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Effect of Waste Glass on Properties of Asphalt Concrete Mixtures

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ABSTRACT

With the rapid economy growth and continuously increased consumption, a large amount of glass waste materials is generated. This study attends to study the performance of asphalt concrete mix, where some of fractional fine aggregate is substituted with different percentages of crashed glass materials of 5%, 10%, 15% and 20 %. The Marshall design was used to examine the influence of the Optimum Asphalt Content (O.A.C.) at different fine glass percentages and the resistance against water. Asphalt-concrete mix properties can be improved by using a hydrated lime admixture and other mixtures. It is expected that the recycling and use of waste glass in asphalt mixes is feasible. Subsequently, by obtaining low price and economic mixes that will reduce the O.A.C., increase the stability and the durability of the mix, in addition to increasing the skid resistance of the road surface, this will reduce accidents and save a lot of money. By crushing and sieving, waste glass materials can be used as fine aggregates in asphalt concrete, where this is called glassphalt. Satisfactory performance of upper asphalt pavement layers can be achieved by adding glass waste with 10% of the mix.

KEYWORDS: Glass waste, Water stability, Skid resistance, Optimum asphalt content (O.A.C.).

INTRODUCTION

A large amount of glass waste from industry has been an urgent subject at both national and global levels. Glass recycling can save energy and decrease environmental waste. Nearly 10 million tons of glass waste have been generated every year around the world. Hundreds of tons are generated in Jordan, amounting to around 3-5% of domestic waste.

At the present time, the commercial use of waste glass in asphalt paving applications has been limited to communities such as the city of New York in the USA, where the quantity of waste glass produced and collected provides a sufficient incentive to recycle it in pavement applications. Most of the earlier applications of glass use have been limited to test pavements or specialty applications.

In the late 1960s and early 1970s, a number of studies and field demonstrations were undertaken in the United States to examine the potential of using waste glass as an aggregate substitute material in hot mix asphalt. During this period, test-paving strips were placed at approximately 33 locations throughout the United States and Canada.

From the mid-1970s through the mid-1980s, the city of Baltimore made use of glass in its street pavement program. At least 17 streets were paved with glass to produce a "sparkle" effect, resulting from the reflection of sunlight or street lamp light off the glass pavement. In the mid-1980s research, activities were undertaken on Long Island and a glass processing plant was designed and began operation, processing over 12,600 metric tons (14,000 tons) of mixed waste glass

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for use as an aggregate substitute in paving applications.

More recently, numerous paving projects using waste glass have been undertaken around the world. However, by far, the most aggressive program has been undertaken by the city of New York's Department of Transportation, where from 1990 through 1995 a quantity of approximately 225,000 metric tons (250,000 tons) of glass has been used in resurfacing applications.

Flat and elongated particles that could contribute to pavement raveling, stripping, poor skid resistance, abnormally high tire wear and excessive glare were all identified by early researchers as potential problems. Since glass does not absorb any of the asphalt cement binder and since glass is also "hydrophilic", moisture damage (stripping) is a particular concern that has been identified, especially when high percentages and large gradations are introduced into a surface course mix. Many of the early investigators recommended the addition of lime as an antistripping agent to reduce potential stripping problems. Early glassphalt projects used high percentages of glass (greater than 25 percent by weight of the mix) with coarse glass gradations (greater than 12.7 mm (1/2 in)). Current data suggest that the use of high glass percentages and large particles of glass probably contributed to most of the stripping and raveling problems that were reported during the early test pavement demonstrations of the 1960s and 1970s.

The high angularity of cullet, compared with rounded sand, can enhance the stability of asphalt mixes, where properly sized cullet is used. Stabilities comparable and, in many cases, better than those of conventional mixes have been reported. Other beneficial characteristics include low absorption, low specific gravity and low thermal conductivity, which reportedly offer enhanced heat retention in mixes with glass.

Proper mix design with suitable ingredients will ensure an improvement of the existing performance of roads. It is anticipated that some failures are attributed to the poor design of the asphalt mixes and/or to the materials having been used. The existence of varied properties for local materials requires different mix designs to be used. One of the major concerns in mix designing is the type and amount of filler used, which is known to highly affect the mix design, especially the optimum asphalt content. The amount of filler used in the plant mixes will be a factor in affecting the properties of the mix produced. However, it is not possible to establish the exact amount of this filler due to the loss of fines in the form of dust from the plant. When filler is added to the asphalt, a marked change in the consistency of asphalt will result. This change can be clearly inspected by increasing the viscosity, penetration and softening point of the asphalt filler mix. Various studies have been conducted to study the properties of mineral filler, especially the material passing 0.075 mm sieve (No. 200) and to evaluate its effect on the performance of asphalt paving mixtures in terms of consistency, void filling, resistance to displacement, water susceptibility, Marshall stability and mix strength.

Shafabakhsh and Sajed (2014) indicated that the dynamic properties of glass–asphalt concrete, the fatigue life, stiffness modulus and creep compliance are improved in comparison with those of ordinary asphalt concrete. Arabani (2011) found that the behavior of Hot Mix Asphalt (HMA) in different temperature conditions, depending on the variation of the admixture contents and the gradation of the aggregates, is improved in comparison with that of HMA mixtures.

Al-Qaisi (1981) studied the effect of filler-asphalt ratio on the properties of filler- mastic and asphalt paving mixture, using five types of filler (Portland cement, lime dust stone, hydrated lime, powder of crushed gravel and sulfur). He stated that the range of the filler-asphalt ratio required to produce the desired properties of paving mixtures is influenced by the type of filler used and that such range should be set accordingly. Also, he showed that several locally available materials could be used to replace Portland cement as filler in asphalt paving mixtures.

Abrahams (1973) concluded that fillers containing large particles result in a more stable mortar than if the large particles are not present. This phenomenon was attributed to the fact that a large surface area of fine powder could adsorb more bitumen and the portion adsorbed was the asphaltenes, which are the most rigid particles. This resulted in lighter, more fluid oil between particles, increasing flow capabilities. Also, the large particles were believed to offer mechanical resistance to flow which was not present in the smaller particles. The researcher concluded that the baghouse fines can greatly affect the properties of the mix, such as the optimum asphalt content, stability and stability loss.

Abdul-Raheem (2001) studied the effect of sulfur (blowdown) and polyethylene wastes on rheological properties and temperature susceptibility of virgin and aged asphalt cement, as well as on their mixture properties and studied the effect of these wastes on the moisture susceptibility of asphalt-concrete mixtures and other performance properties. He concluded that adding 9% polyethylene wastes by weight of (40-50) asphalt grade resulted in increasing ring and ball softening point by 28% than that of original asphalt and increasing the absolute viscosity at 25˚C by 5% compared to that of original asphalt. The addition of polyethylene to asphalt-concrete mixtures at optimum content resulted in decreasing unit weight, air voids and Marshal flow, while increasing Marshal stability, stiffness, VFB and expected theoretical stiffness modulus. In addition, the results indicated that the stiffness determined from mechanical properties (flexural strength test) resists the pavement deformation forces. Therefore, polyethylene should be used at truck stops and parking lots where standard loads cause extended periods of such deformation.

Salman (1983) investigated the effect of hydrated limestone and silty-sized soil filler on the properties of asphalt and showed that lime and silty-sized soil could be used as a satisfactory filler material when used in a limited range. He also concluded that, at higher filler percentage, some irregular relationship is observed between filler content and percent of air voids in the compacted mix.

Sadoon (2010) studied the effect of different filler types on performance properties of asphalt paving materials. Six different types of filler from five local sources in Iraq were used to evaluate the resistance to plastic flow using Marshall stiffness test and low temperature cracking and temperature susceptibility using indirect tensile strength test, in addition to studying moisture susceptibility by using retained strength test and resistance to permanent deformation by using indirect tensile creep test. The results indicated that filler type has a great effect on the cohesion of the mix, where such type of filler showed high indirect tensile strength values with respect to other types of filler at different test temperatures. He concluded that the moisture damage also is affected by the type of filler, where one type showed high susceptibility to water attack with a higher value of index retained strength compared with other types.

Aschuri and Woodside (2007) investigated the behavior of asphalt-concrete mix containing fly ash and hydrated lime in binder. The fillers as modifier were prepared with 3%, 6% and 9% by weight of bitumen, respectively. Marshall tests were carried out at optimum bitumen content to evaluate the effect of fly ash and hydrated lime on the properties of asphalt concrete in terms of stability, unit weight, air void in mix, void in mineral aggregate and stripping resistance. Test results showed that the performance of bitumen mixes prepared using fly ash and hydrated lime as modifier was better than that of origin bitumen mixes.

Pinto et al. (2009) studied the performance changes and fundamental material characteristics associated with moisture damage due to various anti-stripping additives in HMA mixtures through various experimental approaches and a numerical solution. Three additives (i.e., one reference additive, hydrated lime and two alternative additives: fly ash and cement) were investigated by adding them into two types of mixes, where two different asphalt binders were used. Two asphalt concrete mixture scale performance tests and two local - scale mixture constituent tests were conducted to characterize the effect of binder-specific anti-striping additives on the binder- aggregate bonding potential in mixtures. The test results showed that all treated mixtures performed well even after severe moisture-conditioning processes, while the untreated mixture did not pass the requirement with six cycles.

Many research works were published on the topic of adding waste glass to asphalt paving mixture as an alternative solution to reduce the generated bulk of waste glass and to establish a ground for understanding and examining the waste glass recycle process (Abrahams, 1972; Chesner, 1992; Chesner and Petrarca, 1987; Flynn, 1993; Iraqi State Commission of Roads and Bridges, 2003; Jiang, 2003; Khedawi and Al-Qadi, 2008; Leite and Young, 1971; Marti and Mielke, 2002; Transportation Research Board of National Academies, 2003; Molisch et al., 1975; Molisch et al., 1972; Nansu and Chen, 2002; Paker et al., 1998; Petrarca, 1988; Prithvi, 1998; Samtur, 1974; Shafabakhsh and Sajed, 2014; Shaopeng et al., 2003; ASTM, 1994).

The main objectives of this research are as follows:

(1) To investigate the feasibility of using fine waste glass in asphalt mixtures to achieve economic advantages and good performance.

(2) To find the optimum percentage of waste glass which will give the best properties of the asphalt mix (stability, density AV% and VMA).

(3) To find the percentage of stability loss for samples with waste glass compared with others without glass.

(4) To find the skid resistance for the surface of the pavement mix by using the O.A.C. with and without waste glass.

Materials Used

The materials used in the research are:

Aggregate

One type of lime stone aggregate was used, which was brought from Al-Hizam queries in the northeast of Amman-Jordan .Gradation type was used according to the Jordanian Ministry of Public Works and Housing (MPWH) (2010) gradation specifications.

Table (1) shows the gradation of aggregate and Table (2) summarizes the properties of aggregate used in the research.

Table 1. Gradation of aggregate

Sieve size	Specification limits % passing	% passing mid point	% retained	Cumulative % retained
3/4” (19.5 mm)	100	100	0	0
½”(12.5 mm)	80 – 100	90	10	10
3/8” (9.5 mm)	56 – 80	68	22	32
# 4 (4.76 mm)	35 – 56	45	23	55
# 8 (2.36 mm)	23 – 38	30	15	70
0.85 mm	13 – 27	20	10	80
0.425 mm	8 – 12	10	10	90
0.075 mm	2 – 8	5	5	95
pan				100

Table 2. The properties of aggregate used in the research

Aggregate type (limestone) Al-Hizam quarries, Amman - Jordan	ASTM test designation	Bulk specific gravity	Apparent specific gravity	Absorption %
Coarse	C 127	2.5	2.52	4.5
Fine	C 128	2.47	2.485	7
Mineral filler	C 128	2.515	2.534	

Asphalt

One penetration grade of asphalt cement (85-100) was used in this study and was obtained from the Jordanian Petroleum Refinery Company in Zarqa / Jordan, as it is widely used in flexible pavement construction. Table (3) presents the physical properties of this asphalt.

Table 3. Properties of the Jordanian petroleum refinery asphalt

Properties	Methods	Test results
Penetration @25^{o}C	ASTM D5	85 – 100
Ductility (cm) @ 25^{o}C	ASTM D113	100
Specific gravity @25^{o}C	ASTM D70	1.01
Softening point C^o	ASTM D36	49
Flash point C^o	ASTM D92	300
Fire point C^o	ASTM D92	315
Solubility in trichloroethylene %		99

Crushed Waste Glass

Fine passing sieve # 8-2.36 mm with the graduation in SG of waste glass was used. Table (4) presents the sieve analysis gradations of the crushed waste glass.

Table 4. Sieve analysis gradations of the crushed waste glass

Sieve size	% passing mid-point	% retained	cumulative % retained
3/4” (19.5 mm)	100	0	0
½”(12.5 mm)	95	5	5
3/8” (9.5 mm)	88	7	12
# 4 (4.76 mm)	51	37	49
# 8 (2.36 mm)	31	20	69
0.85 mm	11	20	89
0.425 mm	6	5	94
0.075 mm	2	4	98
pan		2	100

Chemical Properties of the Waste Glass

Glass-formers are those elements that can be converted into glass when combined with oxygen. Silicon dioxide (SiO_2), used in the form of sand, is by far the most common glass-former. Common glass contains about 70% SiO_2. Soda ash (anhydrous sodium carbonate, Na_2CO_3) acts as a fluxing agent in the melt. It lowers the melting point and the viscosity of the formed glass, releases carbon dioxide and helps stir the melt. Other additives are also introduced into glass to achieve specific properties. For example, either limestone or dolomites are sometimes used *in lieu* of soda ash. Alumina, lead and cadmium are used to increase the strength of glass and increase resistance to chemical attack.

Various iron compounds, chromium compounds, carbon and sulfur are used as coloring agents. Most glass bottles and window glass are made from soda-lime glass, which accounts for approximately 90% of the glass produced in the United States. Lead-alkali-silicate glasses are used in the manufacturing light bulbs, neon signs, as well as crystal and optical glassware.

Borosilicate glasses, which have extraordinary chemical resistance and high temperature softening points, are used in manufacturing cooking and laboratory ware (Aschuri and Woodside, 2007). Table (5) lists the typical chemical compositions of these glasses. These compositions interact with the asphalt mix to produce better properties and enhance the properties of the mix.

Table 5. Typical chemical composition of glass types

Constituent	Borosilicate	Lead	Soda-Lime
SiO_2	60 - 80	60 - 70	70 - 73
Al_2O_3[a]	1 - 4	--	1.7 - 2.0
Fe_2O_3	--	--	0.06 - 0.24
Cr_2O_3[b]	--	--	0.1
CaO	--	1	9.1 - 9.8
MgO	--	--	1.1 - 1.7
BaO	--	--	0.14 - 0.18
Na_2O	45	7 - 10	13.8 - 14.4
K_2O	--	7	0.55 - 0.68
PbO	--	15 - 25	--
B_2O_3	10 - 25	--	--

a. Higher levels for amber-colored glass. b. Only present in green glass.

Glass is generally considered an inert material. However, it is not chemically resistant to hydrofluoric acid and alkalis. Expansive reactions between amorphous silica (glass) and alkalis (such as sodium and potassium found in high concentrations in high alkali Portland cement) could have deleterious effects if glass is used in Portland cement concrete structures.

RESULTS AND DISCUSSION

Mix Design

Asphalt mixes containing crushed glass were designed using standard laboratory procedures. Conventional fine hot mix aggregate gradations, as specified in AASHTO M29 (ASTM, 1994), were used. It is recommended that mix design testing includes stripping potential evaluations as outlined in AASHTO T283.

Currently, most highway departments allow the use of 5% to 10% glass in their asphalt mixes. Although some areas use 6.4 mm to 12.7 mm (1/4 in to 1/2 in) and larger gradations, many users are taking a more conservative approach to gradation size. The city of New York has lowered its specified gradation top size in its mix design to 9.5 mm (3/8 in) from 15.3 mm (5/8 in). Los Angeles has specified the use of 9.5 mm (3/8 in) glass. Studies in Virginia and Florida also have recommended the use of 9.5 mm (3/8 in) gradation (User Guidelines for Waste and Byproduct Materials in Pavement Construction, Internet).

Most data at the present time indicate that larger gravel-sized glass particles will reduce pavement performance and that optimum performance can be achieved by using crushed glass as a sand or fine aggregate substitute (less than 4.75 mm, or No. 4 size sieve). When waste glass is used as a fine aggregate substitute material, glass performance in hot mix asphalt should be comparable to that of conventional mixes. Where larger gravel-sized glass particles are used, raveling and stripping in particular could be a problem (User Guidelines for Waste and Byproduct Materials in Pavement Construction, Internet).

The introduction of an anti-stripping agent such as hydrated lime (approximately 2% by weight of aggregate) could be beneficial, but performance should be satisfactory if only fine-grained 4.75 mm (No. 4 sieve) glass is used and substitution rates do not exceed 15%.

Figure (1): Specimens ready for testing

Figure (2): Specimen testing

Determination of Optimum Asphalt Content

To determine the optimum asphalt content for the mixture, the procedure indicated by the standard American Institute MS-2 Manual (2008) and ASTM D1559 (2008) was followed as part of this study.

Three specimens at each asphalt content (4, 5, 6 and 7%) were tested for stability, flow and air voids in mineral aggregate. The optimum asphalt content, which was the average of asphalt contents that meet optimum stability, maximum unit weight and 4% air voids, was determined as follows.

By using different percentages of glass waste of 5%,10%,15% and 20%, the optimum binder content was found to be 5.75% for 0%, 5.615% for 5%, 5.35% for 10%, 5.65% for 15% and 5.68% for 20% of glassphalt, as indicated in Tables 6 through 10 and Figures 3 through 7.

Table 6. 0% glass content of asphalt

0% Glass							
PHA	**AC**	**Density**	**Stability**	**AV**	**VMA**	**VFA**	**FLOW**
%	**%**	**g cm^{-3}**	**kg**	**%**	**%**	**%**	**in**
4	3.85	2.174	8492	8.36	16.68	50.02	13.04
5	4.76	2.2019	9999	6.04	16.45	63.09	15.60
6	5.67	2.214	10439	4.31	16.72	73.80	16.86
7	6.54	2.2025	10229	3.58	17.91	80.01	19.26

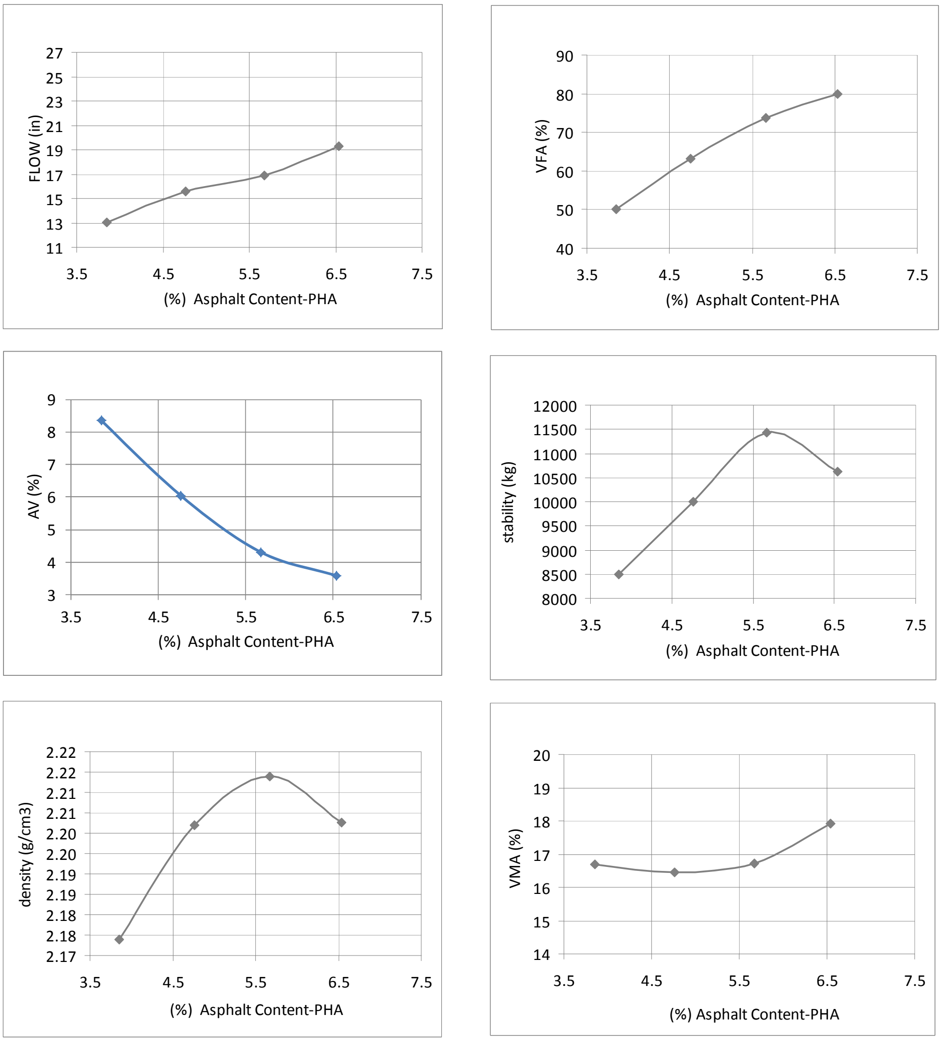

Figure (3): Experimental results for mixes with 0% glass powder

The optimum asphalt content for the mixture with 0% glass powder; OBC = (5.7+5.65+5.9)/3 = 5.75%.

Table 7. 5% glass content of asphalt

5% Glass							
PHA %	**AC %**	**Density g cm^{-3}**	**Stability kg**	**AV %**	**VMA %**	**VFA %**	**FLOW in**
4	3.85	2.123	10641	10.28	18.39	44.10	14.50
5	4.76	2.172	11008	7.67	17.87	57.11	16.45
6	5.67	2.251	12949	2.74	15.36	82.18	17.50
7	6.54	2.237	9707	2.13	16.63	87.21	26.00

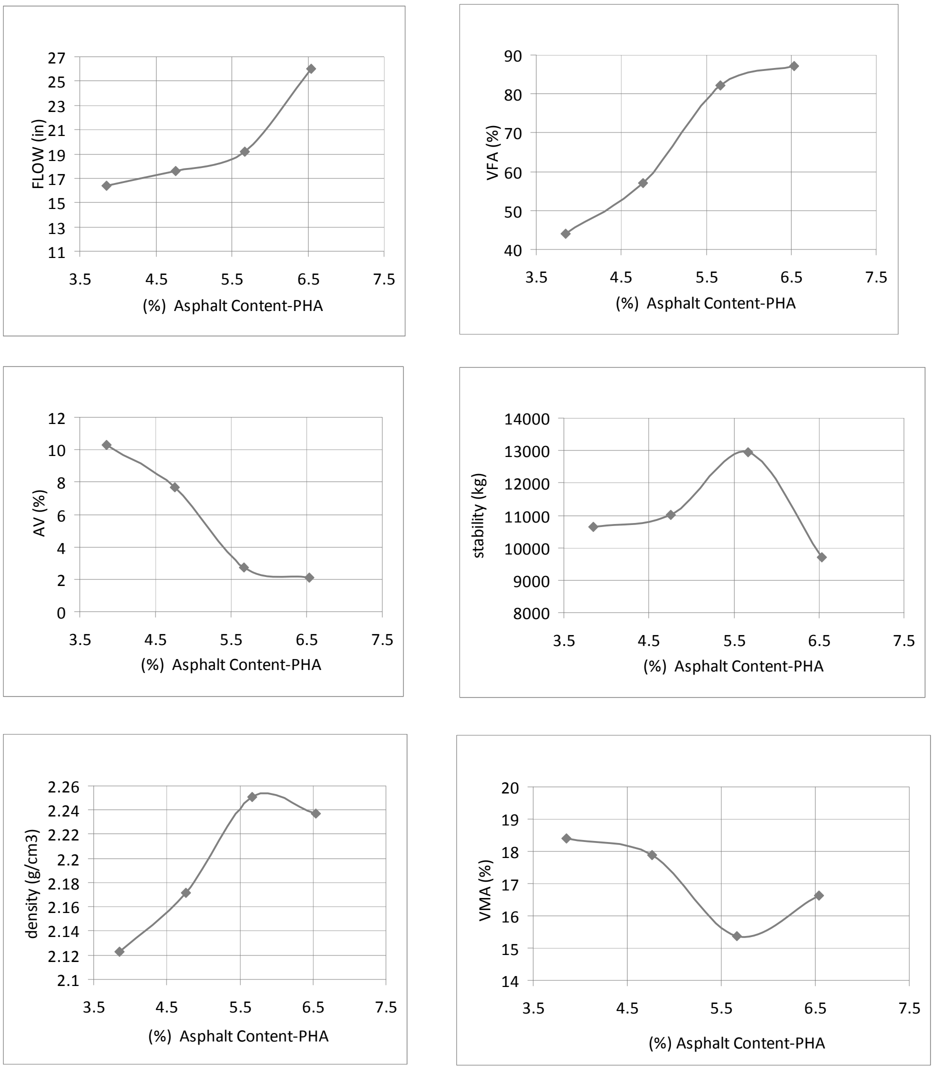

Figure (4): Experimental results for mixes with 5% glass powder

The optimum asphalt content for the mixture with 5% glass powder; OBC = (5.65+5.4+5.8)/3=5.615%.

Table 8. 10% glass content of asphalt

10% Glass							
PHA %	**AC %**	**Density g cm^{-3}**	**Stability kg**	**AV %**	**VMA %**	**VFA %**	**FLOW in**
4	3.85	2.137	10471	10.32	18.45	44.22	12.99
5	4.76	2.174	11696	7.58	17.83	57.51	15.00
6	5.67	2.247	9627	3.30	15.89	79.28	17.00
7	6.54	2.241	8153	2.37	16.89	85.96	19.10

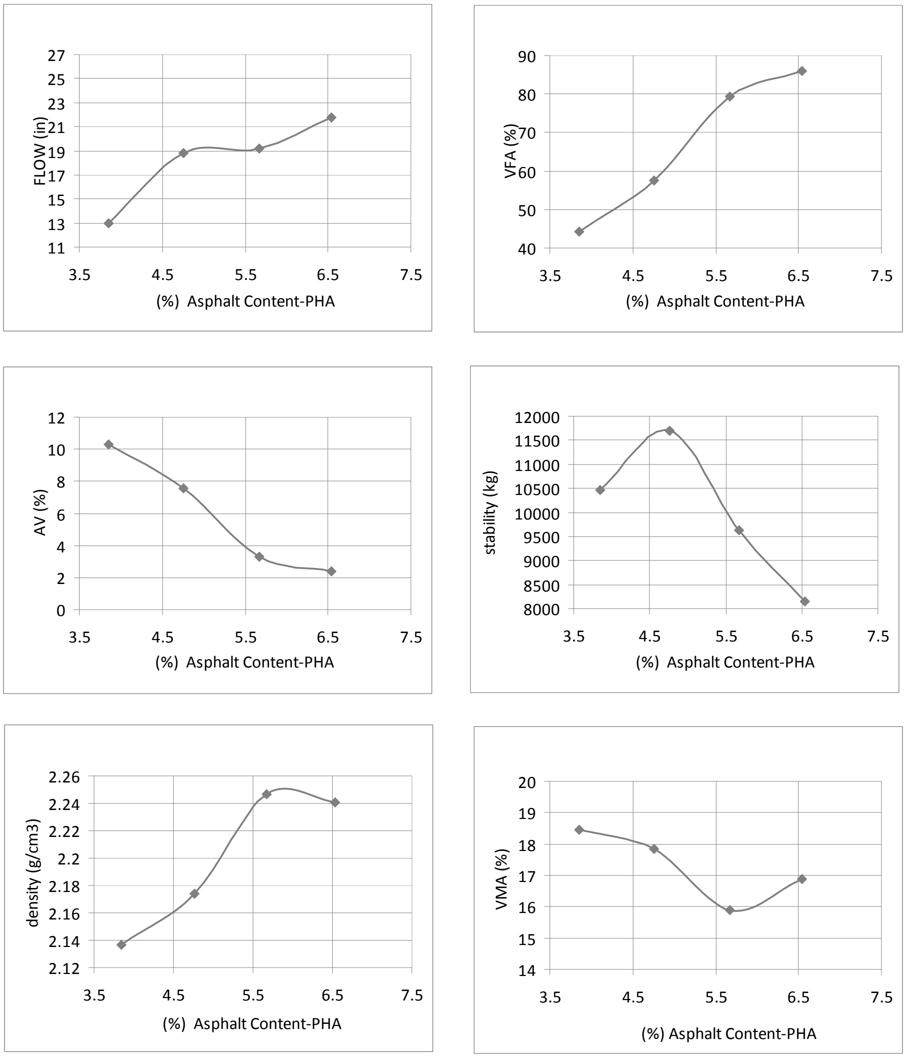

Figure (5): Experimental results for mixes with 10% glass powder

The optimum asphalt content for the mixture with 10% glass powder; OBC= (4.75+5.5+5.8)/3=5.35%.

Table 9. 15% glass content of asphalt

15% Glass							
PHA %	**AC %**	**Density g cm^{-3}**	**Stability kg**	**AV %**	**VMA %**	**VFA %**	**FLOW in**
4	3.85	2.133	5813	10.18	18.30	44.38	16.06
5	4.76	2.203	9498	6.04	16.42	63.27	16.46
6	5.67	2.241	10992	3.54	16.05	77.97	18.82
7	6.54	2.234	8901	2.01	16.53	87.83	22.85

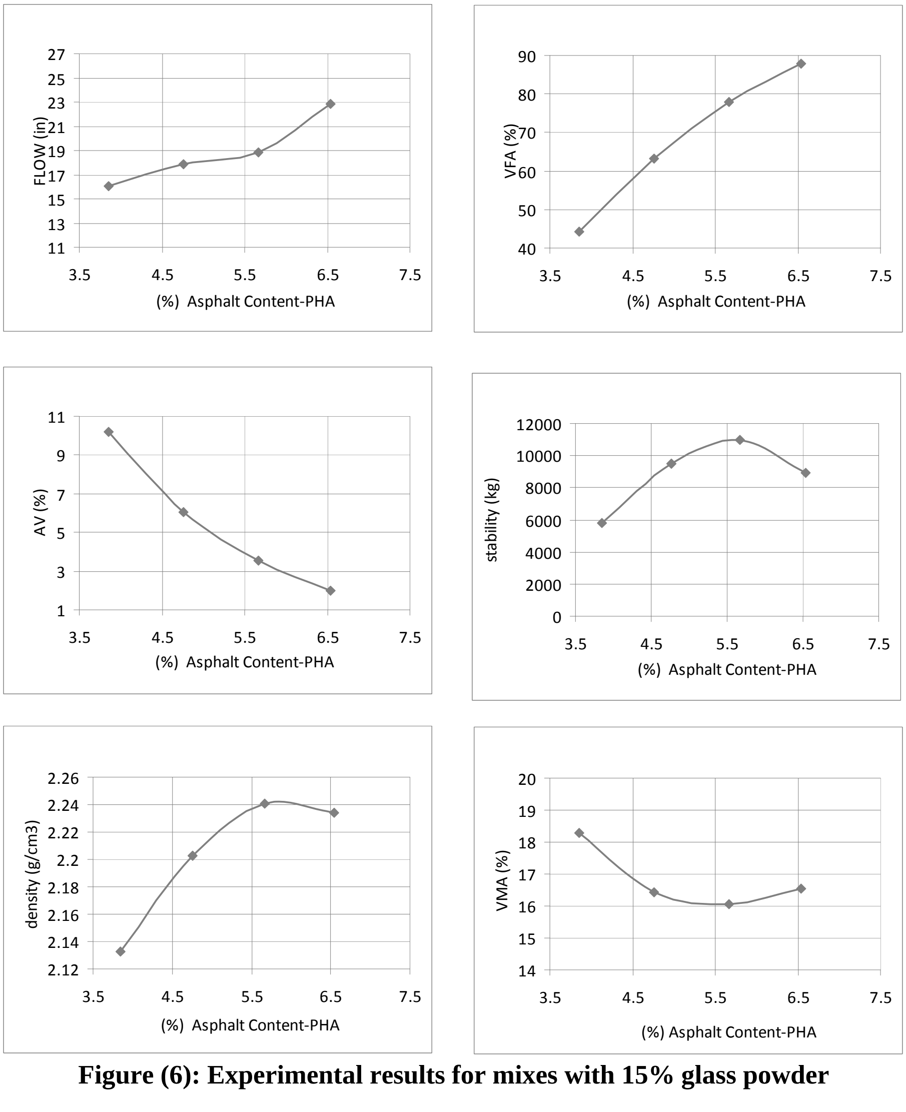

Figure (6): Experimental results for mixes with 15% glass powder

The optimum asphalt content for the mixture with 15% glass powder; OBC= (5.65+5.5+5.8)/3=5.65%.

Table 10. 20% glass content of asphalt

20% Glass							
PHA %	**AC %**	**Density g cm^{-3}**	**Stability Kg**	**AV %**	**VMA %**	**VFA %**	**FLOW in**
4	3.85	2.119	8103	10.75	18.82	42.93	11.48
5	4.76	2.178	9701	7.26	17.51	58.71	14.78
6	5.67	2.246	11349	2.65	15.29	83.31	16.28
7	6.54	2.244	9080	2.37	16.84	85.98	17.79

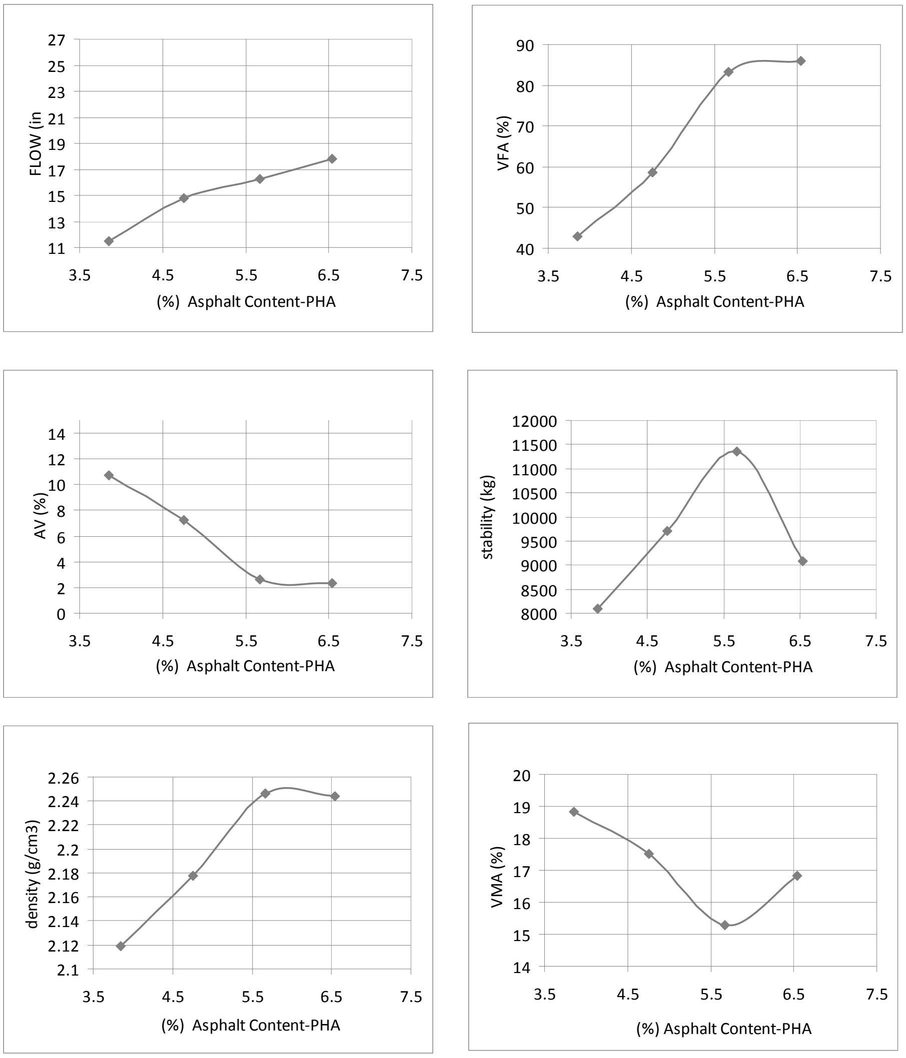

Figure (7): Experimental results for mixes with 20% glass powder

The optimum asphalt content for the mixture with 20% glass powder; OBC= (5.65+6+5.4)/3=5.68%.

Table 11 indicates the percentage of waste glass and the optimum binder content as well as the results of the effect of adding waste glass on the properties of asphalt-concrete mixtures. The optimum binder content (OBC) was found to be 5.35% for the 10% of glassphalt which satisfied all the requirements as per the specification limits and gave a lower OBC of 7.2% than the 0% of glassphalt.

Analysis of Results

Glassphalt surfaces appear to dry faster than traditional pavings after rain, because the glass particles do not absorb water. Glassphalt surfaces are also more reflective than conventional asphalt and may improve nighttime road visibility.

By using different percentages of glass waste of 5%,10%,15% and 20%, the optimum binder content was found to be 5.75% for 0% and 5.35% for 10% glassphalt which satisfied all the requirements as per the specification limits. The specification limits are as follows: Stability (>550 kg), Flow (0.08 in-0.16 in), AV (3%-5%), VMA (>14 %), VFA (65%-78%).

Table 11. Properties of asphalt-concrete mixtures with the addition of waste glass

Properties	% waste glass by weight of fine aggregate				
	0	5	10	15	20
Marshall stability, kg	1075	1110	1195	1100	1153
Flow 0.01"	17	17.5	16	18	16.2
Unit weight, g cm^{-3}	2.213	2.248	2.225	2.24	2.247
Voids in mineral aggregate, %	16.5	15.35	16.35	16	15.2
Air voids, %	4.2	2.8	4.4	3.5	2.5
Voids filled with asphalt, %	73.5	81	72.5	77	83.5
Marshall stiffness, kg/in	68.8	69.2	53.77	60.1	71.17
Retained stability, %	69.5	78.5	84.7	87.2	90.2
Optimum Binder Content (O.B.C.), %	5.75	5.615	5.35	5.65	5.68

Use Limitations: Most installations of glassphalt have been designed to meet the standards of the Asphalt Institute for medium traffic asphalt, which specify a maximum speed limit of 40 mph. These standards include requirements for stability, flow, voids in mineral aggregate, percentage of air voids in the mix and unit weight.

The most common applications are as surface pavement (surface coarse) for residential streets, secondary roads, parking lots, sidewalks and curbing.

CONCLUSIONS

Based on the results obtained in this study, the following conclusions can be drawn:

1. Waste broken glass can be used in asphalt concrete with the maximal size of 2.36 mm and the optimal replacement ratio of 10%.
2. The performances, such as strength index, high temperature stability and water stability achieve the standards of the asphalt mix design.
3. The water stability of glassphalt can be improved by introducing hydrated lime or liquid anti-stripping agent. Liquid anti-stripping agent is more effective in improving the water stability of glassphalt than hydrated lime.
4. Using waste glass in hot mixed asphalt will decrease pollution and environmental problems.

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