Influence of Glass Powder as a Filler on the Mechanical Characteristics of Bituminous Concrete Semi-grenu 0/14 Based on Alluvial Sands

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Abstract

Alluvial sands found in abundance in the regions of southern Algeria are not sufficiently exploited because of their siliceous mineralogical nature and their relatively tight granular fraction devoid of fines. Glass powder, derived from waste glass bottles and other elements, is an ecological alternative material that can remedy the lack of fines in addition to its physico-chemical aspects. This article deals with the study of a road bituminous concrete consisting of local alluvial sand in substitution for gravel 0/3 and in which the lack of fines is filled by glass powder of granularity less than 80µ at variable grades. The aim is to evaluate the influence of the added powder on the mechanical characteristics of the asphalt. To achieve this, five bituminous mixtures according to different percentages of glass powder: 1, 3, 5, 7 and 9% were made and studied mechanically by means of Marshall and Duriez tests in addition to the module test at the NAT, their results are discussed and compared to conventional concrete. The results obtained showed that the optimal 3% glass powder content improves the stabilities by about 15% and the flow by 10%, while the modulus remains substantially unchanged.

***Keywords*: glass powder, Marshall Stability, alluvial Sand, flow, module, bituminous concrete**

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I. Introduction

The layers of pavement constituting Algerian roads consist mainly of aggregates from crushing massive rocks, and they are divided into fractions of different dimensions. In Algeria, the granular materials composing the bituminous concrete of asphalt for road surfaces are of 0/3, 3/8, 8/15 and 15/25 dimensions.

Glass powder is a white colored product obtained after collecting and grinding glass fragments. Its high content of amorphous silica is SiO_2. Glass powder from glass bottle waste is a harmful non-degradable material to the environment. This waste poses a major threat to our environment because it takes a long time to degrade if it is not treated properly[1]. At present, many associations are sounding the alarm to warn governments and citizens of the danger that this waste can cause to nature. So, government leaders have not hesitated to take action and put laws to reduce the volume of this waste. Its reduction either by recycling because this material has the advantage of being recycled infinitely, or by reusing it in powder form in the building sector. The mixture that forms the surface layer of roads, which consists of varieties of gravel and asphalt and the reaction that occurs between these compounds is responsible for the physical and mechanical properties of the mixture that forms asphalt concrete [12], [13], [14] which receives the charges from the compounds.

If we look at this, we will find that more than 60% of bituminous concrete is gravel, and this has a negative impact on the environment and the population, especially [9], particularly in its extraction especially small sizes; therefore, it is not essential to think of another alternative and integrate other materials similar to aggregates. Among these materials is glass, which could be a partial alternative to low-caliber aggregates, since this material is increasingly collected in a specific place such as waste. [2]

There are some countries that have problems related to landfills and clean-up (the cost of land areas and environmental constraints have become high costs in some regions). [10].

The waste of glass is characterized by a chemical composition qualifying it to be a partial replacement provided that the glass powder is of the same size with the fine aggregates. But as it is a non-degradable or burnable material, it ends up buried, this process is very expensive. Glass is considered a solid waste that is difficult to dispose of; it is a silicic substance with properties similar to aggregates. [3]

Studies in developed countries have shown that the total amount of crushed glass varies annually from about 10% to 75% of glass production in previous years. [4] All over the world, nearly 10 million tons of glass waste are produced, of which 3 to 5% is household waste. [5]

The recycling of this material consequently reduces the costs of burial as well as the emission of carbon dioxide CO_2.

The study of alternative materials for pavements is considered a viable alternative from an environmental point of view because it allows the final disposal of solid waste and reduces overexploitation of quarries and proposes new sources of materials that can be used as filler in the mixture [11]. Several researchers have studied the physical, chemical and rheological characteristics of bituminous sealant with desert of alternative materials, to characterize the mechanical behavior of the mixture and induce pavement performance during the lifetime e [13,14,15,16,17], as an example:

Doulal carried out a test on the impact of glass on different bituminous mortar and larger gauge 4.75 mm and different amount of glass 2.5%, 5% and 7.5%, these Marshal tests showed that the ideal rate of bitumen is 5% and as for the glass powder is 7.5%. [2]

Aissa also did his test with different rates of glass powder with a higher degree compared to Doulal which is 5, 10 and 15% of the grammage of the sample. [6]

As for Abousalem he performed the test with different levels of glass powder and mortar. [7]

The use of glass powder waste has an effective impact and significant value on the economy and requires a low bitumen rate to give a significant percentage of Marshall.

Through his studies and research project,

Hassan proposed various calibers of glass powder up to 4.75 mm and that it results from his studies that glass powder is similar to natural aggregates[8].

Singh and Sakale replaced the fine aggregates of an asphalt mixture with different solid wastes such as plastic and glass. In conclusion, the authors report that the optimal percentage of use of shredded glass waste in bituminous asphalt is in the range of 2.5% to 7.5%. If not, the Marshall stability of the asphalt mixture with solid waste has increased by 50% more than the conventional mixture and among the materials discussed in our study is the natural sand that is found and accumulates in streams especially after the occurrence of floods, characterized by their purity, and completeness and its density between 2.6 to 2.7 kg/m2, this material is easy to extract and does not cause harmful effects on the environment .

Anochie-Boateng and George conducted a laboratory study to develop a CGW-containing asphalt concrete mixture as a partial replacement for conventional aggregates.

The gradation of the aggregates used for the wear layer has a maximum size of 9.5 mm, and the gradation of the crushed glass waste ranges from a sieve size of 4.75 to sieve No. 200. The glass content was 15% by weight of the selected fine aggregate. The optimal asphalt content was 5.1% for glass asphalt and was close to the optimal asphalt content for the reference asphalt (5%). the results of volumetric analysis of the asphalt mixture contained in the glass showed that they meet South African standards [19]

The objective of this study is to seek to integrate glass powder with a gauge of less than 0.08mm into the formulation of bituminous mortar with different bitumen rates and the use of alluvial sand as a partial alternative instead of 0/3 aggregate, as much as possible, to test Marshall rate and perform it on the sample to test compressive strength and stiffness by module testing.

II . Material used:

II.1Asphalt

The binder used is ordinary bitumen class 40/50, which is brought back from the Naftal station in Ghardaïa. Table 1 summarizes the characteristics of the bitumen used.

Tableau 1. Main characteristics of bitumen used.

Test	Standard	Result	Spécifications
Penetration grade at 25°C	EN 1426	47	40/50
Softening Point, (°C)	EN 1427	56	47 à 60
Specific weight at 25°C	ASTM D-70	1.02	1.00-1.10

II.1Asphalt

The gravel used in our study belongs to the same stone and comes from the crusher of the company Alko-gaz located in the commune of Metlili, wilaya of Ghardaïa. Figure 1 shows the particle size curves of the different aggregates used in the experiment as well as the alluvial sand

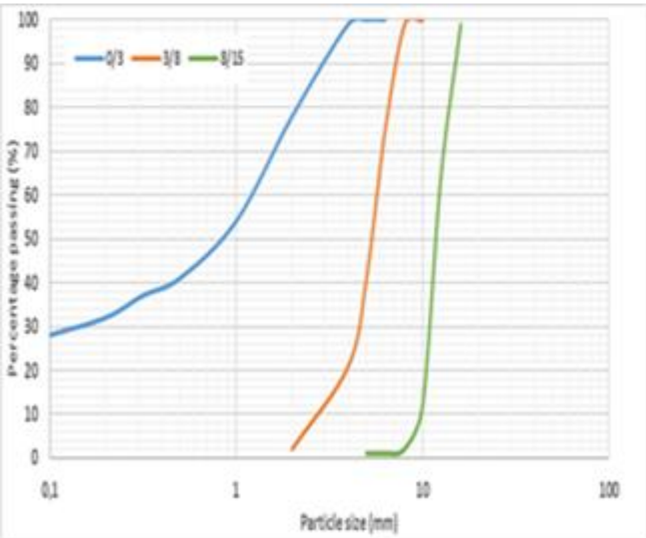

Figure 1. Particle Size Curves of the Used Aggregates

II.2 Aggregate:

The aggregates used belong to classes 0/3, 3/8 and 8/15 in addition to alluvial sand (AS). The geotechnical characteristics of these aggregates are listed in Table 2.

Table 2. Physico-mechanical Properties of Used Aggregates

Test		Standard	AS*	0/3	3/8	8/15
Flattening coefficient (%)		NF P933-3	/	/	17	15
LA Abrasion (%)		NF P18-573	/	/	36	33
Sand Equivalent (%)		NF P18-597	75	61	/	/
Specific Gravity (g/cm3)		NF P18-554	2.64	2.73	2.64	2.61
			1.7	1.50	1.18	1.16
Analyse chimique	Insolubles	SiO_2 + silicates	93,85	5,32	7,82	7,82
	carbonates	$CaCO_3$	3,27	95,1	94,4	94,4
	Chlorures	NaCl		0,21	0,23	0,24
	Fe2O3+Al2O3			1,63	2,26	2,21

AS*: Alluvial Sand

II.3 Sable alluvionnaire:

The alluvial sand used is the natural sand taken from the valley of the Zelfana region. According to the particle size curve established according to standard NFP 18-560 [9], this sand is relatively clean and coarse with particles between0,08 and4mm.

II.3 *Powder Glass:*

The glass crumb used comes from the mechanical grinding of waste transparent coloured glass bottles found in nature. After washing, cleaning and drying, the pieces of glass are broken manually into small pieces and then crushed in the micro-Deval device for about 2 hours, everything is sieved with a 0.08 mm sieve to obtain the glass powder. The photo in Figure 2 shows the powder obtained, while the chemical composition is given in Table 3.

Table 3. Chemical composition of glass powder

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Component		Result
Spécific Surface		350 m²/kg
Silicon Dioxide	SiO_2	71.71%
Sodium Oxide	Na_2O	12.35%
Calcium Oxide	CaO	8.36%
Aluminum Oxide	Al_2O_3	0.81%

Fig 2. Glass Powder used

III . Materials and Methods :

The manufacture of test specimens is established in accordance with standard NF EN 12697-30 relating to bituminous hot mixtures.

The binding content of the bituminous mixture is determined according to the method based on the modulus of richness and the specific surface area.

The tests carried out on the different samples are:
- The Marshall Test (NF P 98-251-2)

- test Duriez

- Module testing

% of bitumen =$\boldsymbol{\alpha k}\sqrt{\boldsymbol{\Sigma}}$

The Marshall test determines the stability and flow of cylindrical specimens subjected to compression exerted according to its generator under an energy compaction of 55 hammer strokes on each face. This compression is applied at a speed of 50 mm/min after 1/2 hour of immersion at 60 ° C in the water bath

. The measurements made from the Marshall test are:

- stability, which is the maximum load reached at the time of rupture of the test piece expressed in [kN]
- flow, which is the collapse of the same specimen at fracture by compression expressed in [mm].
- the Marshall quotient which is an indicator for resistance to permanent deformation

The preparation of bituminous mixtures is carried out according to three bitumen dosages.

Figure 3. Appareil Marshall

The bituminous mixtures are poured into heated Marshall moulds, a number of 50 strokes on both sides of the specimen is applied as compaction. These are left cooled for 24 hours in the open air.

For the Duriez test carried out according to standard NF P 98-251-1, the samples are exposed to a pressure of 60 kN for 5 minutes before cooling for 24 hours in the open air.

In general, the experimental stage goes through the following four steps;

Then we put the six samples one after the other in a Duriez device to calculate the resistance.

Then the same experimental steps are performed on the following steps:

- preparation of the mixture of hot bituminous asphalt from aggregates 0/3, 3/8,8/15 and alluvial sand with bitumen 40/50.
-Addition of glass powder according to proportions 1, 3, 5, 7 and 9% and performance of mechanical

- washing tests of the 0/3 fraction and alluvial sand with a 0.08 sieve in order to evaluate the effect of glass powder only.

- The test of modulus carried out on cylindrical specimens has the aim of measuring the behavior of asphalt mixes through the values of modulus of rigidity and complex modulus, in our study we carried out this test.

IV. Results & Discussion

IV .1Marshall test

Figures 6 to 11 show the variation of Marshall stability with bitumen dosage for each glass powder content. The values reported are the averages of three measurements

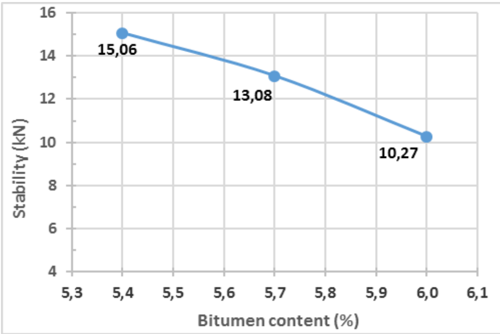

Fig 6. Stability variation (Glass Powder 0%)

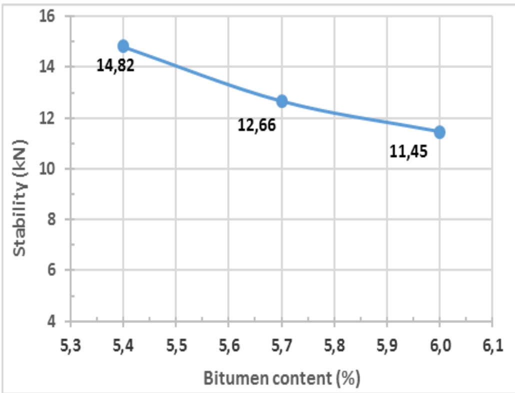

Fig 7. Stability variation (Glass Powder 1%)

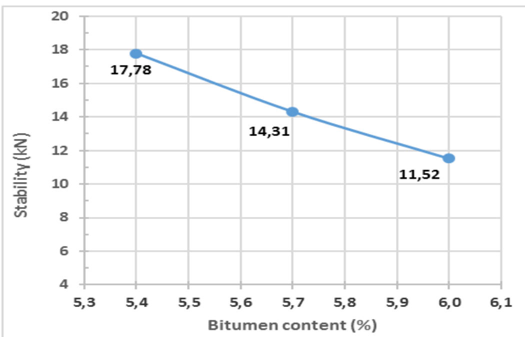

Fig 8. Stability variation (Glass Powder 3%)

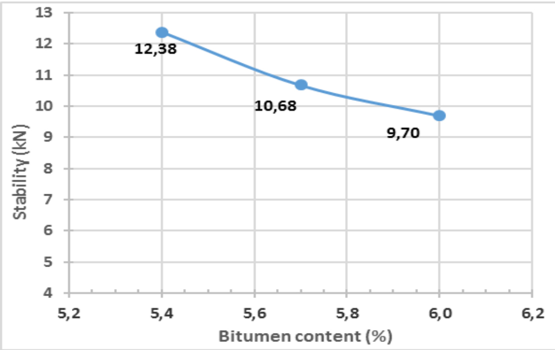

Figure 9. Stability variation (Glass Powder 5%)

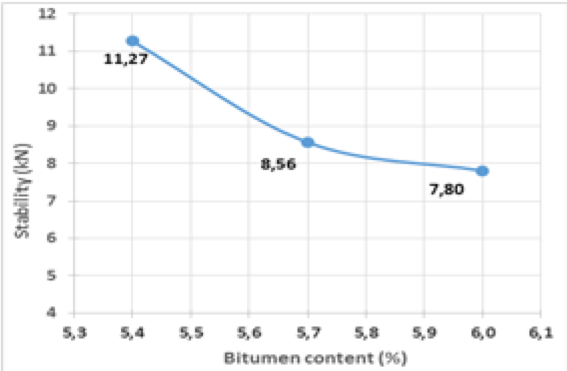

Fig 10. Stability variation (Glass Powder 7%)

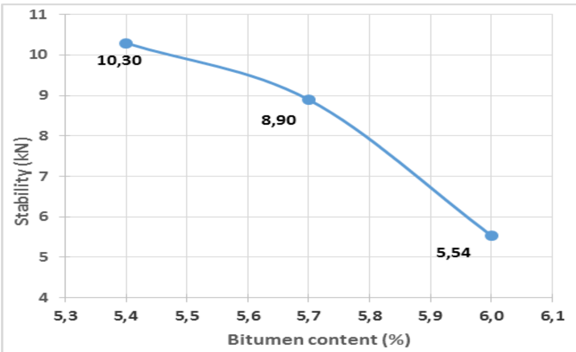

Figure 11. Stability variation (Glass Powder 9%)

These figures clearly show that the increase in dosage leads to a decrease of the probabilities and this for the whole range of variation of the powder contents studied [5.4-6.0%].

Although the values obtained for stability are relatively dispersed, it is noted that the most important stabilities are obtained for low bitumen contents, therefore with low binder consumption, while the lowest stabilities - generally less than 11 kN - are recorded between 7 and 9% glass powder.

The 3% value seems to be the optimal powder content that gives the best stabilities especially for low bitumen dosages.

In general, the addition of fiberglass in low contents leads to a decrease in stabilities that lose 20 to 40% of their value when the powder contents go from 0 to 9%.

Figure 12 shows the evolution of creep according to the glass powder content. The creeps obtained vary between 2.79 and 3.88 mm which attests that they are acceptable overall in accordance with the specifications of the LCPC Manual which recommend a folw of less than 4mm. The lowest creep value of 2.79 mm is recorded at 3% glass powder.

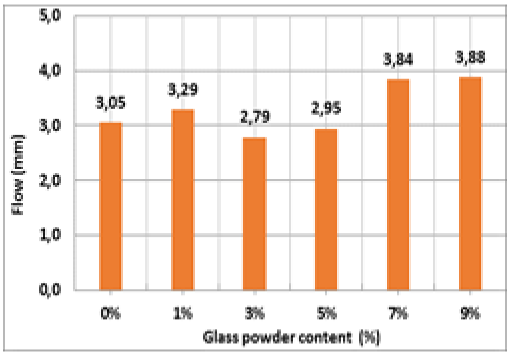

Figure 12. Flow evolution according to the powder

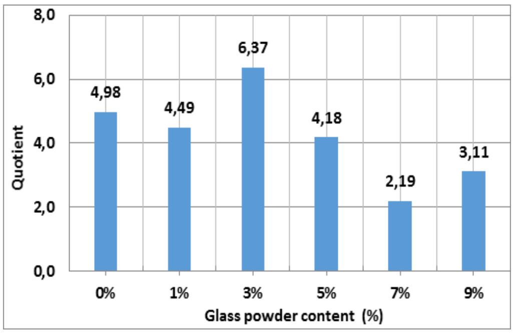

Figure 13. Quotient ratio according to powder

The evolution of the Marshall quotient ratio, which represents the stability/creep ratio, as a function of the glass powder contents shown in Figure 13, clearly shows that 3% of glass powder remains the optimal content giving the best quotient ratio which is 6.37 which indicates a significant stiffness.

IV .2Duriez test

Compressive strengths are evaluated using the Duriez test in accordance with standard Curves 14 to 19 show the variation in simple compressive strength after storage in air and under water for each percentage of glass powder. Depending on the results obtained, the method of preservation has a considerable influence since the simple compression values under water are significantly higher than those obtained in the open air.

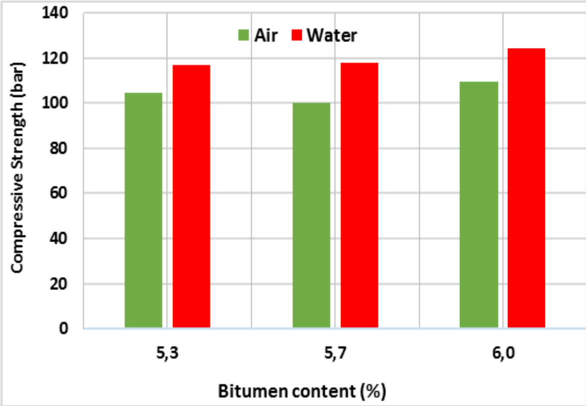

Figure 15. CS according to bitumen content (0% GP)

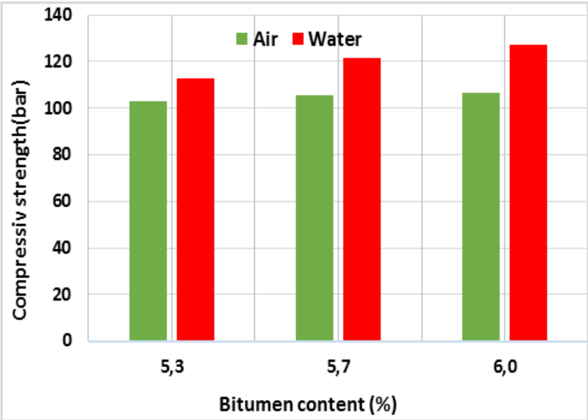

Figure 16. CS according to bitumen content (1% GP)

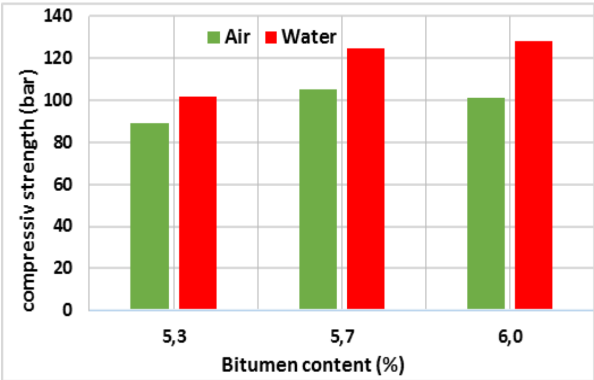

Figure 17. CS according to bitumen content (3% GP)

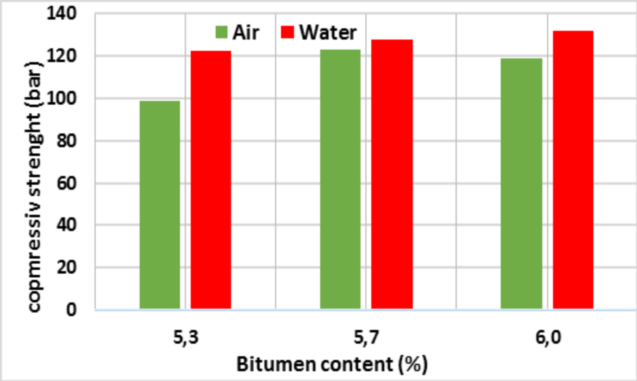

Figure 18. CS according to bitumen content (5% GP)

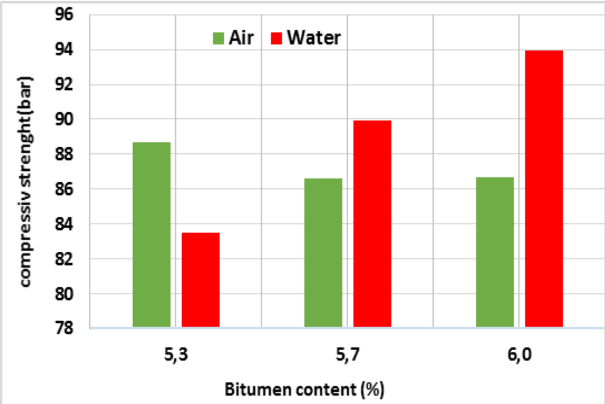

Figure 19. CS according to bitumen content (7% GP)

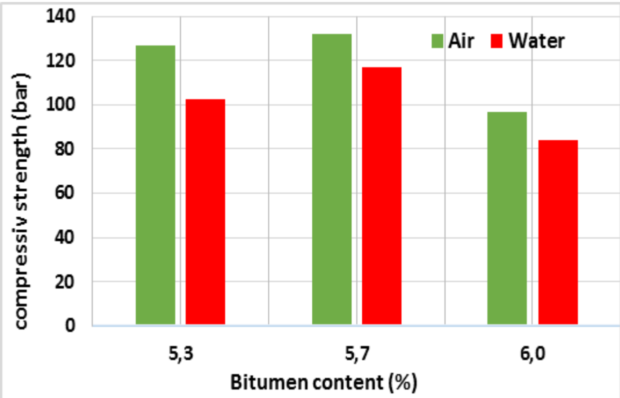

Figure 20. CS according to bitumen content (9% GP)

Compared to the control mixture (0%), a slight increase in water compressive strengths is recorded which is 05 to 10%. In the open air, the resistors are practically not influenced by the addition of glass powder.

Similarly, it should be noted that the most important resistances are recorded at the level of the highest bitumen dosages. The results obtained correspond favourably to the Algerian specifications given in Table 4.

Tableau 4. Marshall Test Limit Specification according to Algerian Specifications

Marshall Propriety	Specification
Stability	>10.50 kN
Fluage	<4 mm
Percentage of voids	<8%
Compacity	>92%

IV .3Module testing

The modulus tests are performed with the Nottingham Asphalt Tester (NAT) according to EN 12697-26 on cylindrical specimens (Fig. 21), the ratio of stress to strain) (Eed) is calculated for each elementary uni-axial tensile test in the low-

strain range. Figure 22 shows the results obtained

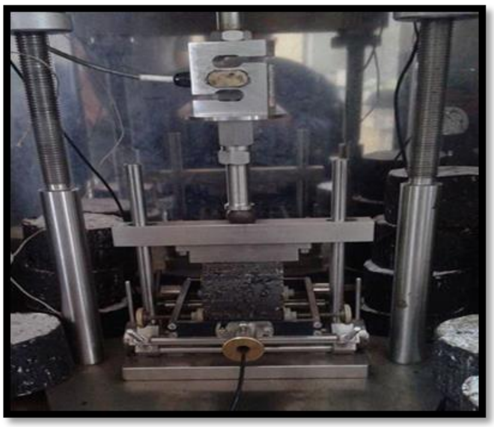

Figure21. Appareillage d'essai de module

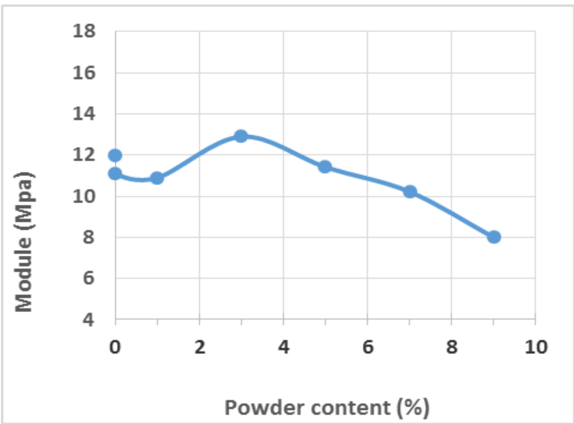

Figure22. Variation du module selon la poudre

According to figure 16, all the mixes meet the EN 12697-26 specifications. The 3% powder percentage is the highest content evaluated at more than 13 kN, which gives the most rigid concrete.

V. Conclusion:

The present work aims to study the mechanical characteristics and rheological behavior of an asphalt for road surface partially designed of local alluvial sand as a substitute for gravel 0/3 and glass powder of less than 80μ as filler fines. The objective is to achieve bituminous concrete with characteristics comparable to ordinary concrete. Based on the results of mechanical tests including Marshall and Duriez on several bituminous mixtures made at different grades of glass powder, we concluded the following

- The results obtained on the various bituminous mixtures were satisfactory to acceptable on the whole and meet the standards in force.

- According to the standards, with the exception of 9% which was low.

- The possibility of considering glass powder as a partial replacement for fine aggregates lower than 80μ is an interesting possibility that combines the economic aspect with the environmental side.

- The ideal ratio that gave the greatest stability and the least flow rate is 3% glass powder, with a lower concentration of bitumen.

- - The Marshall quotient (MQ) (used for asphalt formulation) cannot be an indicator of permanent deformation because of the contradiction of these values with the results of the rutting test.

VI . Perspectives and recommendations:

For perspectives, complementary work in the same direction can contribute to the enrichment and improvement of the approach, to confirm and broaden the research implemented in the field of road geotechnics:

- To associate with the addition MC another compound to further improve the behavior of the bituminous mixture,
- Study the influence of time, particle size and mixing speed,
- To review the specifications in force in Algeria which are not based at any time on the rheological behavior of bitumens.

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