The Effect of Using Glass Powder Filler on Hot Asphalt Concrete Mixtures Properties

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Abstract

The early use of asphalt for road and street construction began in the late 1800s, and grew rapidly with the emerging automobile industry. Since that time, asphalt technology has made strides such that today the equipment, techniques and materials used to build asphalt pavement structures are highly sophisticated.

Waste glass has been used in highway construction as an aggregate substitute in hot mix asphalt paving. Many countries have recently incorporated glass into their roadway specifications, which had encouraged greater use of the material. While the use of waste glass as filler in hot mix asphalt is still not widely experimented.

In this research glass powder is proposed as an alternative to traditional lime stone powder (Gubraa) and ordinary Portland cement fillers in hot asphalt mixtures. Where, the effect of using waste glass powder as mineral filler on Marshall Properties of hot asphalt concrete mixtures is investigated. Nine mixtures with three types of fillers (lime stone powder, ordinary Portland cement and glass powder) and three filler contents (4%, 7% and 10% by weight of total aggregate) are investigated.

The main outcome of this research is the possibility of using glass powder as filler in hot asphalt concrete mixtures. The optimum glass powder content is 7%. Where it is found that using of glass powder as filler with such replacement leading to produce asphalt mixture with higher stability (% of increase up to 13%), lower flow (% of decrease up to 39%) and lower density (% of decrease up to 10%) comparing to corresponding ordinary Portland cement or lime stone powder mixtures.

تأثير استخدام مسحوق الزجاج كمادة مالئة على خواص الخلطات الاسفلتية الساخنة

الخلاصة

لقد بدأ استخدام الاسفلت في انشاء الطرق منذ نهاية القرن التاسع عشر, وتطورسريعا مع تطورصناعة المركبات. ومنذ ذلك الوقت فان تقنيات الاسفلت حققت خطوات واسعة حيث اصبحت اليوم كل من الاليات و التقنيات و المواد المستخدمة في انشاء التبليط الاسفلتي متطورة جدا.

تم استخدام زجاج النفايات في اعمال انشاء الطرق كتعويض عن الركام في الخلطات الاسفلتية الساخنة. ومؤخرا قامت العديد من البلدان بتضمين استخدام الزجاج في مواصفات الطرق الخاصة بها,

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بالشكل الذي شجع استخدام هذه المواد بشكل اوسع. بينما بقي استخدام زجاج النفايات كمادة مالئة في الخلطات الاسفلتية غير شائع التطبيق.

تم في هذا البحث استخدام مسحوق الزجاج كمادة مالئة في الخلطات الاسفلتية الساخنة كبديل عن استخدام مسحوق الحجر الجيري (الغبرة) او السمنت البورتلاندي الاعتيادي. حيث تم اختبارتاثير استخدام مسحوق زجاج النفايات كمادة مالئة على خواص مارشال للخلطات الاسفلتية الساخنة. تمت دراسة خواص تسعة خلطات تحتوي على ثلاثة انواع من المواد المالئة (مسحوق الحجر الجيري, السمنت البورتلاندي الاعتيادي و مسحوق الزجاج) وبثلاثة نسب (4%, 7% و 10% كنسبة من وزن الركام الكلي).

ان الاستنتاج الرئيسي لهذا البحث هوامكانية استخدام مسحوق الزجاج كمادة مالئة في الخلطات الاسفلتية الساخنة وبنسبة مثلى مقدارها 7%. حيث وجد ان استخدام مسحوق الزجاج كمادة مالئة بتلك النسبة التعويضية يؤدي الى ثبات اعلى (النسبة المئوية للزيادة تصل الى 13%) و انسياب اقل (النسبة المئوية للنقصان تصل الى 39%) و كثافة اوطئ (النسبة المئوية للنقصان تصل الى 10%) للخلطات الاسفلتية بالمقارنة مع الخلطات الاسفلتية المناظرة الحاوية على السمنت البورتلاندي الاعتيادي اومسحوق الحجر الجيري.

Nomenclature

G. P: Glass powder
L. S. P: Limestone powder
O. P. C: Ordinary Portland cement
V.F.B: Voids Filled with Binder
V.M.A: Voids in Mineral Aggregate
V.T.M: Voids in Total Mix

1. Introduction

A major step in the improvement of the existing performance of roads starts with ensuring proper mix design and using suitable ingredients. It is anticipated that some failures are attributed to the poor design of the asphalt mixes and\ or to the materials have been used. The existence of varied properties for local materials requires different mix designs to be used.

One of the major concerns in the mix designing is the type and amount of filler used, which is known to highly affecting 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. [1, 2] When filler is added to the asphalt, a marked change in the consistency of asphalt will result. This change can be inspected clearly 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. [3]

Al-Qaisi [4] 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 sulpher). 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 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.

Abdulwahhab [1] 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, stability and stability loss.

Abdul Raheem (5) studied the effect of sulfur (blow down) and polyethylene wastes on rheological properties and temperature susceptibility virgin and aged asphalt cement, as well as on their mixture properties and studied effect of these wastes on the moisture susceptibility of asphalt concrete mixture and other performance properties. He concluded that adding of 9% polyethylene wastes by weight of (40-50) asphalt grade to 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) resist the pavement deformation forces, therefore it should be used at truck stops and parking lots where standard loads which cause extended periods of such deformation.

Salman [6] 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 percentage filler, some irregular relationship is observed between the filler content and percent of air voids in the compacted mix.

Sadoon [7] studied the effect of different filler types on performance properties of asphalt paving materials, so six different types of filer are used 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 study moisture susceptibility by using retained strength test and resistance to permanent deformation by using indirect tensile creep test. The results indicate that filler type has a great effect on the cohesion of the mix where such types shows high indirect tensile strength values with respect to other types of filler at different test temperature. He concluded that the moisture damage also is affected by the type of filler, on which one type shows high susceptibility to water attack with high value of indexretained strength compared with others.

Aschuri and Woodside [8] investigated the behavior of the 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 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 were better than origin bitumen mixes.

Pinto et. al. [9] concluded that the performance changes and fundamental material characteristics associated with moisture damage due to various anti-stripping additives in HMA mixtures were studied 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 binder are used. Two asphalt concrete mixture scale performance tests, and two local – scale mixture constituent test were conducted to characterize the effect of binder-specific anti-specific anti-striping additives on the binder-aggregate bonding potential in mixtures. The test results presented that all treated mixtures performed well even after sever moistures-conditioning process, while the untreated mixture did not pass the requirement with six cycles.

2. Waste Glass powder as filler:-

The use of waste materials (recycling) in the construction of pavements has benefits in not only reducing the amount of waste materials requiring disposal but can provide construction materials with significant savings over new materials. The use of these materials can actually provide value to what was once a costly disposal problem.

Historically, because of the large volume of materials required for construction, pavements have been favorable structures for the recycling of a wide range of waste materials. Initially, this recycling was limited to the reuse of materials removed from previous pavement structures such as: recyclable asphalt pavement, recyclable Portland cement concrete, and various base course materials. Recently, various other materials, not originating or historically associated with pavements, have come into use, for example various latex materials added to the asphalt cement.

Waste glass considered one of the most important parts of the collected waste materials, it is nonmetallic and inorganic, it can neither be incinerated nor decomposed, so it may be difficult to reclaim. Hence, it has been used in highway construction as an aggregate substitute in hot mix asphalt paving. When crushed waste glass is incorporated in hot mix asphalt the resulting mixture is sometimes referred to as "glasphalt." (10)

Many communities have recently incorporated crushed glass aggregate into their roadway specifications, which could help to encourage greater use of the material. While the use of waste glass as filler in hot mix asphalt is still not widely experimented. Glass material is brittle and rich in silicon, so the key technical indexes of glasphalt are strength and resistance against water damage. Shaopeng et. al. (11) concluded in their study that waste broken glass can be used in asphalt concrete mixture with the maximal size of 4.75 mm and the optimal replacement ratio of 10%. They had also indicate that performance such as strength index, high temperature stability and water stability achieve the standards.

This research will discuss the possibility of use waste glass powder as filler material into hot mix asphalt mixes.

3. Materials:-

3.1. Asphalt Cement:-

Petroleum asphalt cement binder with grade 40/50 was used within this research. Physical properties and other necessary tests for this asphalt cement are presented in Table (1).

3.2.Aggregate:-

Natural fine and crushed coarse aggregates are used in this research. To produce identical controlled gradation, aggregates were sieved and recombined in laboratory to meet the selected gradation which is shown in Table (2). The physical properties of the aggregates are shown in Table (3).

3.3. Mineral Filler:-

Three types of mineral fillers have been used in this work, those are: limestone dust, ordinary Portland cement and glass powder. The chemical composition and physical properties are shown in Table (4).

4. Experimental Program:

The experimental program in this research is divided into three stages as shown in schematic diagram No. (1).

4.1. Stage 1 : Preparation of Mixtures

Each aggregate sample was blended for each specimen separately according to the mix formula. Aggregate are first dried to constant weight at 110±5°C. The aggregates are then heated to a temperature of 135°C before mixing with asphalt cement. Asphalt was heated up to 145 °C prior mixing. Pre-heated asphalt was avoided. Excess heated asphalt was disposed of to avoid variability in the asphalt properties.

The required amount of asphalt were then added to the heated aggregate and mixed thoroughly for at least three minutes and until a homogenous mix is obtained. Standard Marshall molds were heated in an oven up to 130 °C. The hot mix is placed in the mold and compacted with 75 blows for each face of specimen according to General Specification for Roads and Bridge [12].

4.2. Stage 2: Determining the optimum binder content

I.Marshall Test Method

The Marshall Stability test is used in this research for both mix design and evaluation. Although Marshall Method is essentially empirical, it is useful in comparing mixtures under specific conditions.

This 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 [13]. The prepared mixture was placed in preheated mold 4inch (101.6mm) in diameter by 2.5 inch (63.5mm) in height, and compacted with 75 blows for each face of specimen.

The specimens were then left to cool at room temperature for 24 hours. Marshall stability and flow tests were preformed on each specimen, where the cylindrical specimen was placed in water path at 60° C for 30 to 40 minutes then compressed on the lateral surface at constant rate of 2inch/min. (50.8mm/min.) until the maximum load (failure) is reached.

The maximum load resistance and the corresponding flow value are recorded. Three specimens for each combination were prepared and the average results were reported. The bulk specific gravity and density (ASTM D-2726 [14]), theoretical (maximum) specific gravity (ASTM D-2041[15]) and percent air voids (ASTM D-3203 [16]) are determined for each specimen.

II. Optimum Binder Content;

Marshall Test has been used to determine the optimum binder content. Lime stone powder has been used as filler in this stage.

The Marshall test results of mixtures with different binder content are shown in Table (5). The relationships between binder content and the properties of mixtures such as stability, flow, V.T.M, V.F.B, VMA and bulk density are shown in Fig. (1). The optimum binder content was found equal to 5% by weight of the total mix (which is calculated as the average of binder content values that corresponding the maximum stability, maximum density and median of the V.T.M %).

4.3. Stage 3: Investigating the effect of using different fillers with different contents on Marshall properties:

In this stage nine mixtures are prepared with three types of fillers those are: ordinary Portland cement, lime stone powder and glass powder. Three filler contents for each filler have been investigated (4, 7 and 10 % by weight of total aggregate). All mixtur**es** are prepared with the same binder content (5%).

Table (6) shows the test results for Marshall stability, flow, V.T.M, V.F.B, VMA and bulk density for all mixtures. The results show that the increment of the filler content up to 7% for all types of fillers leading to an increase in the Marshall stability values as shown in Fig. (2). Glass powder mixtures develop a better behavior corresponding to lime stone powder and ordinary Portland cement mixtures. According to this Figure, the value of stability is high for glass powder than for Portland cement and lime stone dust where the maximum stability attained at 7% content for three types.

Fig. (3) shows the test results of flow for all mixtures. All mixtures show an acceptable flow values as compared with the specification limits [(11)]. The results indicate that the increase of the filler content lead to an increase in flow for both lime stone powder and ordinary Portland cement mixtures, while glass powder mixtures exhibit a discrepant behavior. Where the values of flow increased for asphalt mixtures with both types of filler (Portland cement and limestone dust) 2 mm and 2.4mm at 4% content to 3 mm and 3.6 mm at 10% content respectively. While the value of flow for asphalt mixture with glass powder as filler decreased from 3 mm at 4% content to 2 mm at 7% and 10 % content and this behavior may be attributed to the siliceous biases of glass powder. Fig. (4) displays the relation between filler content and percentage of voids in total mix (V.T.M) for all mixtures. The results show that the V.T.M values are decrease with the increment of the filler content. Where the V.T.M for asphalt mixture with lime stone dust decreased from 6.1% at 4% content to 3.1 % at 10 % content, while V.T.M with Portland cement decreased from 4.2 % at 4% content to 3.3 %. But the values of V.T.M increased with glass powder filler and that could be attributed to sliding action for these particles which is limited in certain percentage at acceptable value of V.T.M according to the limitation of the specifications. On the other hand, it could be notice that's mixtures with finer filler is the lower V.T.M values.

The density values for all mixtures are shown in Fig. (5). The results reveal a slight differs in density values, which depend on the specific gravity of fillers. The results indicated that the density for Portland cement and lime stone powder mixtures increased from 2.38 and 2.28 gm/ cm^3 at 4% content to 2.46 and 2.33 gm/ cm^3 at 10 % content respectively. While it is decreased for glass powder from 2.31 gm/ cm^3 at4% content to 2.09 gm/ cm^3 at 10 % content which is may be attributed to sliding action of particles and may be depending on the specific gravity of fillers.

5. Conclusions

The main study considered in this paper is to investigate the effect of using glass powder filler on hot asphalt concrete mixture properties where the results can be concluded as the following:

I. A satisfactory stability is indicated, where using glass powder filler improve the Marshall stability values for all mixtures comparing to Portland cement or limestone powder fillers. The percentage of increase ranging from 6% to 36% depending on percentage of filler.

II. The average value of Marshall flow is less than resulted from mixtures with ordinary Portland cement or limestone powder fillers.

III. Using glass powder filler in hot asphalt concrete mixtures led to produce lighter mixtures almost with higher percentage of voids as compared with corresponding mixtures containing ordinary Portland cement or limestone powder. The maximum redaction is 15% achieved at 10 % replacement as compared with corresponding ordinary Portland cement mixture.

6. Recommendations

The following may be suggested for further work:

1- studying the effect of using glass powder as filler in asphalt mixture on tensile and flexural strength under repeated load.
2- Studies are required on durability of mixtures with glass powder fiber by testing resistance to many cycles of freezing and thawing.

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Table (1): Physical properties of asphalt cement

Test	Unit	specification	Test Results	Specification limits
Penetration 25°C	1/10 mm	ASTM D-5	47	40-50
Kinematics Viscosity at 135° C	cSt	ASTM D-2170	420	400 min
Ring and Ball Softening point	C	ASTM D-36	59	NA
Specific Gravity at 25° C	-	ASTM D-70	1.02	NA
Flash point	C	ASTM D-92	>232	232 min
Ductility at 25° C	Cm	AASHTO T51	> 100	100 min

Table (2): selected combined gradation of aggregate *

Sieve size Inch (mm)	Specification limit (SORB/R9)	gradation of aggregate (% of passing by weight)
3/4" (19)	100	100
1/2" (12.5)	90-100	94.4
3/8" (9)	76-90	76.6
No.4 (4.75)	44-74	49.8
No.8 (2.36)	28-58	33.4
No.50 (0.3)	5-21	21.5
No.200 (0.075)	4-10	8.2

* Tested in laboratory of Building and Construction Dept./ University of Technology

Table (3): Physical properties of Aggregates.*

Property	Coarse aggregate	Fine Aggregate
Bulk specific gravity	2.64	2.66
Apparent specific gravity	2.69	2.70
% water absorption	0.5	0.7

* Tested in laboratory of Building and Construction Dept./ University of Technology

Table (4): Chemical composition and physical properties of mineral filler*

Chemical composition	Limestone Powder (%)	Ordinary Portland Cement (%)	Glass Powder (%)
CaO	56.1	62.20	8.1
SiO_2	01.38	22.10	72.1
Al_2O_3	0.72	4.55	1.6
Fe_2O_3	0.12	3.34	-
MgO	0.13	2.32	2.5
SO_3	0.21	1.85	0.3
Na_2O	-	0.31	13.1
K_2O	-	0.43	-
L. O. I.	40.65	1.54	0.41
I. R.	-	0.45	-
L. S. F.	-	0.74	-
Physical properties			
Apparent Specific Gravity	2.78	3.15	2.65
% passing sieve No.200 (0.075 mm)	94	96	93

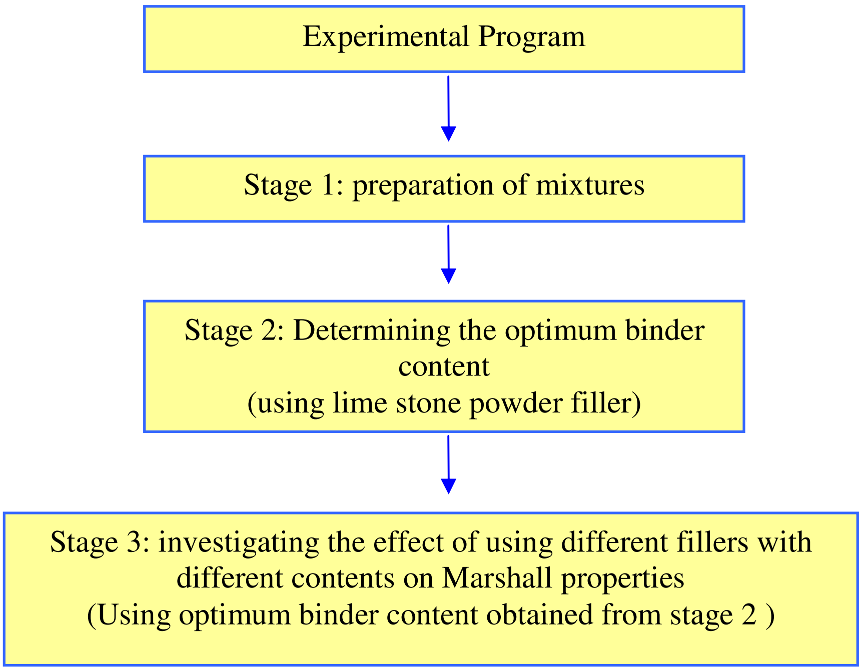
*Chemical and physical tests are made by the National Center for Geoslogical Survey and Mines.

Table (5): Optimum binder content

Binder content	4%	4.5%	5%	5.5%	6%
Stability (kN)	8.4	8.7	9.3	9.0	8.1
Flow (mm)	2.4	3.1	3.7	3.9	4.1
Bulk Density (gm\cm^3)	2.31	2.33	2.35	2.29	2.27
Theoretical Density (gm\cm^3)	2.40	2.41	2.43	2.36	2.33
% of Voids in Total Mix V.T.M (%)	3.75	3.32	3.29	2.97	2.58
% of Voids in Mineral Agg. V.M.A (%)	14.58	13.59	13.69	16.07	18.85
% of Voids Filled with Binder V.F.B. (%)	74	76	76	82	86

Table (6): properties of mixtures with different filler types and different filler content

Type of Filler	Percent of filler % (by weight of total mix)	Stability (kN)	Flow (mm)	Bulk Density (gm\cm^3)	Theoretical Density (gm\cm^3)	% of Voids in Total Mix V.T.M (%)	% of Voids in Mineral Agg. V.M.A (%)	% of Voids Filled with Binder V.F.B. (%)
Ordinary Portland Cement	4%	6.2	2.0	2.38	2.48	4.2	14.48	71
	7%	8.5	3.0	2.41	2.50	3.9	14.44	73
	10%	9.1	3.0	2.46	2.54	3.3	12.19	68
Limestone powder	4%	5.6	2.4	2.28	2.43	6.1	14.44	62
	7%	8.9	3.3	2.30	2.39	3.6	12.00	70
	10%	8.6	3.6	2.33	2.40	3.1	11.92	74
	4%	7.6	3.0	2.31	2.40	3.7	12.76	71
	7%	9.6	2.0	2.18	2.28	4.5	20.45	78
	10%	9.1	2.0	2.09	2.20	5.2	21.67	76



Schematic (1): representation of the experimental work

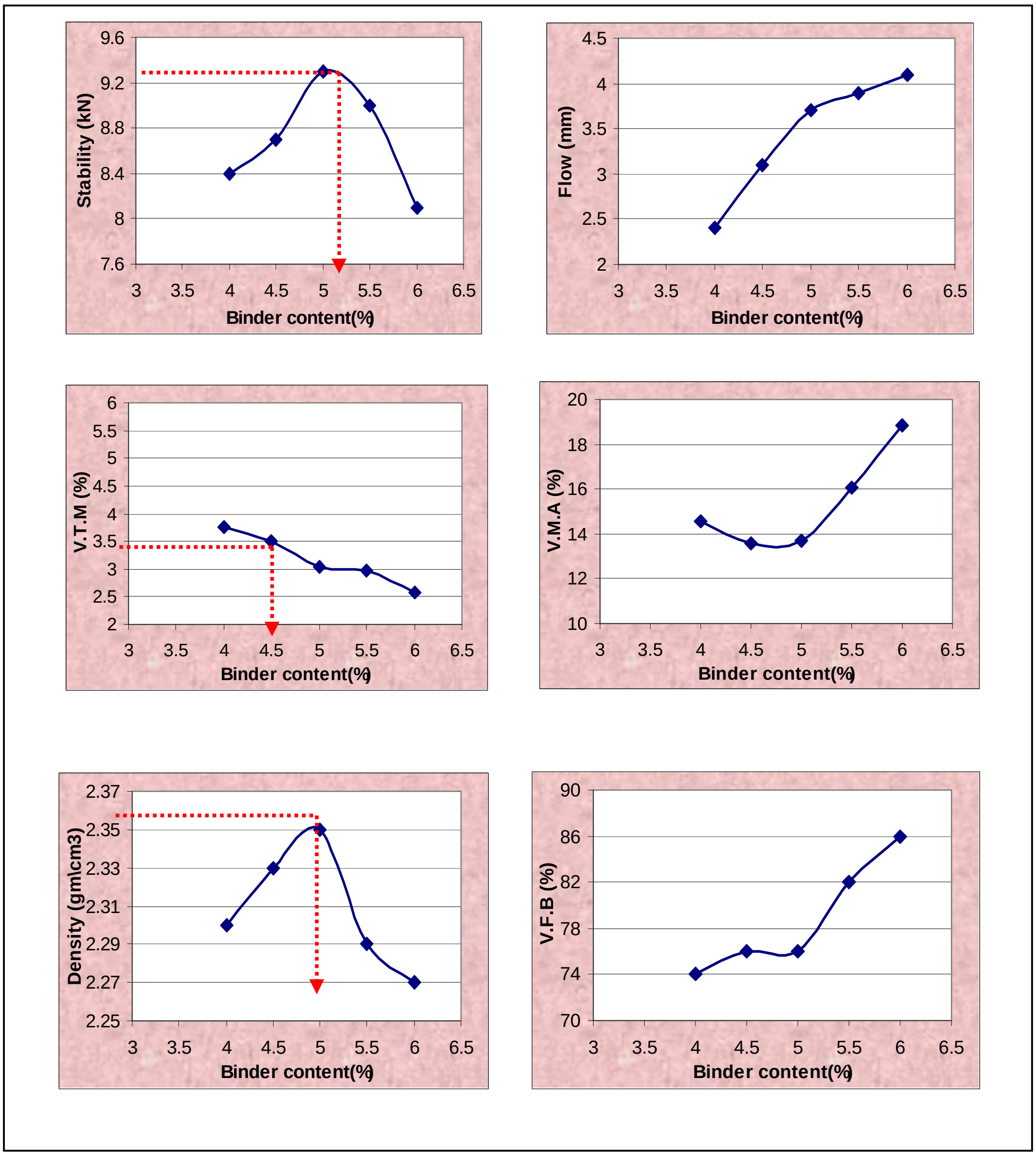


Figure (1): The relationships between binder content and the properties of mixtures

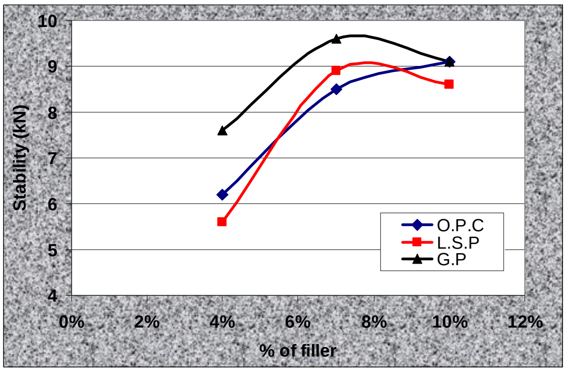


Figure (2): relationship between Marshal stability and different% of fillers

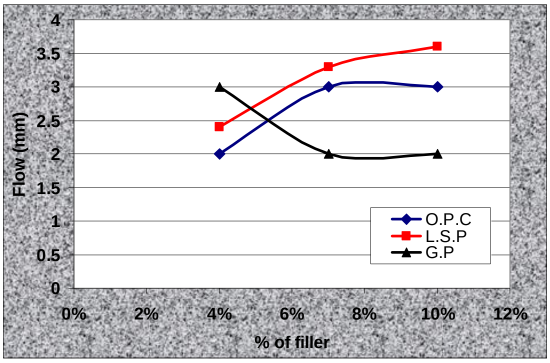


Figure (3) relationship between flow and different% of fillers

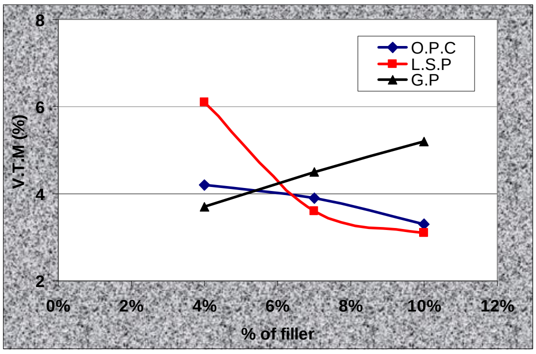


Figure (4) relationship between V.T.M and different% of fillers

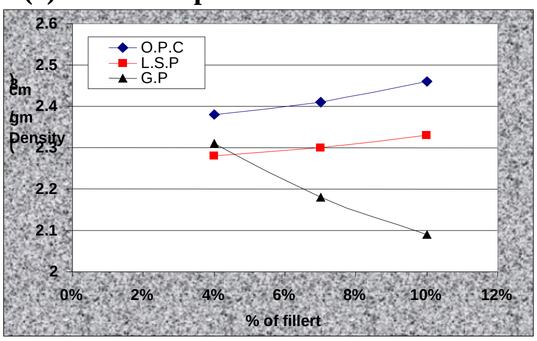


Figure (5) relationship between Density and different% of fillers