INFLUENȚA AGREGATELOR RECICLATE ASUPRA BETONULUI ASFALTIC CU ADITIVI
INFLUENCE OF RECYCLED AGGREGATES ON THE RESISTANCE OF BITUMINOUS CONCRETE IN THE PRESENCE OF ADDITIVES

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The design of a safe and respectful roadway to the environment must meet the users' requirements in the present without compromising those of future generations. Under the traffic action, always more constraint and the climatic blitzes, the pavements crumbling occurs rapidly, which leads to severe impairments that are reflected on the surface layers: rutting, cracking, substances rejection, polishing and pulling out the aggregates on surface. This situation often involves the renovation of the surface's layers. It is, therefore urgent to appeal to a new vision of pavement design based on optimizing the use of local materials, non-renewable, and respect for the environment. The recycling of bituminous substances are one of the relevant solutions. It has the advantage of reusing building materials by mixing them with a proportion of refined ones to achieve the required performance. This assignment researches for different rates of coated aggregates, the effects of manufacturing temperature and blending time in the mixing of the constituents during production as well as the additive plastomers of polyolefins on the improvement of the recycled asphalt rutting. Rutting is one of the most encountered degradation phenomena in the Algerian roads. The formulated hypothesis used here assumes that the elastomer polyolefins additive have an influence on the mechanical performance (rutting) of the recycled asphalt and also on the rate of the used asphalt aggregates. To justify this hypothesis it is mandatory to go through the manufacture of the asphalt with different rate of asphalt aggregates. To reduce the number of experimental tests necessary for this study, we used the experimental approaches method.

Keywords: *asphalt, Recycling, polymers, environment, binder, penetrability.*

Notations: **BBSG**: Semi Dense Bituminous Concrete, **Rut:** Rutting, **AE:** Asphalt-Aggregates, **Addit**: Plastomers additive of polyolefins **T °**: temperature of the manufacture, **Tm**: Blending time

1. Introduction

Technical actions are being implemented in the field of road construction to meet environmental policies for sustainable development. They contribute to improve the environmental performance of activities by reducing the use of non-renewable natural raw materials, and reduce the required energy for the manufacture of building materials [1]. This work is part of the techniques used for environmental protection. The reasonable solution of this problem is recycling which can reduce the consumption of the aggregate and asphalt binder, non-renewable raw materials. In order to reduce the ecological footprint of the asphalt, the field of road construction is seeking techniques that maximize the recycling rate and reduce manufacturing temperature. To preserve and ensure the sustainability of road infrastructure, the presented work focuses on understanding the mechanisms administering the mixture of the new and recycled components, to enable a better knowledge of recycled asphalt and optimization of its manufacturing methods. This assignment researches for different rates of asphalt aggregates, the effects of manufacturing temperature and blending time in the mixing of the constituents during production as well as the plastomers of polyolefins additive on the improvement of the recycled asphalt rutting. Rutting is one of the most encountered degradation phenomena in the Algerian roads. As manufacturing techniques of recycled asphalt in Algeria is in the discussion phase, this study is based on the techniques used in more developed countries in the field of asphalt recycled aggregates' production. This method consists of mixing in a hot plant designed for the process: recovered asphalt aggregates with unscathed aggregates and an anhydrous bituminous binder [2]. We distinguish low recycling rate from 10% to 25% of asphalt aggregates and recycling on high rates of 30% to 75 %. Some recycling operations at even higher rates have been achieved whether as experience or accomplishment, going even to 100%. Of course, they are viable only with

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homogeneous storage reclaimed asphalt and perfectly identified [3]. The used hypothesis here assumes that, until now, researches have mainly focused on the asphalt aggregates binder including interactions with the binder [4]. For this reason, we used the elastomer polyolefins additive in the mixture of recycled asphalt and followed its influence on the mechanical performances (rutting) of the recycled asphalt. To justify this hypothesis, it is recommended to go through the manufacture of the recycled asphalt with different: rate of additive, asphalt aggregates, manufacturing temperature and blending time. To reduce the number of experimental tests necessary for this study, we used the experimental approaches method. The type of asphalt used for carrying out these tests is anBBSG 0/14.The mechanical characteristic referred by the current study is the distortion due to rutting determined by the rut test. This test is very important for busy roads and with a quite high percentage of heavy vehicles, it will simulate in the laboratory the resistance of the asphalt to rutting. Rutting is very popular, since it is a method that is more representative than other laboratory methods while evaluating the resistance to permanent deformation and the results showed excellent correlation with the deformation of roadway service [5]. The test is to determine the depth of the rut in repeated passage (several cycles are applied in 1000, 3000, 10000, 30000, 100000) of a pneumatic, depending on the thickness of the asphalt. Compacting energy is normalized at 60°C, the result is the insertion of the wheel in the mix of the asphalt [6].

2. The experimental design approach

2.1. Full factorial design method

The experimental designs allow to better organizing tests that are involved in a scientific study or industrial studies [7]. In our case, the number of tests has been reported as basic plan 4X16 = 64 to 16 with three control trials (central points). The experimental design used was a full factorial design; it allowed us to characterize the evolution of a quantity depending on 4 parameters. For this, the experimental features to be characterized are partly determined by the experimental design. The experimenter chose the parameters to be considered, and the value range over which each parameter is evolving: a minimum value and a maximum value. The experimental design theory requires that the midpoint of this range as being a point to characterize. The three midpoints of each parameter define the center of the experimental field of study. The model is priory reported as: YJ=f (Xi) where the function f is a considerably high polynomial development of Xi, the polynomial order that is dependent on the desired degree of precision that was written as the following. See equation1.

$$Y(X_1, X_2, X_3, X_4) = a_0 + a_1.X_1 + a_2.X_2 + a_3.X_3 + a_4.X_4 + a_{12}.X_1.X_2 \quad + a_{13}.X_1.X_3 + a_{14}.X_1.X_4 + a_{23}.X_2.X_3 + a_{24}.X_2.X_4 + a_{34}.X_3.X_{4+}\mathrm{e} \qquad (1)$$

The values of the coefficients ai and of the equation residue are the unknowns who are determined by solving a system of n equations obtained using all the experimental points made during the realization of the full factorial design. The expertise is to identify the factors Xi, the shape of the model that can incorporate any eventual couplings between factors, and then choose the values that factors take for each of the experiments. To facilitate the processing of the results, it is advisable to work with dimensionless factors, renorming the values, for example, if the Xi factor varies in the range $[X_i^-, X_i^+]$, we renorm it in the range [-1, +1] by the relationship:

$$x_i = \frac{2X-(X_i^+ + X_i^-)}{(X_i^+ - X_i^-)} \qquad (2)$$

Thus all the constants of the polynomial model are expressed in the same unit, that of Yi response, the amplitude of each constant is directly proportional to the degree of sensitivity of the response to the factor or interaction. The mathematical regression allows the estimation of the effects of different actions (factors and interactions), the optimization is also a solution to determine the range preferred of the response.

2.2. The study parameters

In our study, we have chosen the influence of the four parameters that are the percentage of the asphalt aggregates, the percentage of polyolefinsPlastomers additives', the temperature of manufacturing and blending duration on mechanical performance of recycled asphalt (rutting). The asphalt aggregates' percentage was chosen according to the existing plants with a recycling module to the low rate model (15%), the most used and the model of high rate (75%) that corresponds to the double drums type of plants dedicated to the manufacture of recycled asphalt at high rates. The choice of these two values, maximum and minimum, requires an intermediate point at 45% of recycles. The direct incorporation of polyolefin plastomers adds to the mixer has the advantage of facilitating the use of the process at the coating level, in our study we set the minimum at a rate of 0% of binder and a maximum of 6% of binder and the intermediate point becomes 3% binder. The maximum temperature is set at 160 ° C, this is the maximum manufacture temperature that can be achieved in the laboratory for a rate of 75% recycling. The minimal temperature is chosen to be equal to 120 ° C. This minimum temperature represents the case of minimum remobilization of binder asphalt aggregates. The choice of these two values, maximum and minimum, requires an intermediate point at 140° C. The standard governing the mixing at a laboratory (NF 12697-35 2007) sets the maximum blending duration of the constituents to 3 minutes during the manufacture of an asphalt without asphalt aggregate and to 5 minutes if asphalt aggregates are used . In our study a minimum duration of 3 minutes to ensure proper blending, 5 minutes maximum and the intermediate value becomes 4 minutes.

3. Experimental study

The studied formula is theSemi Dense Bituminous Concrete (BBSG) type of 0/14 granulometry for the production of surface courses and pavement connections must comply with the NF P 98-130 norm. The thickness average application of SDBC 0/14 is 6 to 8 cm, with an absolute minimum of 5 cm of surface course. The pure bitumen class recommended for the used BBSG is 35/50 for a high level of load (for an altitude <500 m northern Algerian case). We have chosen this type of asphalt as it is the most used in Algeria.

3.1. Used materials

3.1.1 Binder (a new binder)

The binder content of asphalt was set at 5.40%. The used bitumen is 35/50 coming from NAFTAL, a branch of the Algerian oil company Sonatrach. The physical and mechanical properties of the base bitumen are summarized in Table 1. The analyzed bitumen meets the requirements of the 35/50 class according to the NFT65-001 norm.

Table 1

Binder characteristics (a new binder)

testType	results	Mean	specifications
Penetrability at 25 °C (1/10 mm)	43	40	35-50
Temperature ring and ball (TRB °C)	53	53	50-58
Relative density (g/cm^3)	1.02	1.01	1.0-1.05

3.1.2. Asphalt Aggregate binder (old Binder)

In order to know the characteristics of the used asphalt aggregate binder, an extraction tests campaign was performed on samples of asphalt aggregate, the results in Table 2 showing that the binder has known a change in its physical characteristics such as penetrability which experienced a decrease of 42 the day of the asphalt implementation in May 2010 to 22 on the day test in July 2014, so we can say that the penetrability has stiffened the asphalt along this period, which means that the binder aggregate has improved in this study as a very important phase.

Tableau 2

Asphalt aggregate binder characteristics (old Binder)

Asphalt aggregate binder	Binder content	Penetrability	TRB
ECH1	3.1	24	49
ECH2	2.9	20	50
ECH3	2.7	22	49
Mean	2.9	22	49

3.1.3. Asphalt Aggregate

The asphalt aggregates used in this research are the granules of the national highway No. 21 that the initial asphalt is a 0/14 BBSG of its fifth year, to give a consistency to the used aggregates in the tests, we eliminated asphalt aggregates of a size superior to 14 mm, the granulometry of the rest of the asphalt aggregate is shown in the Figure 1.

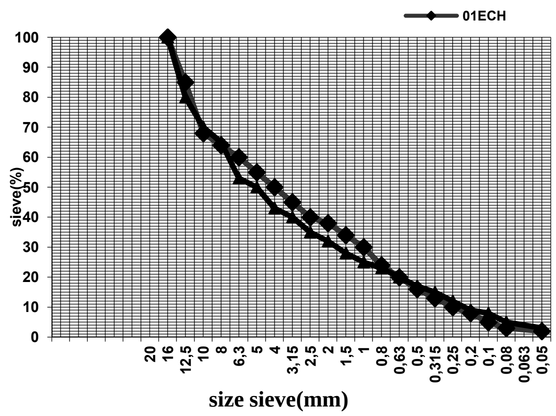

Fig.1-Particle size analysis of asphalt aggregate.

3.1.4. Additive

The used Additive is a polyolefin plastomers, it is presented in a granulate form and which can be introduced as a percentage relative to the binder in the mixture at the time of blending. Its characteristics are listed in Table 3:

Table 3

Additive characteristics (Plastomers of polyolefin)

Density (g/cm ^{3})	Fusion point (°C)	size	Plastomers(%)
0.91 to 0.96	120 to 150	4 mm	> 95

3.2. Tests

3.2.1. Reference tests (pure asphalt without additions)

To determine the characteristics of the reference formula, we conducted a test campaign on new asphalt aggregates and pure bitumen in order to determine the percentages of new aggregate fractions and the rate of the pure binder to produce new asphalt and its behavior in accordance with rutting, the Table 4 summarizes these results:

Table 4

Test resultsof asphalt specific nine

Bitumen content (%)	G 0/3 %	G 3/8 %	G 8/14 %	rutting (C°=60°) after 3000 cycles
5.40	45	30	25	4.9

3.2.2 Tests on recycled asphalt (The purpose of the study)

In the experimental design we proposed four factors that imply the realization of sixteen trials in addition to three median test, the researched answer is the reaction of the recycled asphalt on rutting and the influence of the studied factors on the response to each formula. The tests were conducted in an environment of 60 ° C and after an exposure to 3000 cycles on the sample of recycled asphalt, the results are shown in Table 6 .The control of changes made on the physical characteristics of the binder after the adding of asphalt aggregates (old binder) and the additive is totally useful for determining the compatibility of the modified binder (new binder + old binder and additive) with recycled asphalt, for this reason, we have made the test of the penetrability on the modified binder for different formulas. See Table 5.

Table 5

Results rutting tests according to the experimental design(experimental and calculated)

Order of tests	AE %	Addit %	T°	T m	% rutting experi-mental	% rutting calcul-ated
1	1	-1	1	1	6.6	6.256
2	1	-1	-1	1	6.0	5.856
3	0	0	0	0	5.2	5.318
4	-1	1	-1	1	4.9	4.681
5	-1	1	1	1	4.6	4.330
6	-1	-1	1	1	5.4	5.231
7	-1	1	-1	-1	5.0	4.781
8	1	1	-1	1	5.7	5.406
9	1	-1	1	-1	6.4	6.381
10	0	0	0	0	5.0	5.318
11	1	1	1	-1	5.9	5.481
12	-1	-1	-1	1	5.2	5.056
13	-1	-1	1	-1	5.7	5.431
14	1	-1	-1	-1	6.1	5.806
15	-1	1	1	-1	4.7	4.606
16	0	0	0	0	5.1	5.318
17	1	1	-1	-1	5.5	5.431
18	-1	-1	-1	-1	5.3	5.081
19	1	1	1	1	5.3	5.281

Table 6

Penetrability of the modified asphalt binders based on recycled asphalt aggregate

Asphalt agregate	Additive	Penetrability
15 %	0 %	32
75 %	0 %	28
45 %	3 %	35
15 %	6 %	38
75%	6%	40

4. Modelisation results

After the use of the experimental design by MINITAB.17 software, we determined the unknowns of the polynomial presented above where we reached the equation.3 that expresses the recycled asphalt resistance to rutting (the answer) according to the parameters of the experimental design (the factors), the analysis of the variance allows to calculate a very useful statistic parameter, it is the R2 which is the sum’s ratio of the responses’ squares (rutting) calculated on the squares’ sum of the measured responses [5] in our study this ratio is equal to 95.07 see Table 6, what indicates that the model is of good quality, when R2 is veryclose to the value1, the qualityof the tests isgood.

$$\mathrm{Rut} = 5.5187 + 0.4188.\mathrm{EA} - 0.3187.\mathrm{Addit} + 0.0562.\mathrm{T°} - 0.0563.\mathrm{Tm} - 0.0187.\mathrm{AE.Addit} + 0.0563.\mathrm{AE.T°} + 0.0187.\mathrm{AE.Tm} - 0.1313.\mathrm{Addit.T°} - 0.0188.\mathrm{Addit.Tm} - 0.0438.\mathrm{T°.Tm} - 0.2 \quad (3)$$

With (Rut: rutting, AA: asphalt aggregates, Addit: additive, T °: temperature manufacturing, Tm: blending time) are reduced variables whose variation is by definition between -1 and +1. To determine the values of real variables, we have to go through the following equations:

$$\mathrm{AE} = \frac{(\mathrm{AE_{reel}} - 45\%)}{(75\% - 45\%)} \text{ with } 15\% \le \mathrm{AE_{reel}} \le 75\% \quad (4)$$

$$\mathrm{Addit} = \frac{(\mathrm{Addit_{reel}} - 3\%)}{(6\% - 3\%)} \text{ with } 0\% \le \mathrm{Addit_{reel}} \le 6\% \quad (5)$$

$$\mathrm{T°} = \frac{(\mathrm{T°_{reel}} - 140\%)}{(160\% - 140\%)} \text{ with } 120\% \le \mathrm{T°_{reel}} \le 160\% \quad (6)$$

$$\mathrm{Tm} = \frac{(\mathrm{Tm_{reel}} - 4\%)}{(5\% - 4\%)} \text{ with } 3\% \le \mathrm{Tm_{reel}} \le 5\% \quad (7)$$

4.1 Factors effects on the response

Following the results presented in the Figure 2, we have noticed that the two factors influencing the resistance of recycled asphalt is the asphalt aggregates and the additive and also the interaction between the temperature

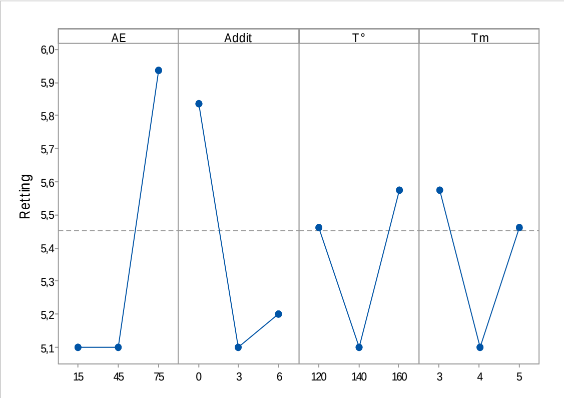

Fig.2 -Main effects plot for retting.

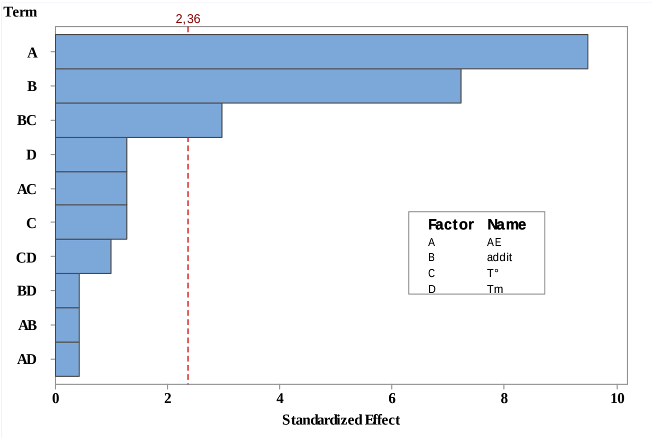

Fig.3 -Pareto chart of the standardized effects.

and the additive is the remarkable importance by the PARITO graph as the additive requires a temperature that is able to transform it to a binder.Figure 3 presents the effect of the studied factors on rutting that has been optimized to a maximum value of 5.45, thus a time of mixing with a period between 05 min and 03 min 30 seconds,recycled asphalt resists on the rutting inferior to 5.45 also this limit to the rutting resistance requires a temperature between 120 ° and 155 °.
Concerning the additive, we note that as long as the rate of additive is greater than 1%, the better is the resistance of the recycled asphalt in accordance with the rutting, however, for the asphalt aggregates, a rate of 60% can increase the rutting and a rate of 15% up to 45% has no influence on the resistance because rutting is constant in this range. We also note that rutting is weak in the medium points of the modelisation.

4.2. Evolution of the recycled asphalt's resistance to rutting compared to asphalt aggregate and the used additive

For asphalt aggregates without additives, we noticed that a rate of 15% of asphalt aggregates causes an increased rutting up to 7% with a manufacturer temperature between 120 ° up to 160 ° and 3 to 5 minutes of mixing. However, a rate of 75% causes an increased in rutting of 20% for (T ° = 120 ° and Blt = 3 minutes) and 25% for (T ° = 160 ° and Blt= 5 minutes). When adding a rate of 6% of additive Plastomerspolyolefins of the binder's rate to the mixture of the recycled asphalt, an improvement of the rutting resistance occurs as for a rate of 15% of asphalt aggregates with (T ° = 120 ° and Blt = 3 minutes), rutting is reduced by 6% compared to those without additives but with (T ° = 160 ° and Blt = 5 minutes) resistance to rutting becomes remarkable where we recorded a decrease of 13% for a rate of 75% of asphalt aggregates (T ° = 120 ° and Blt = 3 minutes), rutting is reduced by 9% also with (T ° = 160 ° and Blt = 5 minutes) resistance to rutting is decreased to 19% compared to that without additives. Comparing these results with those presented in the penetrability Table 5, we note that the polyolefin Plastomers additive caused a change in the penetration of the modified binder of the recycled asphalt which turns the modified binder (new binder + old binder + additive) responds well to the recycled asphalt's behavior to rutting. We also note that the additive's mixtures require a manufacture maximum temperature of 160 ° so that the modified binder (new binder + old binder + additive) takes homogeneity in these characteristics.

5. Optimization of a formula for manufacturing recycled asphalt

The optimization task is to look for an answer (rutting) of quality, that is to say, in our study is to minimize rutting , maximize the rate of asphalt aggregates and decrease the rate of the added additive, the results shown in Figure 4 show that a rate of additive between 1% and 3% and a rate of recycled asphalt of 40% to 70% provide a resistant to rutting recycled

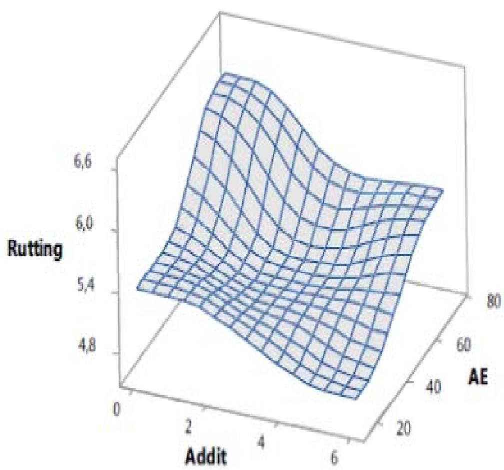

Fig.4 -Surface plot of rutting vs EE,addit.

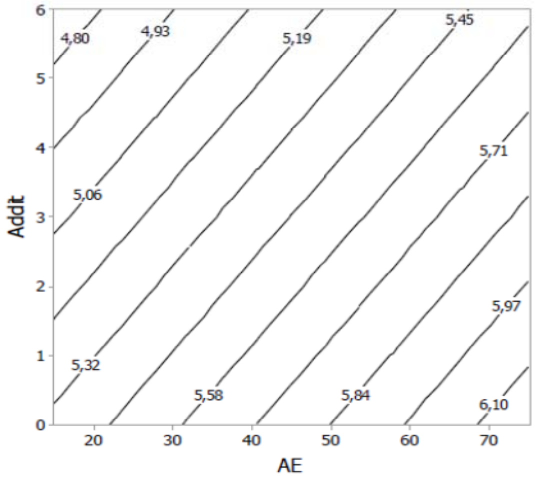

Fig.5- Contour plot of rutting vs AE.Addit

asphalt as it does not exceed 5.4% so, in the range, the additive may improve the characteristics of the modified binder (sound binder, old binder, additive), since it increases the penetrability of the modified binder and makes it adapt to the recycled mixture.

Also optimization allowed us to determine the iso-response curves of rutting see Figure 5.

6. Conclusion

1. The additive polyolefin plastomerseffect is very important, as it ensured a resistance increase counterpart rutting with its power to improve the characteristics of the recycled asphalt's modified binder (new binder + old binder + additive) and making it compatible with the recycled asphalt.

2. Modelisation through the use of experimental design methods allowed us to determine the formula (3) and rutting surface diagram which can be estimated in rutting for different rate factors studied.

3. The study showed that we can reach a rate of 75% of asphalt aggregates in the recycled asphalt mixture while keeping good mechanical performance following the adding of polyolefin plastomers.

4. This work showed that the mixing time during the preparation of recycled asphalt is limited by three minutes at a low rate. However, we may reach five minutes for the high rates. Also, the temperature in the mixer must be limited by 120 ° and 150 °.

5. The current study allowed us to master the preparation of the modified binder (new binder + additive) in order to have the same characteristics of the recycled asphalt's binder (new binder + additive + old binder) at the addition of asphalt aggregates; which facilitates the manufacture of recycled asphalt with a high rate of aggregates in the mixing plant.

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