixture under water, the total area of the aggregate on which the bituminous film is retained is estimated visually, as above or below 95%.

IV. ASPHALT CONCRETE TESTS

The following test methods are used in this work to evaluate the performance of asphalt concrete mixture.

A. Resistance to Plastic Flow (Marshall Method)

The method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to (ASTM D1559). The prepared mixture is placed in preheated mold (4in) (101. 6mm) in diameter by (3in) (76. 2mm) in height, and compacted with 50 blows/end with a hammer of 10 lb. (4. 536 kg) sliding weight, and a free fall of (18 in) (457. 2 mm) on the top and bottom of each specimen. The specimens are then left to cool in room temperature for 24 hours. Marshall stability and flow tests are performed on each specimen according to the method described by ASTM D-1559. The cylindrical specimen is placed in water bath at 60 °C for 30 to 40 minutes, and then compressed on the lateral surface at constant rate of 2 in/min (50. 8 mm/min) until the maximum load resistance and corresponding flow value is recorded. Three specimens for each combination are prepared and the average results are reported. The bulk specific gravity is determined for each specimen in accordance with ASTM D-2726.

B. Index of Retained Strength Test

This method covers the measurement of loss of cohesion resulting from the action of water on compacted specimens prepared in accordance with ASTM D-1074. A set of six specimens is prepared for each mix combination with optimum asphalt content. The tested specimens 4in (101. 6 mm) in diameter, and 4 in (101. 6 mm) in height are prepared by compressing the mixture under an initial load of 150 psi (1 Mpa) to set against the side of the mold, then a molding load of 3000 psi (20 Mpa) is applied for 2 min. Three specimens are tested for compressive strength at a uniform rate of 0. 2 in/min (5. 08 mm/min) after storing in air bath at 25 °C for about 4 hours. The other three specimens are placed in a water bath for 24 hours at 60 °C, then transferred to a water bath and maintained at 25 °C for 2 hours, before testing for compressive strength. The index of retained strength is calculated as follows:

$$\text{Index of Retained Strength (\%)} = \frac{S_2}{S1} \times 100 \qquad (3)$$

Where:
S1 = Compressive strength of dry specimens.
S2 = Compressive strength of immersed specimen.

V. TESTING PROGRAM

To achieve the objectives of this study; seven different types of demolished wastes (concrete elements, blocks, bricks, ceramic tiles, terrazzo tiles, granite tiles, and marble tiles) were used instead of crushed aggregate of conventional mixture, blended with filler, and one type of bitumen grade (40-50) with 0. 5% increments of asphalt content, starting from lowest content of 3. 5% reaching the highest content of 6% so as to determine the optimum asphalt content for each type of aggregate, and evaluate the suitability of use of these demolished wastes in hot mix asphalt for surface course of pavement. Figure (2)shows the flow chart of this study.

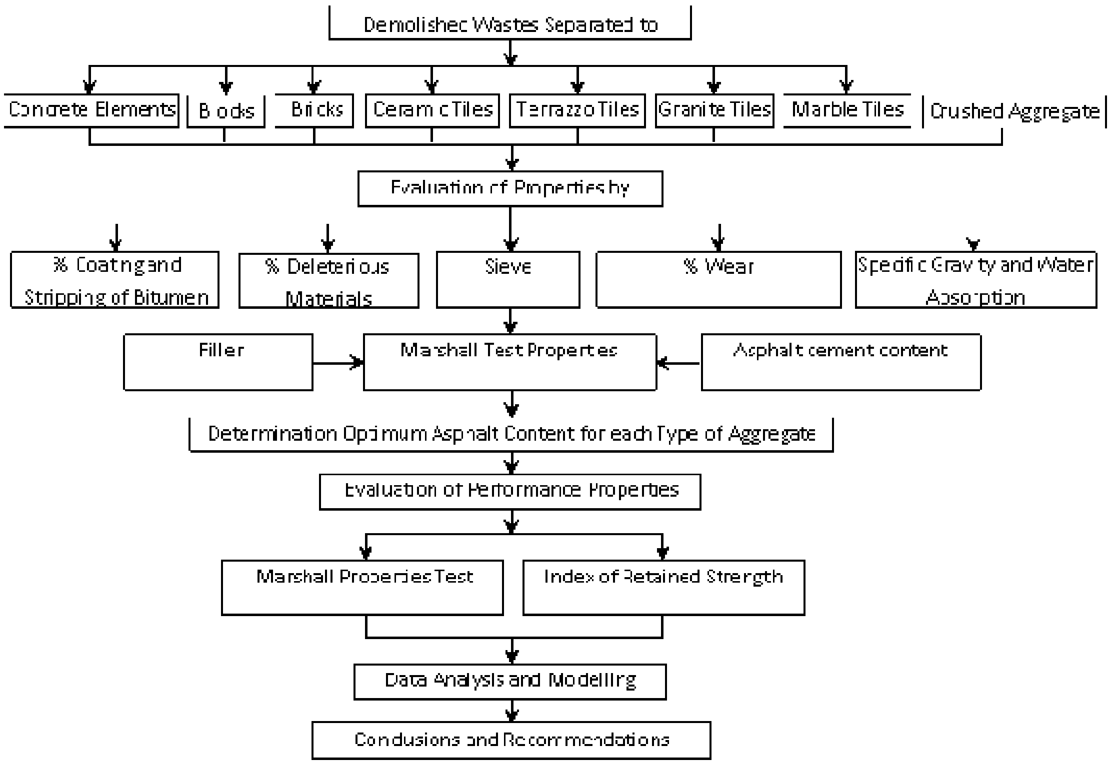


Figure (2) The flow chart of the study

VI. Results and Discussions

A. ***Optimum Asphalt Content***

Tests were conducted on mixtures prepared by using seven different types of demolished wastes (concrete elements, blocks, bricks, ceramic tiles, terrazzo tiles, granite tiles, and marble tiles) and crushed aggregate, blended with Portland cement filler and one type of asphalt cement grade (40-50) with different percentages varying from (3. 5%-6 %) at increment of 0. 5%. The optimum asphalt content for each aggregate type was selected corresponding to (4 ± 0. 05) % air voids . The results of Marshall test properties for each type of aggregate are shown in table (5) and represented in Figures (3 to 10).

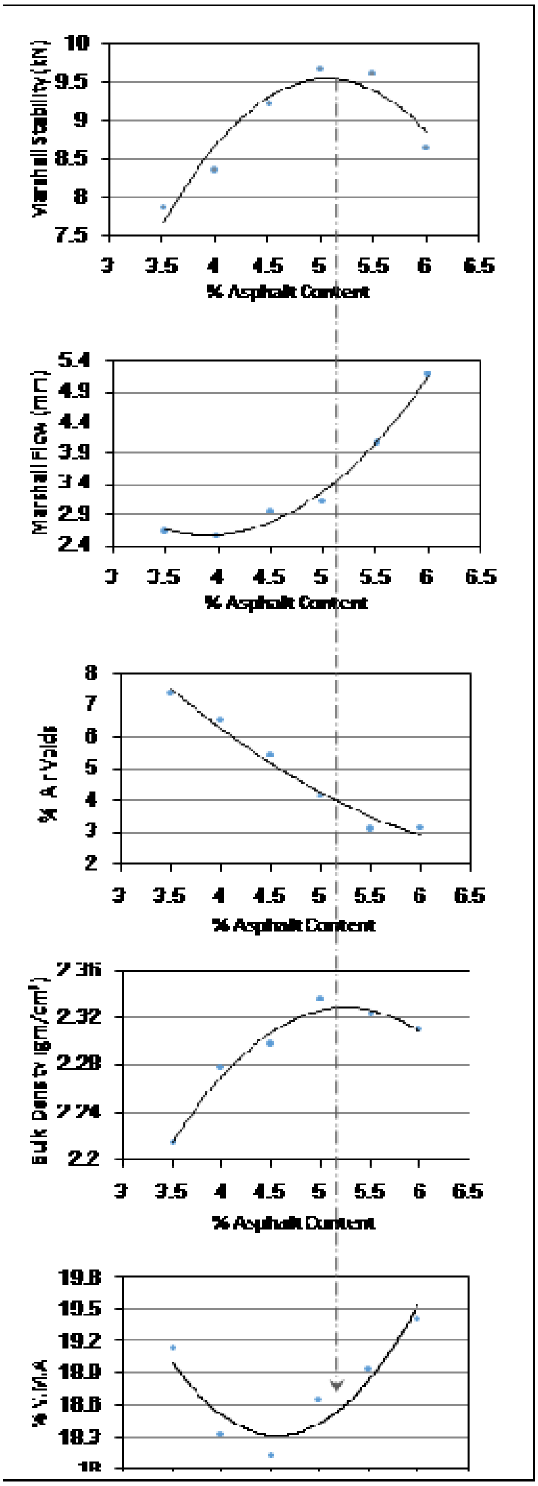


Figure (3) The optimum asphalt content of crushed aggregate (O. A. C = 5. 2%)

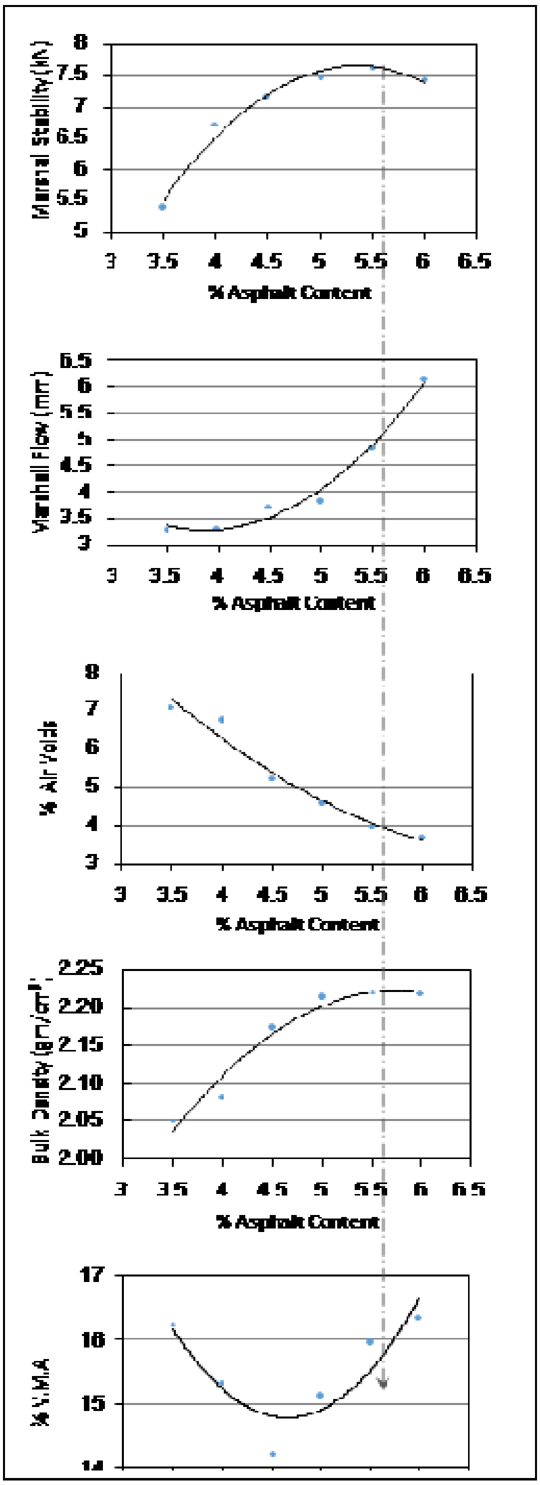
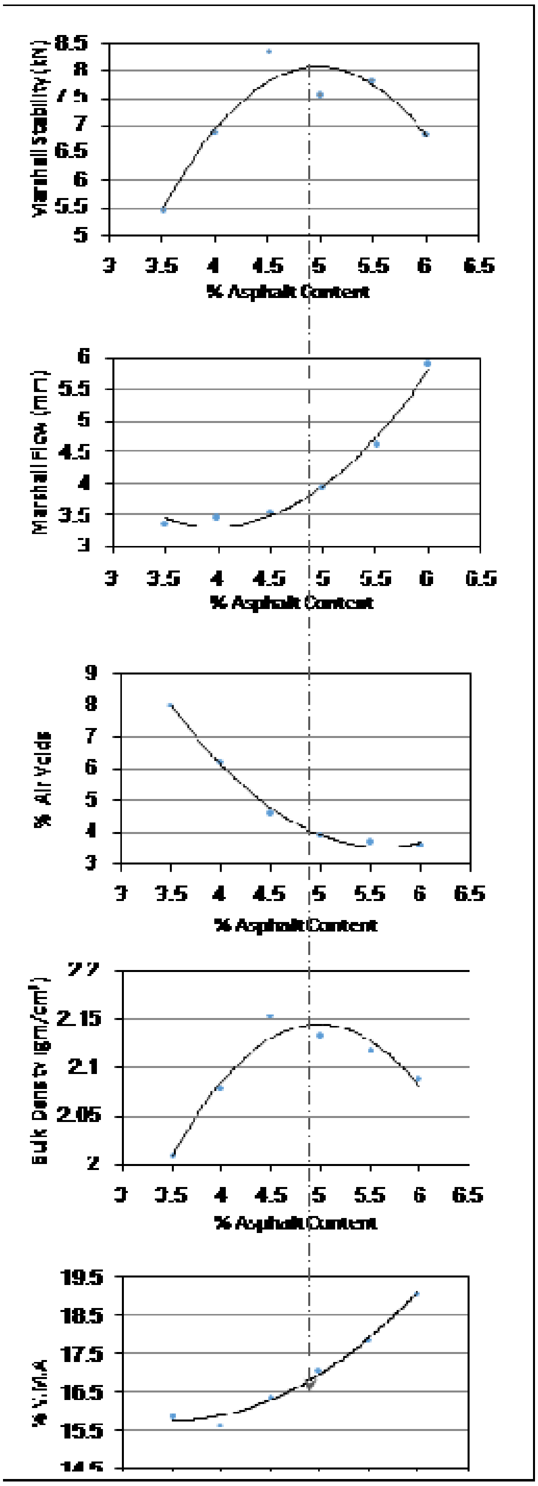


Figure (4) The optimum asphalt content of ceramic tiles (O. A. C = 5. 6%)



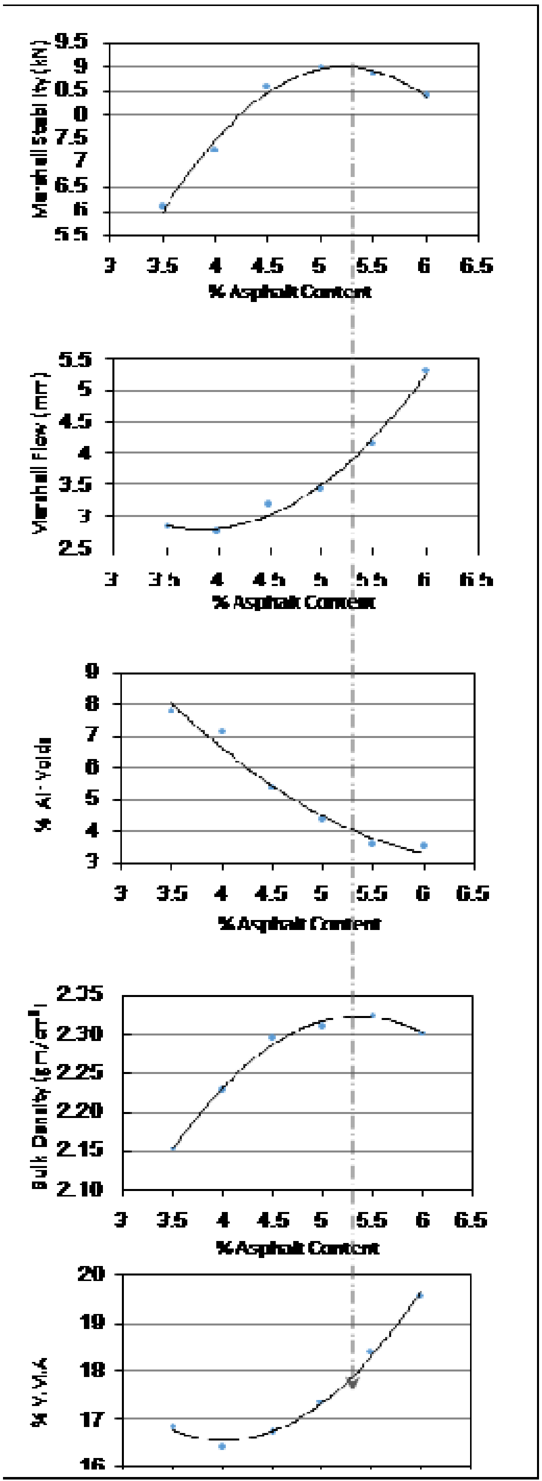


Figure (5) The optimum asphalt content of block (O. A. C = 4. 9%)

Figure (6) The optimum asphalt content of terrazzo tiles (O. A. C = 5. 3%)

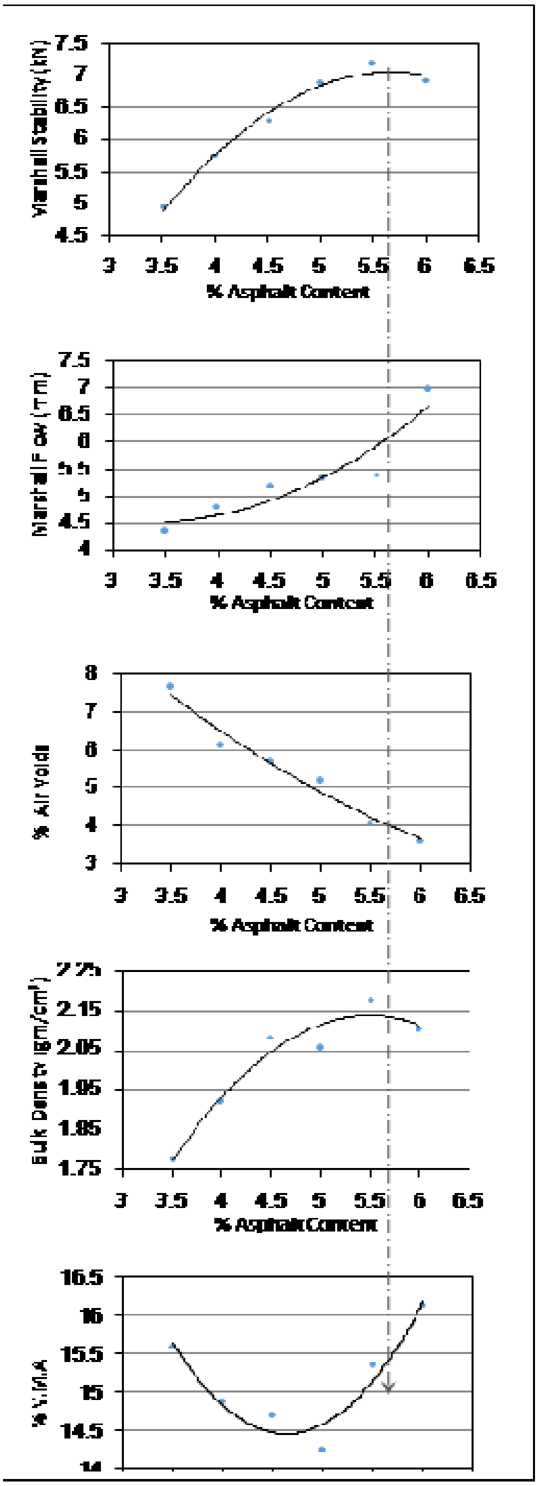


Figure (7) The optimum asphalt content of bricks (O. A. C = 5. 7%)

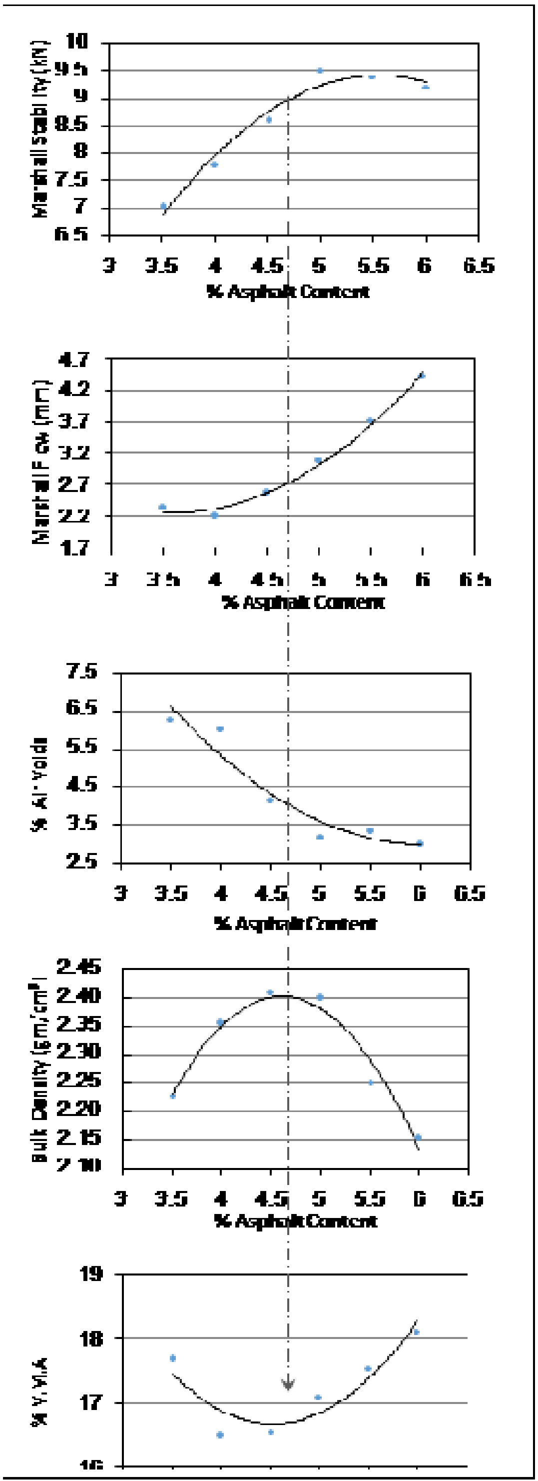


Figure (8) The optimum asphalt content of granite tiles (O. A. C = 4. 7%)

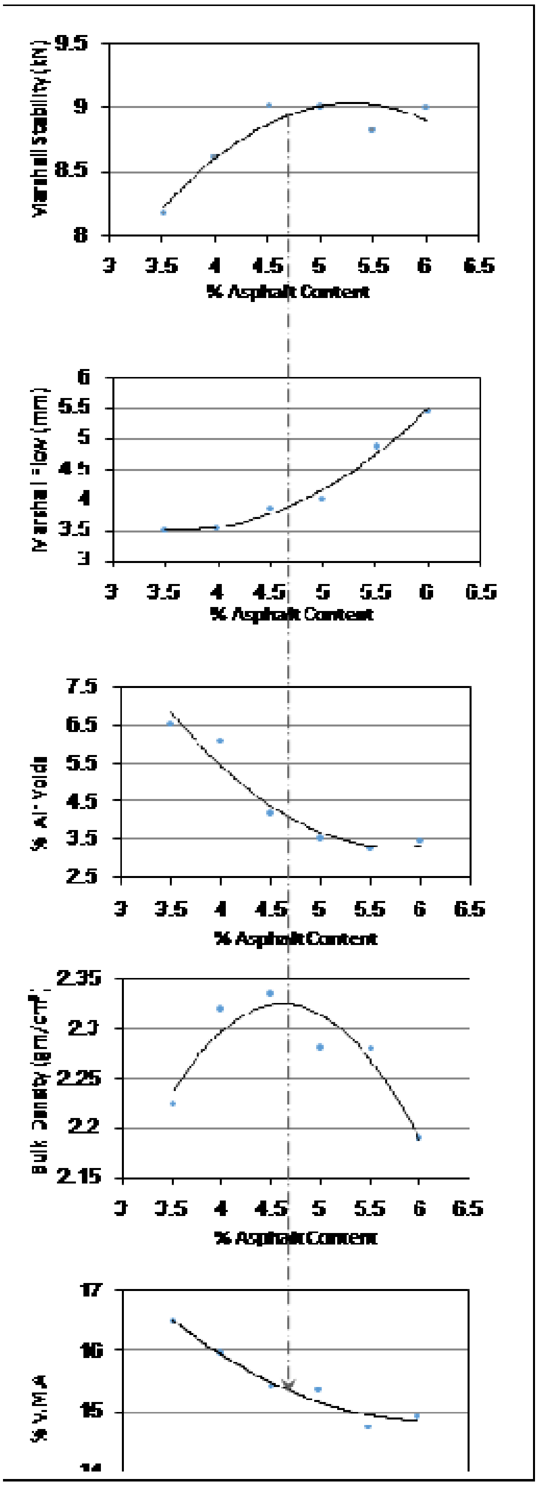


Figure (9) The optimum asphalt content of marble tiles (O. A. C = 4. 7%)

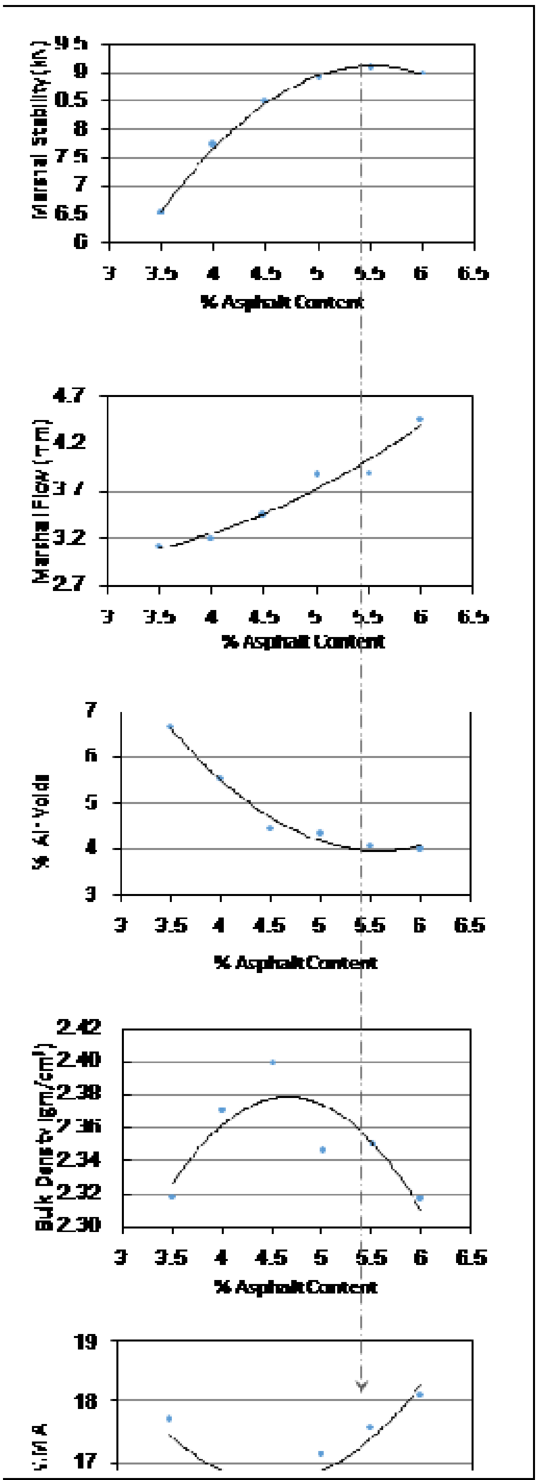


Figure (10) The optimum asphalt content of concrete elements (O. A. C = 5. 4%)

TABLE (5): MARSHALL PROPERTIES FOR CRUSHED AGGREGATE AND DEMOLISHED WASTES

Crushed Aggregate						
% Asphalt Content	**3. 5**	**4. 0**	**4. 5**	**5. 0**	**5. 5**	**6. 0**
Stability (kN)	7. 88	8. 34	9. 22	9. 68	9. 61	8. 66
Flow (mm)	2. 64	2. 59	2. 95	3. 13	4. 08	5. 19
Bulk Density (gm/cm^3)	2. 214	2. 278	2. 298	2. 336	2. 323	2. 31
Air Voids (%)	7. 352	7. 505	5. 423	4. 175	3. 089	3. 182
Voids in Mineral Aggregate (%)	19. 13	18. 34	18. 14	18. 65	18. 952	19. 42
Ceramic Tiles						
Stability (kN)	5. 38	6. 73	7. 18	7. 46	7. 63	7. 45
Flow (mm)	3. 28	3. 32	3. 73	3. 82	4. 83	6. 134
Bulk Density (gm/cm^3)	2. 052	2. 083	2. 175	2. 214	2. 222	2. 218
Air Voids (%)	7. 13	6. 77	5. 257	4. 575	3. 96	3. 728
Voids in Mineral Aggregate (%)	17. 56	15. 35	14. 23	15. 13	15. 96	16. 37
Blocks						
Stability (kN)	5. 46	6. 901	8. 334	7. 552	7. 84	6. 87
Flow (mm)	3. 38	3. 44	3. 57	3. 92	4. 61	5. 89
Bulk Density (gm/cm^3)	2. 008	2. 08	2. 154	2. 132	2. 117	2. 088
Air Voids (%)	8. 004	6. 232	4. 574	3. 89	3. 691	3. 578
Voids in Mineral Aggregate (%)	15. 87	15. 67	16. 33	17. 10	17. 88	19. 10
Terrazzo Tiles						
Stability (kN)	6. 09	7. 27	8. 64	9. 02	8. 87	8. 42
Flow (mm)	2. 86	2. 78	3. 19	3. 44	4. 19	5. 31
Bulk Density (gm/cm^3)	2. 155	2. 229	2. 296	2. 311	2. 327	2. 303
Air Voids (%)	7. 757	7. 174	5. 374	4. 35	3. 562	3. 53
Voids in Mineral Aggregate (%)	16. 856	16. 42	16. 732	17. 38	18. 42	19. 607
Bricks						
Stability (kN)	4. 64	5. 765	6. 308	6. 91	7. 176	6. 93
Flow (mm)	4. 35	4. 83	5. 18	5. 33	5. 42	6. 98
Bulk Density (gm/cm^3)	1. 773	1. 92	2. 083	1. 056	2. 172	2. 101
Air Voids (%)	7. 626	6. 097	5. 672	5. 184	4. 115	3. 628
Voids in Mineral Aggregate (%)	15. 6	14. 88	14. 7	14. 24	15. 35	16. 15
Granite Tiles						
Stability (kN)	7. 02	7. 78	8. 60	9. 52	9. 40	9. 22
Flow (mm)	2. 35	2. 22	2. 58	3. 09	3. 72	4. 45
Bulk Density (gm/cm^3)	2. 226	2. 355	2. 407	2. 400	2. 248	2. 151
Air Voids (%)	6. 286	5. 986	4. 125	3. 162	3. 331	2. 991
Voids in Mineral Aggregate (%)	17. 7	16. 5	16. 56	17. 12	17. 56	18. 14
Marble Tiles						
Stability (kN)	8. 19	8. 61	9. 02	9. 00	8. 82	9. 01
Flow (mm)	3. 52	3. 54	3. 88	4. 0	4. 88	5. 47
Bulk Density (gm/cm^3)	2. 224	2. 32	2. 335	2. 281	2. 282	2. 19

Air Voids (%)	6. 537	6. 11	4. 166	3. 52	3. 23	3. 48
Voids in Mineral Aggregate (%)	16. 52	15. 95	15. 41	15. 34	14. 75	14. 91
Concrete Elements						
Stability (kN)	6. 52	7. 74	8. 51	8. 92	9. 10	9. 02
Flow (mm)	3. 12	3. 21	3. 45	3. 87	3. 90	4. 45
Bulk Density (gm/cm^3)	2. 318	2. 37	2. 40	2. 346	2. 35	2. 317
Air Voids (%)	6. 67	5. 56	4. 46	4. 33	4. 11	4. 02
Voids in Mineral Aggregate (%)	17. 70	16. 50	16. 56	17. 12	17. 56	18. 14

B. ***Resistance to Plastic Flow***

Table (6) shows Marshall test properties results for each mix at optimum asphalt content and represented in Figures (11 to 14). These Figures show that the results for using of demolished wastes were accepted, except the ceramic tiles, bricks were not accepted.

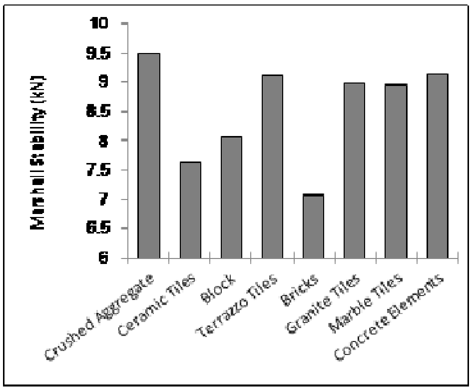


Figure (11) Relation between aggregate types and Marshall stability

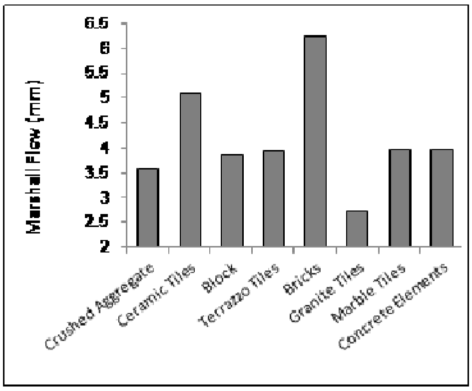


Figure (12) Relation between aggregate types and Marshall flow

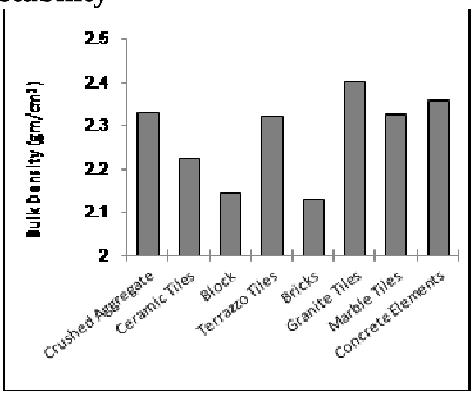


Figure (13) Relation between aggregate types and percentage of bulk density

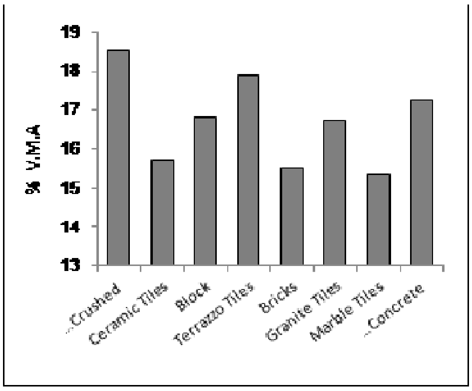


Figure (14) Relation between aggregate types and percentage of voids in mineral aggregate

TABLE (6): MARSHALL PROPERTIES FOR CRUSHED AGGREGATE AND DEMOLISHED WASTES AT OPTIMUM ASPHALT CONTENT

Marshall Test Properties	Specifications	Crushed Aggregate	Ceramic Tiles	Blocks	Terrazzo Tiles	Bricks	Granite Tiles	Marble Tiles	Concrete Elements
Optimum Asphalt Content (%)		5. 2	5. 6	4. 9	5. 3	5. 7	4. 7	4. 7	5. 4
Marshall Stability (kN)	> 8 kN	9. 485	7. 624	8. 076	9. 106	7. 062	8. 981	8. 944	9. 126
Marshall Flow (mm)	(2 – 4) mm	3. 571	5. 10	3. 854	3. 929	6. 219	2. 745	3. 96	3. 974
Bulk Density (gm/cm^3)		2. 33	2. 222	2. 144	2. 323	2. 13	2. 400	2. 325	2. 357
Voids in Mineral Aggregate (%)	> 15 %	18. 557	15. 703	16. 81	17. 873	15. 512	16. 707	15. 334	17. 254

C. ***Moisture Damage***

The results of index of retained strength (I. R. S) are shown in Table (7) and represented in Figure (15) . They indicate that granite tiles, marble tiles, ceramic tiles and bricks have less moisture resistance than other materials, this can be attributed to low cohesion between the particles and asphalt cement due to the smooth surface of tiles and the deleterious materials on surface of bricks .

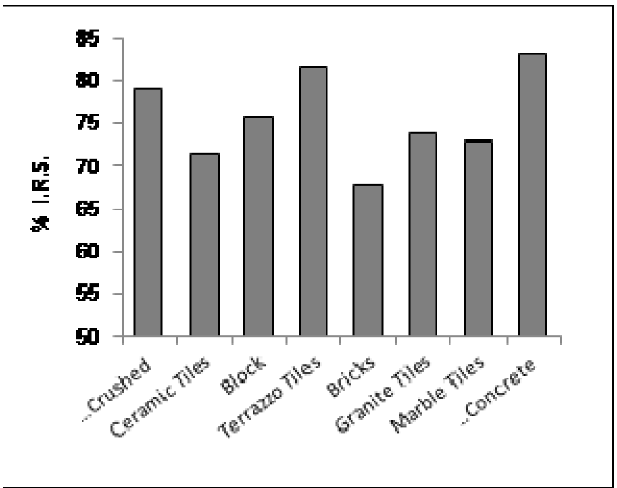


Figure (15) Relation between aggregate types and index of retained strength

TABLE (7): INDEX OF RETAINED STRENGTH FOR CRUSHED AGGREGATE AND DIFFERENT TYPES OF DEMOLISHED WASTES

Compressive Strength (Mpa)			% I. R. S.
Condition	**Dry**	**Wet**	
Crushed Aggregate	3225	2552	79. 13
Ceramic Tiles	2546	1819	71. 44
Blocks	2794	2118	75. 80
Terrazzo Tiles	3185	2597	81. 54
Bricks	1954	1322	67. 65
Granite Tiles	3215	2373	73. 81
Marble Tiles	2988	2176	72. 82
Concrete Elements	3130	2605	83. 22

VII. MODEL DEVELOPMENT

The main step in the development of the statistical models was the selection of the form of the relation between the dependent and the independent variables .

Examination of the figures shown in this study, suggests that the linear models may be used as an initial step. This relation was examined using the SPSS statistical package. The package was used to perform the required regression analysis. The performance related properties include; (Marshall Stability (MS), Marshall Flow (MF), Air Voids (AV), Voids in Mineral Aggregate (VMA) and Index of Retained Strength (IRS).

The range values of the predictor variables are shown in Table (8) and the results of the statistical analysis are shown in Table (9). The obtained (R) values are substantially high; this would suggest that the predicted and observed values will approximately be matching if the selected aggregate (crushed aggregate and demolished wastes) properties fall within the examined range of data. The comparison of predicted and observed values of Marshall stability , Marshall flow , air voids , voids in mineral aggregate and index of retained strength are shown in Figures (16) to (20) respectively.

TABLE (8): THE RANGE VALUES OF THE PREDICTOR VARIABLES

Variables	Symbol	Unit	Range
Bulk Specific Gravity	BSG	gm/cm^3	(2. 3 – 2. 7)
Water Absorption	WA	%	(0. 4 – 2. 2)
% Coating and Stripping of Bitumen	SB	%	(89-98)
% Wear (Los Angeles Abrasion)	WE	%	(19 – 33)
% Deleterious Materials	DM	%	(0. 08-2. 03)
Asphalt Content	AC	%	(4. 7 – 5. 6)

TABLE (9): THE DEVELOPMENT OF STATISTICAL MODELS

Model	R
Marshall stability (kN) = 29. 244-7. 176×BSG-0. 403×WA + 0. 021×SB-0. 283×WE-0. 891×DM + 0. 751×AC	0. 896
Marshall flow (mm) = 38. 436-8. 617×BSG + 0. 898×WA-0. 115×SB-0. 254×WE-0. 469×DM +0. 865×AC	0. 923
% Air voids = 22. 385-3. 953×BSG-0. 017×WA + 0. 02×SB-0. 078×WE +0. 26×DM-1. 565×AC	0. 924
% V. M. A. = 11. 754 ×BSG-1. 833×WA + 0. 311×SB + 0. 286×WE + 2. 394×DM + 0. 391×AC-51. 524	0. 854
% I. R. S =-15. 606 ×BSG-4. 108×WA + 1. 542×SB + 0. 092×WE-2. 91×DM + 6. 159×AC-58. 841	1. 00

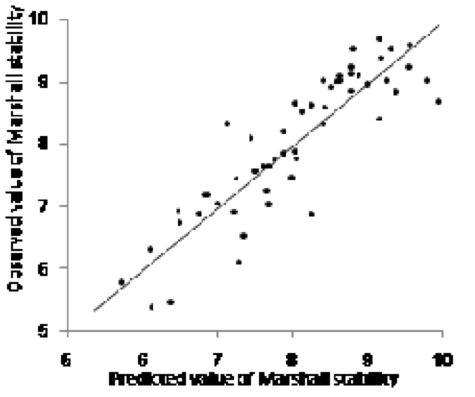


Figure (16) Comparison between the observed and predicted Marshall stability resulted from different types of aggregate.

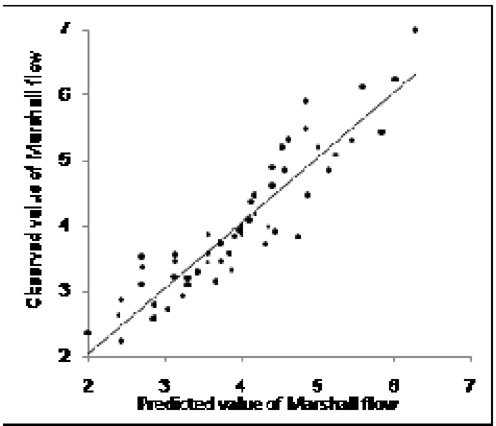


Figure (17) Comparison between the observed and predicted Marshall flow resulted from different types of aggregate.

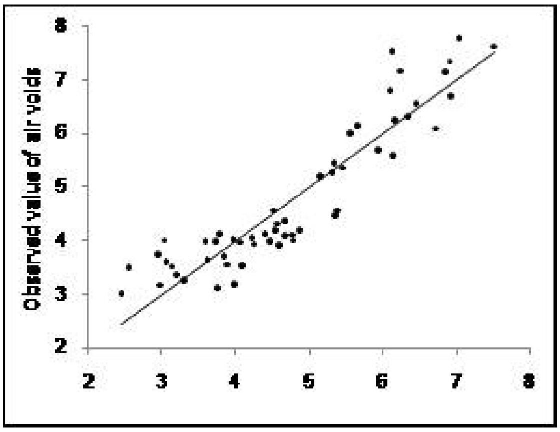


Figure (18) Comparison between the observed and predicted air viods resulted from different types of aggregate.

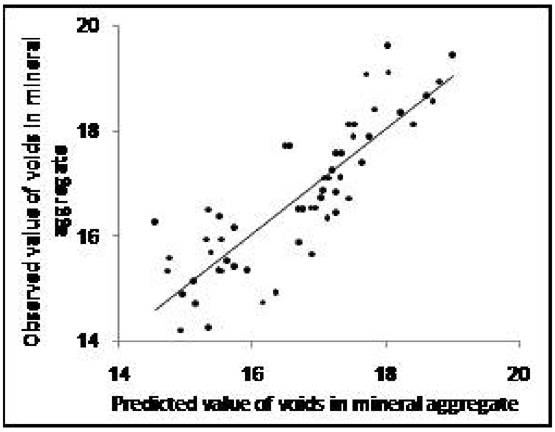


Figure (19) Comparison between the observed and predicted voids in mineral aggregate resulted from different types of aggregate.

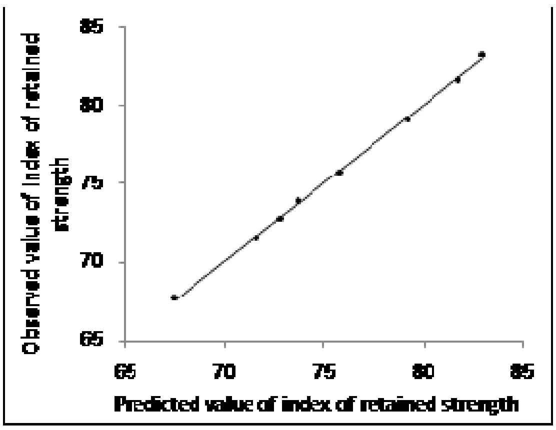


Figure (29) Comparison between the observed and predicted index of retained strength resulted for from different types of aggregate.

VIII. CONCLUSIONS

On the basis of the materials used and laboratory tests performed in this study, the following conclusions can be stated:

1) The Marshall stability for the mixtures containing demolished waste of granite, marble, terrazzo and concrete elements decreases slightly about 5% than conventional mixture stability and is still within the specifications.
2) The Marshall stability for the mixtures containing demolished waste of blocks decreases about 15% than conventional mixture stability, therefore using this material gives critical results.
3) The Marshall stability and flow for the mixtures containing demolished waste of bricks and ceramic were not accepted according to the specifications.
4) The percentages of voids in mineral aggregate of all demolished wastes were accepted.
5) The moisture sensitivity test for demolished wastes showed that the smooth surfaces of granite, marble, ceramic particles decreased the index of retained strength. To improve this performance of the mixtures it is recommended to use these materials with fine sizes to increase crushed faces of particles.
6) The decrease in index of retained strength of the mixture containing demolished waste of bricks is attributed to the presence of high percentage of deleterious materials and the high ability of bricks for water absorption.
7) The developed numerical models can be used as a guide to predict the suitability of demolished wastes for the production of hot mix asphalt by using the properties of demolished wastes to evaluate the mixtures for resistance to plastic flow and moisture damage.

Finally, from this study it can be concluded that the use of demolished wastes as aggregate in the production of hot mix asphalt for surface layer of pavement is suitable, except the demolished wastes of bricks and ceramic tiles due to their Marshall stability decrease by (25% and 20%) respectively compared with the conventional mix.

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