

Research Article

Experimental and Numerical Investigation on Effect of Modified Grading Curve on Macrottexture and Mechanical Performances of Asphalt Mixture**Sadoudi Lyacia^{1,*}, Benbachir Mohamed¹, Ouldakhaoua younes¹, Saadoun Mohamed Billel¹ and Mabrouki Khaled²**¹Faculty of Civil Engineering, University of Sciences and Technology Houari Boumediene, Algiers, Algeria.²National Technical Control Organization for Public Works, Algeria.

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Abstract

To ensure the safety of road users, and in view of the direct contact of vehicles with the surface layer, an in-depth characterization of road pavements would be necessary. For this, the use of porous mixtures has obvious advantages in reducing the flow and infiltration of water into the soil. The main purpose of this study aims to improve the macrottexture and the adhesion of the wearing course, while keeping the level of mechanical performance within the allowable range. That is why artificial grading curve composed of several sub-fractions (twelve in this case) was developed. The volumetric technique by the patch test 13036-1 (Mean Texture Depth) was used to evaluate the macrottexture of mixtures. In addition gyratory compactor was used to determine workability, to evaluate intrinsic characteristic and moisture susceptibility, we performed Duriez test, and Nottingham University to estimate indirect tensile stiffness modulus. The results demonstrated that the use of modified grading curve mixtures improves the performance of the road surface (macrottexture) and keeping their mechanical proprieties. However, a model was developed using fuzzy logic approach aiming to predict compactness and stiffness modulus (SM) of asphalt mixtures as a function of air voids (V_a) and Mean Texture Depth (MTD). The results observed that the values obtained by the developed models are acceptable comparing to experimental results.

Keywords: Adhesion, Macrottexture, Mean Texture Depth, Moisture susceptibility, Stiffness modulus, Workability, Fuzzy logic.

1. Introduction

Tire-pavement adhesion is the most important factor in guaranteeing road user safety. [1, 2]. Pavement adhesion refers to its capacity to mobilize frictional forces between a vehicle's tire and the surface of the road under the action of driving stresses.

Every day, Algeria's road safety agencies report a significant number of traffic incidents involving both dead and injured persons. As a result, human fatalities and financial losses is caused. The state of the pavement and automobiles, as well as human irresponsibility, continue to be the leading causes of accidents. Although there is no systematic strategy in place for receiving and monitoring wearing courses now, related research has revealed that the macro texture of the road surface influences tire-pavement adhesion. In reality, The formulas now in use have a considerably more closed texture, which makes it harder to remove the water coating when it rains and reduces adhesion, especially at high speeds, furthermore, the type of used aggregates plays a significant role in guaranteeing the safety of road users. In Algeria, limestone with a PSV (Polished Stone Value) of less than 50 is utilized. They are therefore particularly vulnerable to the polishing phenomena, which causes quick loss of the microtexture, which ordinarily allows frictional forces to be generated at the tire / road contact. However, road traffic, in particular heavy goods traffic, has tended to increase sharply in recent years in Algeria, with a very large proportion of overloaded vehicles, which leads to both structural and

surface damage (aggressiveness 2 to 3 times higher than normal). This heavy traffic causes these aggregates to polish very quickly and low adhesion levels only a few years of service.

Currently, numerous strategies and procedures have been created to maintain our pavements and assure user safety while also preserving state finances.

In the field of public works, particularly the road network, activities have been conducted to enhance the quality of the road surface, particularly its texture (mega-texture, macro texture, and micro texture) [3-13]. The surface texture of a wet or moist pavement must enable water to escape under the surface (function of macro texture) and re-establish contact conditions as near to those found on dry pavement as feasible (role of micro texture)

Several studies have been defined in this context. An Algerian study shows that adding dune sand improves skid resistance by creating an artificial microtexture that generates friction forces and resists erosion. According to this study, the use of a mixture of two types of aggregates C1 (diorite aggregate) and G2 (limestone) have a good polishing resistance (good coefficient of friction after 180,000 passes).

The properties of the emulsion between the layers of the bituminous concretes are determined according to their dosages and their rupture by means of the shear tests. The adhesion between the pavement layers was studied by the effect of the macrottexture on the different types of asphalt. Optimum shear strength is presented for the mixture with 0.17mm of rough texture and 250 g/m² of emulsion [14]. The results presented by Mio et al [15], show that the parameters (Mean Profile Depth, Skewness, Kurtosis, Fractal Dimension, Average Slope and Average Curvature), can accurately

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characterize the relationship between macrotexture and skid resistance of asphalt pavements. The objective study of Afonso et al [16] was to determine mean texture depth and skid resistance using pendulum test value and PTV respectively aiming to characterize the pavement surface.

The porous asphalt mixture (DLPA) characterized by a structure with a high content of voids gave a rougher macrotexture and good adhesion. While, results show that the (permeable asphalt pavements) PAPs presented good performances of surface layer, ensuring road safety users. The examination of asphalt concrete surfaces (nine surfaces), to solve problems related to pavement texture and skid resistance, showed that coarse aggregates present an important factor for these two properties. A high content of coarse aggregates leads to an increase in texture depth and skid resistance of ribbed tires. Also, the results show that the presence of air voids (AV) and voids in aggregates (VMA) in bituminous mixtures did not show any correlation with surface texture or skid resistance [17].

Al-Assi, et al [18], examined relationship between rubber-pavement adhesion and friction. The findings showed that the observed coefficient of friction and adhesive bond energy have a reasonable association. Higher adhesion rubber pavement systems produced more friction at low speeds. The findings also showed a significant relationship between rubber characteristics and friction on rubber pavement. Higher friction was produced by softer rubber, and vice versa.

However, many numerical models were developed using different approach aiming to predict different proprieties of asphalt mixture. Fuzzy logic and statistical methods were used to modelling the results of stability such as compressive strength and rutting potential of asphalt [19]. Alkawaaz, et al [20]. Using neuro-fuzzy inference system (ANFIS) in, a

model for prediction of the rutting performance of Polyethylene Terephthalate (PET) modified asphalt mixture was developed [21], where the inputs variables were PET percentages, stress levels and temperatures from where the rutting performance was the output. Results shows that the ANFIS method can be used as an effective prediction tool. The results show good correlation for the two approach [22].

Random Forest (RF), Artificial Neural Network (ANN), Adaptive Neuro-Fuzzy Inference System (ANFIS) and Random Tree (RT) were used to predict Marshall Stability of modified concrete bituminous with glass fiber [23]. Mohamed et al, [24] studied the combinatorial effect of critical factors on pavement quality during construction. An expert judgment model, based on fuzzy set and focus group was developed. For the maintenance of asphalt concrete pavements, including its design, life cycle cost analysis and greenhouse gas emissions, [25], used the life cycle approach.

The aim of this study is to investigate an experimental and numerical investigation on effect the effect of modified grading curve on mechanical and performance-Related Properties of Asphalt Mixes in order to increase tire-to-road adhesion.

2. Material and methodology

2.1. Bitumen and Aggregates

In this study, a 35/50 penetration bitumen was used, supplied by the Algerian petroleum refining company (NAFTAL). Granular fractions (0/3, 3/8 and 8/15) from the quarry of Bouzagza in the city of Boumerdès, Algeria were also used. The physical and characteristics of bitumen are shown in Table 1 and Table 2 respectively.

Table 1. Properties of bitumen.

Properties	Test method	Value	Specifications
Penetration (25°, 0.1mm)	EN 1426	37	35-50
Softening point, C°	EN 1427	52	50-58
Flash point C°	EN ISO 2592	300	> 250°
Ductility (25°C) (cm)	NA 5223	>100	>100
Specific gravity (25°C) g/Cm3	NF T 66-007	1.04	1-1.1

Table 2. Properties of mineral aggregate.

Properties	Test method	Fraction			Specifications
		0/3	3/8	8/15	
Specific gravity (g/cm3)	NA P 18-555	2,694	2,699	2,690	>2.6
Los Angeles coeff (%)	EN 1097-2	-	19.14	24.36	20 <LA<30
Micro Deval (%)	EN 1097-2	-	18.65	10.64	20 <ME<25
Sand equivalent (%)	EN 933-8	80	-	-	≥ 60
Flattening coeff (%)	EN 933-3	-	13.45	8.25	< 25
Carbonates content (%)	NA 16210	99			≥ 90 %

2.2. Gyrotory compactor method

The samples tested are prepared according to standard EN 12697-31. A mixture of 4.5 to 4.7 kg as well as the mold of 100 mm in diameter were heated to 160 ° C. The mixture inside the mold is compacted at 30 gyrations per minute with an angle of 0.82 °, and a pressure of 600 kpa. The acquisition system linked to the compactor gives the density, the height of the sample and the percentage of voids for each gyration. The Samples prepared using gyrotory compactor, can be used to verify workability, determined air voids of mixture for each gyration and plot the density curve.

2.3. Duriez Test

The duriez test used in order to determine the intrinsic characteristic and mechanical performances of asphalt mixtures, especially for bulk density, compactness, Air voids and the moisture susceptibility. For this 12 samples are made according to NF EN 12697-12, for measuring density, compactness and percentage of void, 10 specimens stored for 7 days in wet and dry conditions. After storage, the ratio (r/R) is defined as the conditioned specimens to that of the dry specimens.

2.4. Mean texture depth (MTD)

The volumetric patch technique is used to determine the mean texture depth of the pavement surface, according to European

standard EN 13036-1. For this, a known volume of material is carefully applied to the surface and then the total covered area is measured. According to the standard, the material utilized to carry out the procedure was categorized. Essentially round solid glass spheres were used (Fig1). The MTD value was obtained by dividing the volume of the material in the covered area with the average diameter of the circular area at each point (the diameter was evaluated using four axes), as shown by equation 1.

$$MTD = \frac{4V}{\pi D^2} \text{ (mm)} \quad (1)$$



Fig.1. Mean texture depth test.

2.5. Indirect tensile stiffness modulus (ITSM) test

The stiffness of a bituminous mixture is determined by the indirect tensile stiffness modulus test using NU apparatus (Nottingham University). For this, the test was carried out at the LCTP Algiers laboratory (Algeria) according to standard NF EN12697-26. The test was determined at 10 Hz, therefore 5 semi-sinusoidal pulses with a total duration of 3s, consisting of a rise time of 124 ms and a recovery of visco-elastic deformation, were carried out in a deformation control regime (5 μ m). For each pulse, the modulus was determined as follows:

$$ITSM = F(v + 0.27)/(z \times h) \quad (2)$$

Where ITSM represents the indirect tensile stiffness modulus (MPa), F represents the value of the vertical load (N), h is the mean height of specimen (mm), z is the amplitude of the horizontal deformation during the load cycle (mm) and v is the Poisson's ratio. The test was carried out at 15°C on samples compacted using gyratory compactor.

2.6. Preparation of conventional mixture

For preparation of the conventional mixture, the particle size curve of the mixture of aggregates is inserted in the reference spindle as shown in Fig. 2. The mix job was formulated using 38% of sand (0/3), 26% of fine aggregate (3/8) and 36% of coarse aggregate (8/15). The aggregates and bitumen were heated to 160°C separately, and then the aggregates put in a pan and properly mixed. The optimum bitumen content was added to the mixture of aggregates and were mixed until of the aggregate was covered [26].

2.7. Modified grading curve mixtures

The modified grading curve is a particle size curve which shows an absence of one or more intermediate granular classes in a granular composition; generally used for wearing course roughness.

To prepare the different modified grading curve mixtures, an artificial grading curve composed of several sub-fractions (twelve in this case) was developed. Table 3 shows the sub fractions used. According to the standard surface limitations, the aggregate mixture was created, as illustrated in Fig.3, Fig. 4 and Fig. 5 respectively.

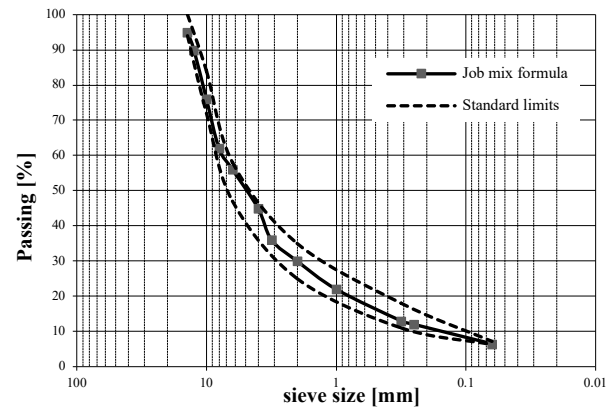


Fig. 2. Mix grading curves.

Table 3. Sub-fraction used.

Fractions	Sub-fractions (mm)
8/15	>14 12.5-14 10-12.5 8-10
3/8	6.3-8 4-6.3 3.15-4
0/3	2-3.15 1-2 0.315-1 0.063-0.315 >0.063

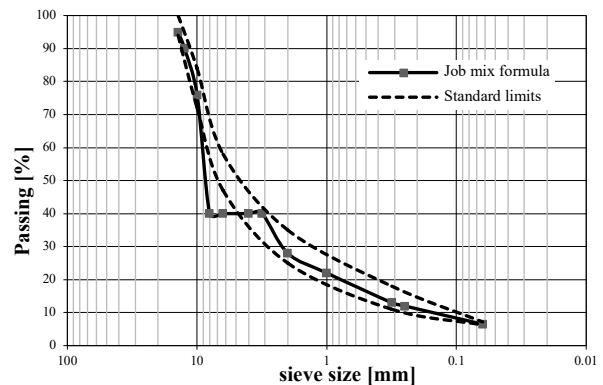


Fig. 3. Mix grading curves D 3/8.

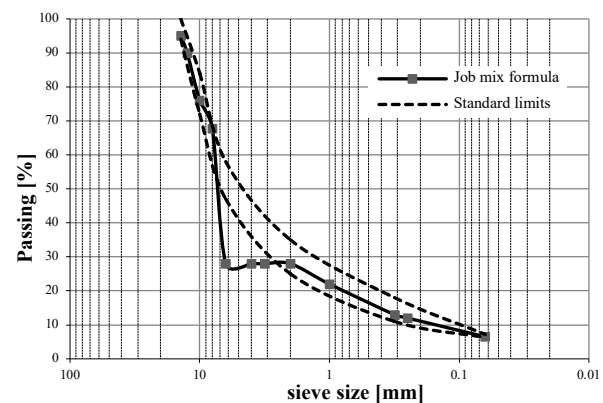


Fig. 4. Mix grading curves D2/6.3.

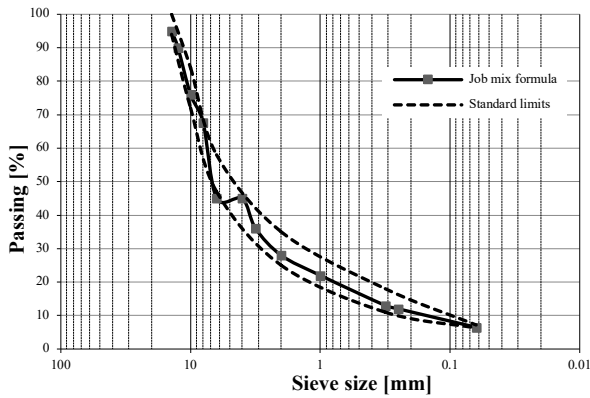


Fig. 5. Mix grading curves D 4/6.3.

The composition of different asphalt mixtures used in this study is as follows:

- Mixture D 3/8: 40% (0/3) and 60% (8/15);
- Mixture D 2/6.3: 28% (0/2), 40% (6.3/8) and 32% (8/15);
- Mixture D 4/6.3: 36% (0/3), 32% (3/4+6.3/8) and 32% (8/15).

3. Results and discussion

3.1. Optimum bitumen content

The effect of bitumen content on the air voids of all mixtures tested is illustrated in Fig 6. In order to determine the

optimum bitumen content, three percentages was varying at 5.30%, 5.40% and 5.65% by weight of mixture. The optimum bitumen content was carried out by study of workability of mixture with gyratory compactor and the moisture susceptibility properties of bituminous specimens corresponding to the requirement specification.

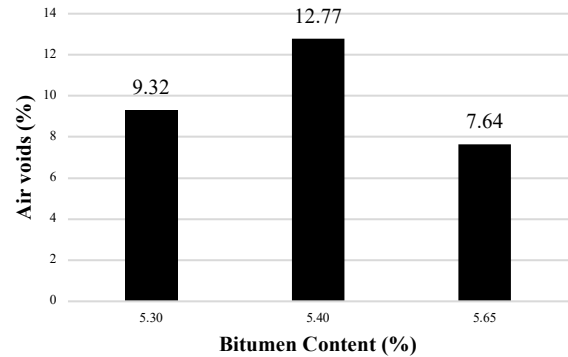


Fig. 6. Percentage of voids for 80 gyrations.

According to the results of workability and moisture susceptibility properties (Table 4). It is found that the mixture with 5.65% of bitumen, gives better performances compared to other mixtures and are acceptable by the specifications given by standard (air voids between 4-9% at 80 gyration and $r/R > 0.75$). In this study, this content of bitumen will be the reference.

Table 4. Moisture susceptibility properties.

Properties	Method	Bitumen content (%)	
		5.65	2.39
Bulk density (g/cm ³)	EN 12967-6	96.40	3.60
Compactness (%)	EN 12967-8	8.2	6.8
Air voids (%)	EN 12967-12	0.82	
Resistance at dry condition R (MPa)			
Resistance at wet condition r (MPa)			
Moisture susceptibility r/R			

3.2. Results of conventional and modified grading curve mixtures

3.2.1. Workability

Fig.7 shows the influence of percentage voids at 80 gyration of control, and modified grading curve mixtures obtained by the test of gyratory compactor. These results are used to verify the workability of asphalt mixtures.

According to the results, we can see clearly that the modified grading curve mixtures voids percentage is comparable to the control mixture one excepting D 2/6.3 mixture. However, we can also notice that this percentage of voids at 80 similar to the control mixture one for D 3/8 mixture. This is can be due to the effect of sand fraction percentage and grading continuity in each mixture. For example D 3/8 mixture, the sand fraction percentage increases comparing to the control mixture, which will compensate the voids created by the absence of fraction 3/8. This effect is less visible in the mixture D4/6.3. For D2/6.3 mixture, a large part of the fine elements is subtracted from the mixture, which generates an increase in the percentage of voids compared to other mixtures.

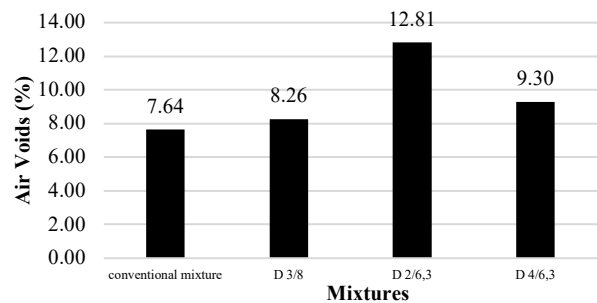


Fig. 7. Percentage of voids at 80 gyration.

3.3. Mean texture depth (MTD)

In order to study the adhesion of all mixtures, MTD test was used on samples compacted by two methods gyratory compactor and rutting (Fig.8). The MTD values of samples are presented in table 5 and table 6 respectively.

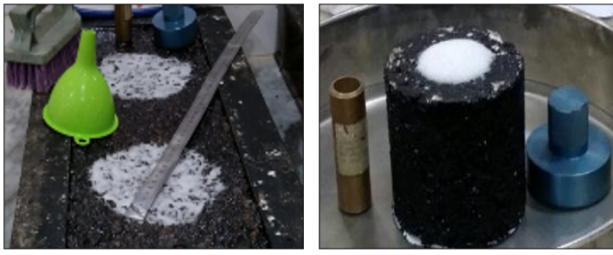


Fig. 8. Samples compacted by rutting and gyratory compactor.

The results obtained in table 5 and table 6 shows that the mixtures D 2/6.3, D 4/6.3 and D3/8 have better performances of MTD compared to the control mixture. These highlights explain the influence of subtraction of sub-fractions of aggregates on the improvement of the mean texture depth (MTD). The results show also that the mixture D 2/6.3 have higher values of MTD compared to the other mixtures, which give 1.51 mm with gyratory compactor and 1.76 mm with rutting method.

Table 5. MTD of samples compacted with gyratory compactor.

Mixtures	M ₀ (g)	M ₁ (g)	M _{glasse} (g)	V(mm ³)	MTD (mm)	Specifications
Conventional	1948.77	1956.15	7.38	4881	0.62	≥ 0.5
D 3/8	1951.06	1963.26	12.20	8069	1.03	
D 2/6.3	1946.68	1964.56	17.88	11825	1.51	
D 4/6.3	1948.08	1962.47	14.39	9517	1.21	

Table 6. MTD of Rutting plates.

Mixtures	Test	D1	D2	D3	D4	Dmen (mm)	MTD (mm)	MTDmean (mm)	Specifications
Conventional	1	135	135	135	135	132.5	0.91	0.85	≥ 0.5
	2	150	150	150	150	141.25	0.80		
D 3/8	1	115	115	115	115	113.25	1.24	1.28	
	2	110	110	110	110	110	1.32		
D 2/6.3	1	95	95	95	95	95	1.76	1.76	
	2	95	95	95	95	95	1.76		
D 4/6.3	1	100	100	100	100	102.25	1.52	1.45	
	2	105	105	105	105	107.5	1.38		

Fig. 9 gives complements the analysis with the differences MTD between two methods used. These differences are not significant, as they do not exceed 0.25 mm, which can be explained by the distinction of compaction mode.

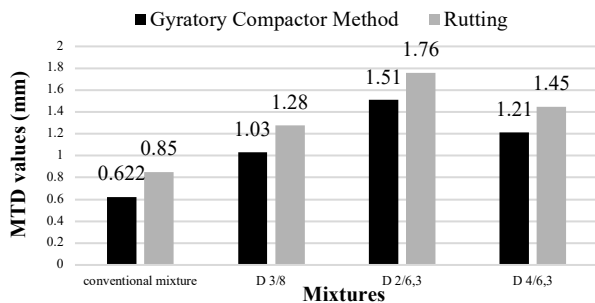


Fig. 9. MTD values obtained by two methods.

Fig. 10 presents MTD gain of modified grading curve mixtures for samples compacted with gyratory compactor and rutting. According to the figure, we notice that the mixture D2/6.3 presents a gain of 142% and 107% for the two compaction methods respectively compared to the control mixture.

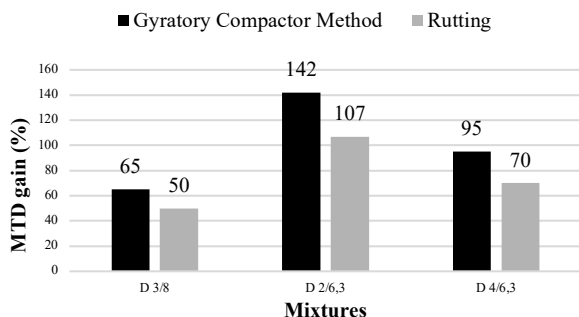


Fig. 10. MTD gain of modified grading curve mixtures for samples compacted with gyratory compactor and rutting.

Fig. 11 presents MTD gain as a function of the percentage of voids. The results show a linear increase of 1% of air voids, lead to gain in MTD of two types of samples is obtained. The MTD gain obtained by gyratory compactor and rutting in this case is 16% and 12% respectively. This improvement can be explained by the subtraction of the intermediate fraction of asphalt mixture, which leads to an increase in the percentage of voids, also the presence of the coarse gravel fraction in the mixture and therefore the decrease in the percentage of sand in mixtures.

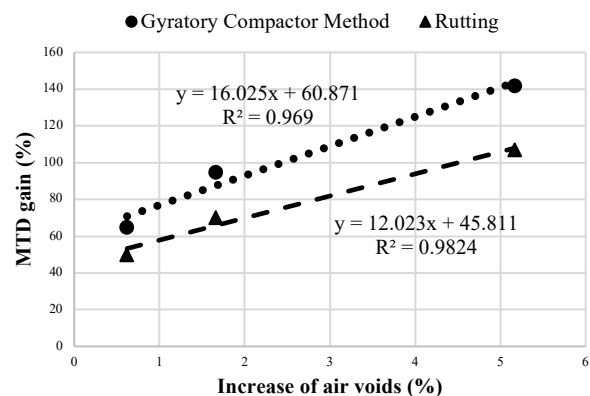


Fig. 11. MTD gain as a function of the percentage of voids.

3.4. Moisture susceptibility and intrinsic characteristics of mixtures.

The intrinsic characteristics of mixtures including bulk density, Specific density, air voids, compactness and moisture susceptibility for a control and discontinuous mixture are presented in Table 7.

To determine intrinsic characteristics and moisture susceptibility of mixtures, samples was made in dry and wet conditions at 18°C for 7 days. Moisture susceptibility of

asphalt mixtures could be assessed by measuring their compressive strength in wet and dry conditions. In order to evaluate and compare the moisture susceptibility of different mixtures the compressive strength ratio (r/R) is defined by R and r which presents the values of compressive strength in dry and wet conditions respectively.

The results obtained in Table 7 show that the intrinsic characteristics and compressive strength ratio values of mixtures satisfy the minimum requirement given by standard. Regarding to these results, we can notice that the ratio r/R for modified grading curve mixtures is higher comparing to control mixture. This is due to the change of specific surface of mixtures, hence the change of the richness modulus.

Table 7. Moisture susceptibility and intrinsic characteristics of mixtures.

Properties	Method	Mixtures			
		Conventional	D 3/8	D 2/6.3	D 4/6.3
Bulk density (g/cm ³)	EN 12967-6	2.393	2.386	2.366	2.369
Specific density (g/cm ³)	EN 12967-5	2.483	2.482	2.484	2.483
Air voids (%)		3.60	3.86	4.75	4.61
Compactness (%)	EN 12967-8	96.40	96.14	95.25	95.39
r (MPa)	EN 12967-12	6.8	6.4	6.0	7.1
R (MPa)	EN 12967-12	8.2	7.7	6.9	8.2
r/R		0.82	0.83	0.87	0.87

3.5. Indirect tensile stiffness modulus (ITSM)

The results of stiffness modulus of conventional and modified grading curve mixtures obtained with samples compacted with gyratory compactor at 15°C and 10Hz are shown in Fig.12, Fig.13.

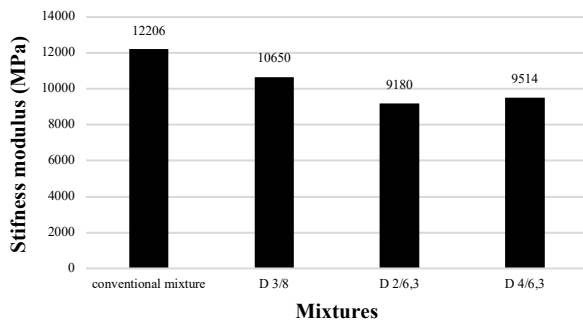


Fig. 12. Stiffness modulus of mixtures at 15°C.

Fig. 12 represent the stiffness modulus values of control and modified grading curve mixtures. From the results of stiffness modulus, we can see that the ITSM value for all mixtures satisfies the specifications (≥ 7000 MPa). It is obvious that the absence of one sub- fraction of aggregates makes ITSM for the modified grading curve mixtures lower than the control mixture one. However, it showed that the ITSM value of mixture D3/8 is greater matched to D 2/6.3 and D 4/6.3 mixtures. This can be explained by the fact that the mixture D 3/8 contains the most important percentage of coarse aggregates (60%). Whereas the percentage of coarse aggregates is less important in the mixtures D 2/6.3 and D 4/6.3 (only 32%).

Fig. 13 presents the loss of stiffness modulus, of modified grading curve mixtures comparing to control mixture, in percentage. Here a loss of ITSM value is observed for modified grading curve mixtures compared to the control mixture. This loss equals to 13% for the mixture D 3/8, 22% for D 4/6.3 mixture and 25% for D 2/6.3 mixture respectively.

3.6. Fuzzy logic approach

The origins of fuzzy logic lie in Heisenberg's uncertainty principle, in the early 1930s, Jan Lukasiewicz developed the logical system with three values and then extended it to all rational numbers between 0 and 1. The auteur defined fuzzy logic as logic that uses the general truth function that can take all values between 0 (false) and 1 (true). During these years, max black applied fuzzy logic to sets of elements or symbols.

Zadeh [27], developed the theory of fuzzy sets and introduced the term fuzzy in the technical literature. This is the beginning of attempts to model systems by fuzzy relations. The first investigations of Zadeh were the use of logic to represent an "expert system" approach to automatic tuning, where the control rule is replaced by fuzzy rules.

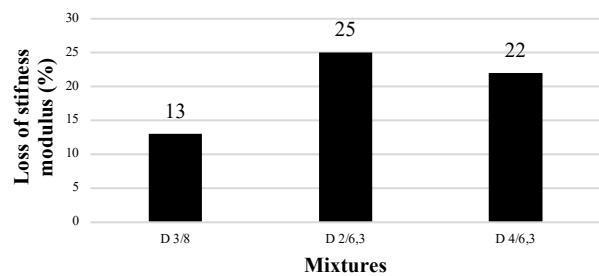


Fig. 13. Influence of the discontinuity on the stiffness modulus.

The fuzzy inference process involves the following successive steps [28]:

1. Fuzzification: This interface performs the following functions:
 - Definition of membership functions for input variables.
 - Transition from physical quantities to linguistic variables.
2. Fuzzy rule base: This step, contains fuzzy rules describing the behavior of the system, composed:
 - A database providing the information necessary for standardization functions
 - A set of linguistic expressions structured around expert knowledge, and represented in the form of rules: If <condition> Then <consequence>
3. Fuzzy inference engine: gathers all the fuzzy rules in the fuzzy rule base and gives for each input an associated output.
4. Defuzzification: consists of making a decision, which is, obtaining an actual command from the command obtained as a fuzzy set.

3.8. Fuzzy logic model for stiffness modulus and compactness

In this study a fuzzy logic model was developed to predict compactness and stiffness modulus of asphalt mixtures. Fig.

14 presents the diagram of the fuzzy model with inputs and outputs parameters.

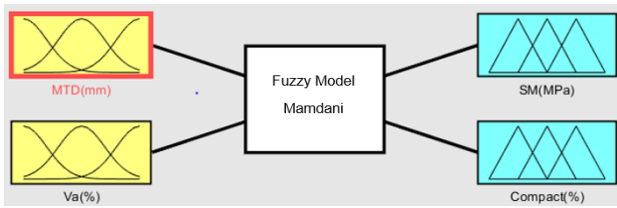


Fig. 14. Fuzzy logic model.

Membership function of inputs, mean texture depth (MTD) and Air Voids (Va) were showed in Fig. 15. So in Fig. 16, we can observed the membership function of outputs stiffness modulus (SM) and compactness (comp).

The relationship among the membership functions and the form of the resulting membership function using measurable or not measurable types of input data is defined by the rule. The eight rules if-then fuzzy applied in this study are:

- If (MTD is M1) and (Va is Va1) then (Compact is C10) (1)
- If (MTD is M5) and (Va is Va2) then (Compact is C9) (1)
- If (MTD is M7) and (Va is Va3) then (Compact is C4) (1)
- If (MTD is M10) and (Va is Va7) then (Compact is C3) (1)
- If (MTD is M1) and (Va is Va1) then (SM is M8) (1)
- If (MTD is M5) and (Va is Va2) then (SM is M5) (1)
- If (MTD is M7) and (Va is Va3) then (SM is M3) (1)
- If (MTD is M10) and (Va is Va7) then (SM is M2) (1)

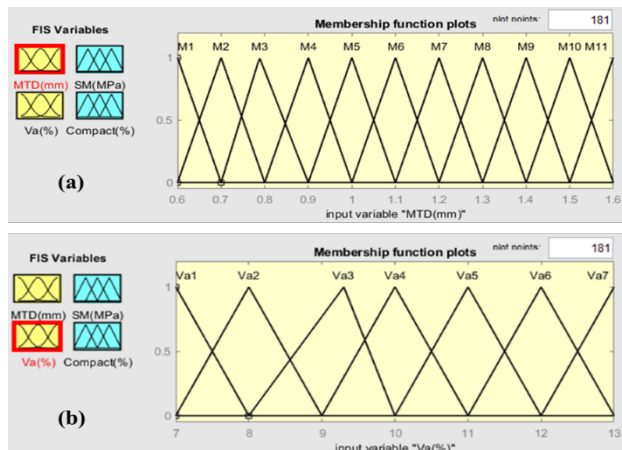


Fig. 15. Membership function of inputs:(a) mean texture depth (MTD), (b) Air Voids(V_a).

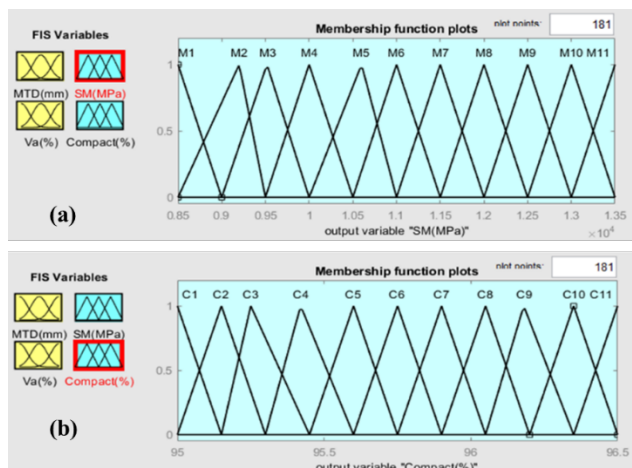


Fig. 16. Membership function of outputs : (a) Stiffness modulus (SM), (b) compactness (comp).

Based on the defuzzification, Fig. 17 and Fig. 18 present the model developed with fuzzy logic of stiffness modulus and compactness respectively. These values are calculated after determining the membership functions and the formation rules.

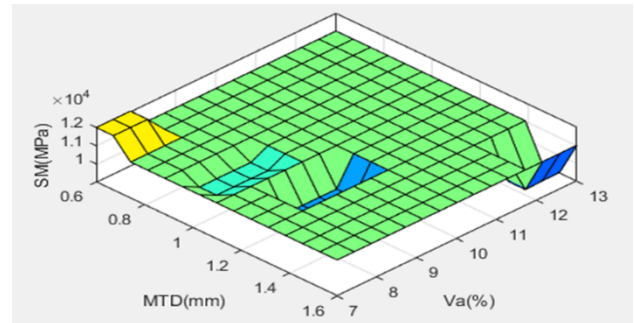


Fig. 17. Surface plot of system set of fuzzy Stiffness modulus as a function of Air voids and MTD.

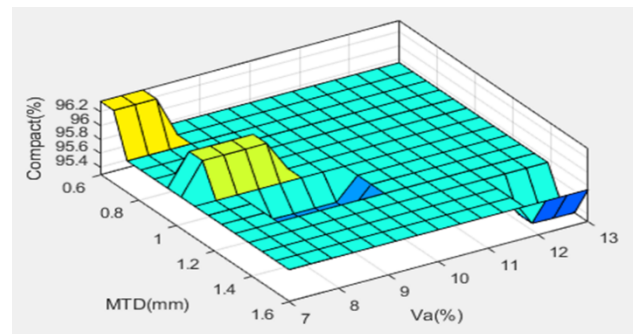


Fig. 18. Surface plot of system set of fuzzy Compactness as a function of Air voids and MTD.

Fig. 19 and Fig. 20 illustrates the relation between measured and predicted stiffness modulus and compactness respectively. According to results obtained with fuzzy logic model (predicted values) it is noted that there are very close to experimental results (measured values). For the conventional mixture we can observed that the measured compactness value equal at the predicted value. For the other mixtures, a slight variation was recorded between the measured and predicted values.

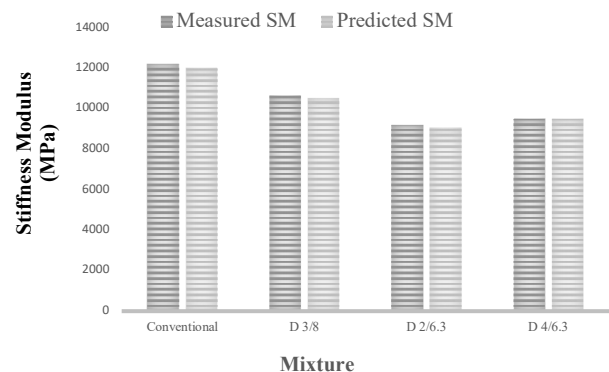


Fig. 19. Measured and predicted Stiffness Modulus.

In addition, it can be noted that the maximum difference for the value of stiffness modulus is recorded for conventional mixture (206 MPa), while the minimum difference is that of mixture D 4/6.3 (4 MPa).

Fig. 21 and Fig. 22, illustrates the relationship between measured and predicted values for stiffness modulus and

compactness of asphalt mixture respectively. From the figures, we notice that there is a good correlation with linear mathematic model, $R^2 = 0,996$ for stiffness modulus and $R^2 = 0.997$ for compactness. Which confirms that the results obtained by the developed model give good relationship between predicted and measured values.

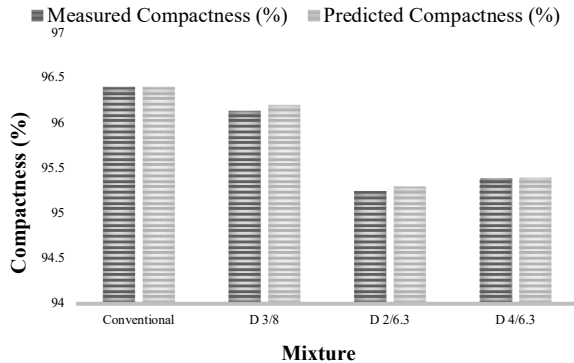


Fig. 20. Measured and predicted Compactness.

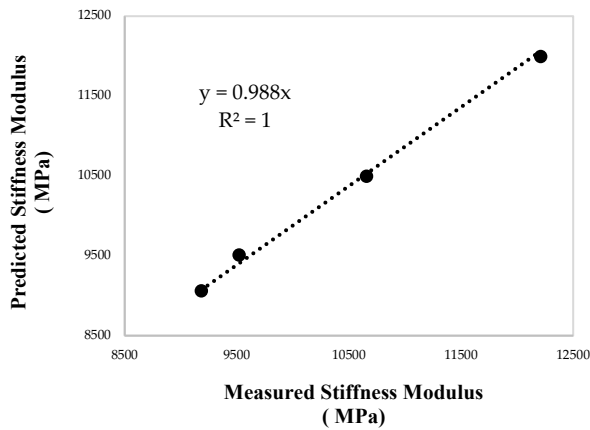


Fig. 21. Relation between predicted and measured Stiffness Modulus.

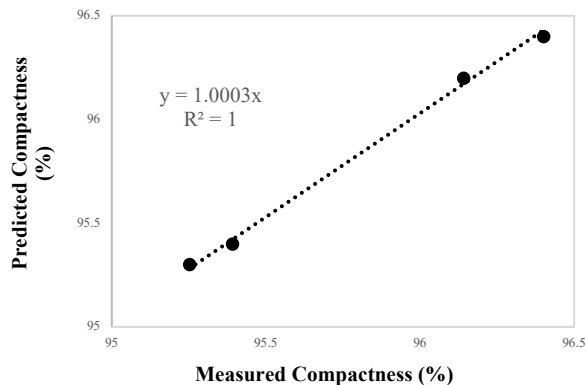


Fig. 22. Relation between predicted and measured compactness.

4. Conclusion

In the present research, several formulations of asphalt mixtures were studied, aiming to improve the macrotexture and the adhesion of the wearing course, while keeping the level of mechanical performance within the allowable range. For this, we chose modified grading curve instead of the conventional grading curve. Also a fuzzy logic model was developed aiming to predicted compactness and stiffness modulus of asphalt mixtures as a function of air voids and Mean Texture Depth.

In light of the results presented in this study; we can make following conclusions:

1. Despite the increase of voids in the modified grading curve mixtures, their moisture susceptibility remains preserved. This can be explained by the slight increase in the richness modulus of these mixtures as well as the good adhesiveness between the bitumen and the limestone aggregates.
2. The decrease in percentage of sand increases significantly the percentage of voids in the mixtures which gives a gain on the macrotexture.
3. By subtracting the aggregate sub-fractions, macrotexture can be significantly improved (by over 50%) with only a slight reduction in stiffness modulus value (less than or equal to 25%), while still meeting the current specifications.
4. An increase of 1% in void for a modified grading curve mixture leads to a gain of 16% in macrotexture and a loss of 2% in terms of stiffness modulus value.
5. Mixture D 3/8 is the best choice for the realization of wearing courses compared to other mixtures. This choice is motivated by their performance in stiffness modulus which is closest to the control mixture, and also a very significant increase of 65% of the macrotexture. The chosen mixture presents also an ease of recreation in our Algerian context (use of odd fractions 0/3, 3/8 and 8/15).
6. The models developed by fuzzy logic, made it possible to predict the values of compactness and of stiffness modulus with a slight variation without resorting to laboratory tests.

Finally, according to this work, it is obvious that the adhesion of the wearing course can be improved using modified grading curve, without affecting its mechanical performance.

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